ISSN 2319-3670

Journal of Rice Research

Volume 18, No. 2

December 2025

Society for Advancement of Rice Research

Society for Advancement of Rice Research

Society For Advancement of Rice Research

(Regd. No.2175/2004 of A.P. Society Regn. Act. 2001)

The Society for Advancement of Rice Research is a registered society started with main objective of providing a platform for exchange of information and knowledge related to latest developments in rice research.

Aims and Objectives

- To advance the cause of rice research and development in the country.
- To disseminate knowledge on latest developments in rice research through publications, seminars, lectures and training programmes.
- To provide consultancy in rice production and development.
- To facilitate research and industry collaboration and public private partnership at national level.
- To honour outstanding achievers in rice research and development.
- To cooperate with other organizations having similar aims and objectives.
- To promote any other scientific/professional activities conducive for the advancement of science of rice and rice improvement.

Journal of Rice Research is an official publication of Society for Advancement of Rice Research (SARR), ICAR-Indian Institute of Rice Research, Hyderabad - 500030 and published twice a year i.e., June and December. All correspondence related to SARR should be addressed to secretary, Dr. R M Kumar (kumarrm21364@gmail.com).

Membership: Membership of the Society is open to all persons interested in furthering the aims and objectives of the Society and in the opinion of the executive committee, have the necessary qualification and experience.

Membership and Journal Subscription fee w.e.f August 2019

Membership category	Subscription price: Annual	Life
A. Individual membership		
Indian (Rs.)	500 (300*)	3000 (2000*)
Foreigner (US $ or its equivalent)	50	300
B. Corporate members/Patrons-one time (Rs.)	----	20,000
C. Libraries and Institutions (Annual)		
Indian (Rs.)	2500	
Foreign (US $ or its equivalent)	550	

Admission fee of Rs. 100/- will be charged in addition to the above subscription fee; *For Students

All remittances should be made in favour of Society for Advancement of Rice Research, Hyderabad with a mail to treasurer, Dr. M S Anantha (treasurersarr@gmail.com).

ISSN 2319-3670

Journal of Rice Research

Volume 18, No. 2 December 2025

Society for Advancement of Rice Research

Journal of Rice Research

Volume 18: Issue No. 2 **December 2025**

Contents	Page No.

Review Articles

Options for Mitigating Green House Gas Emission from Rice Fields - A Review 1

Joel MJ, Nimmy Jose, Seethal MS, Shalini Pillai P, Ameena M and Manju Mary Paul

Research Article

Effect of Zinc Bio-Fortification on Yield and Quality of Pigmented Rice Varieties (*Oryza sativa* L.) 34

Himasri K, Anny Mrudhula K, Manukonda Srinivas, Sandeep Raja B and Suvarna Latha AJ

Optimizing Yield and Profitability in Wet Direct-Seeded Rice: Comparative Analysis of Sowing Time and Establishment Methods in South-Eastern Rajasthan 46

Sharma KM, Meena SN, Manoj Kumar, Chandra Prakash and Mahendra Kumar R

Genetic Variability and Association Studies in F_2 Population of *Indica-Japonica* Crosses of Rice 53

Kundan Bedwa, Neelam Bhardwaj and Surbhi Patyal

Influence of Zinc Source on Yield and Zn Uptake of Hybrid rice 60

Darpana Patel, Gami MR and Patel PB

Sustaining Rice Production in Wet Direct Seeding Under Delayed Sowing Through Drought Tolerant Rice Varieties 65

Soumya Saha, Mangal Deep Tuti, Mahender Kumar R and Vidhan Singh T

Bio-efficacy of Botanicals and Biopesticides against Rice Caseworm, *Parapoynx stagnalis* (Zeller) 73

Muhammed Arshad V, Karthikeyan K, Haseena Bhaskar, Mani Chellappan and Sajitha Vijayan M

Screening of Rice Genotypes for Resistance against Leaffolder 80

Karthikeyan K, Faseela KV, Biji KR and Padmavathi Ch

Evaluation of Resistance in Rice Genotypes against Root-Knot Nematode *Meloidogyne graminicola* 87

Nethi Somasekhar, Satish N Chavan, Shiva Krishna K, Shravan Kumar K, Sai Prasad SV, Senguttuvel P and Sundaram RM

Generation Mean Analysis for Blast Resistance and Yield Traits in Rice (*Oryza sativa* L.) 94

Namrata, Singh RP, Ramlakhan Verma, Prashant Bisen, Prakash Singh, Arsode Pandurang, Madhu Choudhry, Padma Thakur, Bapsila Loitongbam and Ramesh

Morphological and Pathogenic Variability among Isolates of *Xanthomonas oryzae* pv. *oryzae*, Causal Agent of Bacterial Leaf Blight of Rice from Godavari Zone of Andhra Pradesh 102

Shanmuki Shirisha P, Ramabhadra Raju M, Madhusudhan P, Sandhya Rani C, Srinivas T, Bhuvaneswari V and Deepthi Priya B

Contents	Page No.

Need-Based Nitrogen Management Through Leaf Colour Chart in High Yielding Rice Variety 111

Kacha DJ, Makawana NR, Parmar MB and Thorat SS

Impact of Agricultural Inputs on Gross Value Added by Agriculture in Indian Economy 115

Sukhdeep Singh, Jatinder Sachdeva and Sangeet Ranguwal

***In vitro* Efficacy of Essential Oils, Fungicides and Botanicals Against *Bipolaris oryzae* Causing Brown Spot of Rice** 125

Basavaraj K, Prashanth Pandi, Jasudasu GS, Prakasam V, Ladhalakshmi D, Kannan C, Laha GS and Srinivas Prasad M

Short Communication

GR-27 (Bhim): A High Yielding Rice Variety Suitable for Value Addition in Gujarat State 134

Mistry PM, Patel PB, Mungra KS, Parth Patel and Patil VA

Him Palam Dhan 4 (HPR 3201): A Long Grained High-Yielding Rice Variety for Transplanted Irrigated Conditions of Himachal Pradesh and Uttrakhand 137

Neelam Bhardwaj, Daisy Basandrai, Dhirendra Singh, Shivani and Surbhi Patyal

Him Palam Dhan 3 (HPR 2865): A Medium Maturing Long Bold Rice Variety with Stable Yield and Acceptable Grain Quality for Himachal Pradesh and Uttrakhand 140

Neelam Bhardwaj, Dhirendra Singh, Daisy Basandrai, Shivani and Surbhi Patyal

Genetic Stocks

Rice Germplasm Registered during July-December 2025 143

RESEARCH REVIEW https://doi.org/10.58297/EBRQ3412

Options for Mitigating Green House Gas Emission from Rice Fields - A Review

Joel MJ[1]*, Nimmy Jose[2], Seethal MS[1], Shalini Pillai P[1], Ameena M[1] and Manju Mary Paul[1]

[1]College of Agriculture, Vellayani, KAU, Kerala, India 695 552

[2]M. S. Swaminathan Rice Research Station, Moncompu, KAU, Kerala, India 688 503

*Corresponding author e-mail: joelmadathil@gmail.com

Received : 6th July, 2025, Accepted: 11th September, 2025

Abstract

Climate change poses a serious threat to global food security, with rice cultivation emerging as both a contributor to and a victim of this crisis. This review article explores the mechanisms behind greenhouse gas emissions from rice fields, focusing on microbial processes such as methanogenesis and denitrification, and highlights the mitigation strategies that balance productivity with environmental sustainability. The study emphasizes that water and fertilizer management are pivotal levers for reducing emissions. Techniques like Alternate Wetting and Drying, mid-season drainage, and controlled irrigation have shown promise in cutting methane emissions by up to 90%, though they may increase nitrous oxide emissions, necessitating careful trade-off management. Fertilizer innovations including enhanced efficiency fertilizers, nitrification inhibitors, and nano fertilizers offer further avenues for emission reduction while improving nitrogen use efficiency. Beyond agronomic practices, the selection of rice cultivars such as low-emission, high-yielding, and genetically engineered varieties demonstrate significant potential in reducing methane and nitrous oxide emissions. Additionally, rice straw management through composting, biochar production, and avoiding open-field burning can drastically lower the carbon footprint of rice farming. Microbial innovations, such as inoculating rice with methane-oxidizing bacteria or using plant microbial fuel cells, further enhance mitigation efforts. Despite these advances, challenges remain in scaling these solutions due to socio-economic constraints, regional variability and farmer adoption barriers.

Keywords: Alternate wetting and drying (AWD), climate change (CC), rice and greenhouse gas (GHG), methane (CH_4), nitrous oxide (N_2O)

Introduction

The phenomenon of climate change (CC) presents a substantial risk, causing rise in global average temperature and resultant climate catastrophes worldwide (Jackson *et al.*, 2020), chiefly attributable to the augmented atmospheric concentrations of both natural and anthropogenic greenhouse gases (GHGs) including water vapour, ozone (O_3), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases, which collectively modulate atmospheric radiative forcing and influence Earth's temperature by preventing infrared radiation from escaping into space (Kumar, 2024; Patterson, 2012). The Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) reiterated that the rapid warming of the climate system is indisputable, primarily driven by anthropogenic GHG emissions (IPCC, 2023) reaching a record high in 2023, the warmest year on record, with a global average temperature of 1.45°C (±0.12°C) above pre-industrial levels, surpassing the previous record by 0.17°C (Sandford *et al.*, 2024; WMO, 2023). From 2011 to 2020, the global temperature was 1.1°C higher than the pre-industrial period of 1850–1900. Boosted by the *El Nino* phenomenon, the period spanning from February 2023 to January 2024 marked the first instance where the global average temperature surged 0.64°C above the 1991–2020 average and 1.52°C above the 1850-1900 average (Copernicus Climate Change Service, 2024). Moreover, the mean surface temperatures are anticipated to increase by 2.2°C to 3.5°C by mid-century without effective measures to mitigate global warming (IPCC, 2023). The consequences of CC, such as rising temperatures, heat waves, sea level rise, altered precipitation, prolonged droughts, severe storms, and poor air quality, are both observed and anticipated shortly (Sonwani and Saxena, 2022). Projections indicate that the adverse effects of CC will continue to worsen (Dhillon and Sohu, 2024).

Agriculture is the pivotal economic sector accountable for ensuring both food security and nutritional adequacy. Nevertheless, it exerts direct or indirect influence on the phenomenon of global climate alteration through the release of three of the major six GHGs *viz.*, CO_2, CH_4, and N_2O (Panchasara *et al.*, 2021), whereby agricultural soils serve as both source and sink of these gases across nearly all terrestrial ecosystems (Basheer *et al.*, 2024). These gases are integral to regulating the radiative balance by their capacity to absorb and emit specific infrared radiation reflecting from the terrestrial surface. Apart from being a dynamic GHG, CH_4 influences atmospheric oxidation by regulating tropospheric hydroxyl radical levels (Holmes, 2018; Tian *et al.*, 2020), whereas N_2O contributes to the stratospheric ozone depletion (Ravishankara *et al.*, 2009). Likewise, CO_2 also largely contributes to global CC, accounting for over half of the total greenhouse effect (Liu *et al.*, 2013). Additionally, CC is concurrently engendering significant challenges for global agricultural productivity, resulting in elevated food prices (Fahad *et al.*, 2022). Agriculture sector bears the primary responsibility for non-CO_2 emissions, notably CH_4 and N_2O, with their respective global warming potentials (GWPs) being 28 and 273 times greater than that of CO_2, over a century (IPCC, 2023). Agriculture accounts for approximately 50% and 60% of global CH_4 and N_2O emissions, respectively, accounting for approximately 10% to 12% of total anthropogenic GHG emissions (Xu *et al.*, 2016). The emanation of CH_4 from this sector is predominantly from activities such as livestock husbandry (enteric fermentation and manure handling) and the cultivation of rice. N_2O is predominantly released as a result of the utilization of nitrogenous fertilizers on agricultural lands. By 2023, key GHG concentrations have risen significantly from pre-industrial levels, with CO_2 increasing by about 50% from 280 to 420 ppm, CH_4 by 176% from 700 to 1934 ppb, and N_2O by 25% from 270 to 336.9 ppb (EEA, 2025), corroborating the World Meteorological Organization's Greenhouse Gas Bulletin which recorded CO_2 at 415.7 ppm, CH_4 at 1908 ppb, and N_2O at 334.0 ppb in 2021, indicating 149%, 262%, and 124% of pre-industrial levels, respectively.

Rice production is identified as a crucial sector of global agriculture that serves as the primary staple sustenance for over half the global population particularly concentrated in regions such as Asia, Sub-Saharan Africa, and South America, with cultivation spanning approximately 11% of the world's total arable land (USDA, 2023). In the 2023 crop year, global rice cultivation spanned approximately 168 million hectares, with India and China as the foremost producers; India's paddy rice output reached over 206.7 million metric tons (MMT), while China's slightly surpassed 206 MMT, culminating in a total rice production of 537.72 MMT for the 2024 marketing year (Shahbandeh, 2025). Projections indicate an anticipated rise in global rice consumption from 480 million tons in 2014 to close to 550 million tons by 2030 (Yuan *et al.*, 2021). However, the carbon footprint of rice production is substantial, with global emissions of 2430 kg CO_2 eq per megagram of grain in 2020 projected to rise due to rising consumption despite of burgeoning population. This makes rice a major contributor to global warming, particularly in Southeast, South, and East Asia (Abdo *et al.*, 2024). Conversely, rice production is also severely impacted by CC, with forecasts suggesting a potential 51% reduction in cultivation due to factors such as altered rainfall patterns, increased temperatures, and extreme weather events (Hussain *et al.*, 2020). Rising temperatures devastate rice yields, with every 1°C increase in minimum temperature causing 7% to 10% drop during critical growth phases such as reproduction (Fahad *et al.*, 2019; Peng *et al.*, 2004; Saxena and Kumar, 2022; Sanadya *et al.*, 2024; Umarani *et al.*, 2020) with 3.2 % drop in rice yields (Zhao *et al.*, 2017). Therefore, rice cultivation is a major concern to the scientific community and a considerable threat to sustainable agriculture. Furthermore, the attainment of the climate objective to confine global temperature rise to well below 2°C (3.6°F) with an ideal target of 1.5°C (2.7°F) above pre-industrial levels as highlighted in the Paris Climate Agreement (UNFCC, 2015) necessitates substantial reductions in GHGs across all agricultural sectors by 2030, with specific emphasis on the rice sector. This requires a "win-win" rice production strategy which can boost yield while reducing emissions.

Mechanism of greenhouse gas emissions from rice fields

Agricultural soils assume an imperative function in the release of GHGs, specifically CH_4, N_2O, and CO_2 through intricate interactions involving soil flora and microorganisms. In rice-cropping systems, direct emissions include CH_4 from inundated paddy fields, N_2O from nitrogen-based fertilizer application, and CO_2 emissions from plant rhizosphere and soil microbial respiration. Whereas, indirect emissions result from rice production, storage, consumption, waste chains and transportation of agricultural input production such as human inputs, fertilizers, fuel consumption, and pest and weed control (Ji *et al.*, 2024). Rice cultivation is the third most significant contributor to non CO_2 GHG emissions within the agricultural domain, trailing behind livestock and various forms of croplands on a global scale (Trang *et al.*, 2022). The traditional practice of paddy farming with inundated condition, wherein organic matter undergoes anoxic decomposition release of CH_4 by the process of methanogenesis, whereas, in aerobic soil, decomposition occurs in the presence of oxygen with the release of CO_2 (Gupta *et al.*, 2021). N_2O emissions arise from microbial N transformations through the processes of soil nitrification and denitrification, both of which can co-exist in flooded rice soils, and also by the heterotrophic reduction of nitrate-nitrogen to ammonium (Bhattacharyya *et al.*, 2013; Kuypers *et al.*, 2018).

Methanogenesis, methanotrophy and methane emission from rice paddies

CH_4 is the second most crucial GHG after CO_2 in terms of GWP, predominantly released from inundated rice paddies (Conrad, 2007), characterized by high radiative efficiency with shorter lifespan than CO_2. It exhibits high and moderate GWPs, respectively, over short and longer timescales (Balcombe *et al.*, 2018). Its atmospheric concentration has surged from preindustrial benchmark of 722 ppb (Wang *et al.*, 2017), contributing almost one quarter of the cumulative radiative forcings for CO_2, CH_4, and N_2O combined since 1750 (Etminan *et al.*, 2016), while global CH_4 emissions have consistently risen (Lamb *et al.*, 2021). With rice cultivation and livestock contributing to a current concentration of 1,895 ppb (Feng *et al.*, 2023), annual global emissions from rice fields were estimated at 27 ± 6 Tg, and predictions indicate persistent or increasing emissions in the future (Wang *et al.*, 2023). Christensen (2024) reported that wetland emissions, especially CH_4 concentrations, are rising faster than ever in the atmosphere. According to Maraseni *et al.,* (2018), rice cultivation is responsible for over 10 % of global CH_4 emissions, particularly in Southeast Asia, one of the world's major rice bowls, where it is accountable for 25% to 33 % of the region's emissions (Umali-Deininger, 2022). Linquist *et al.,* (2012b) reported the GWP of rice cultivation to be 2.7 and 5.7 times greater than that of maize and wheat systems, respectively, with CH_4 specifically accounting for over 90% of rice system's GWP. Recent reports have shown that the highest CH_4 emissions occur from the tillering to flowering stage in rice (Islam *et al.*, 2022b; Mallareddy *et al.*, 2023). Emission of CH_4 from paddy soils largely depends on the production and oxidation rates, mainly governed by methanogen and methanotroph population dynamics in the system, ultimately determining the net CH_4 emission from the rice fields (Fazli *et al.*, 2013).

Methanogenesis or CH_4 production, which necessitates anoxic conditions and low redox potential ($E_h < -150$ mV), is facilitated by anaerobic obligate bacteriae/archae referred to as methanogens (Penning and Conrad, 2007). They use fermentation products from microbial decomposition of plant matter and root exudates; with three biochemical pathways, namely hydrogenotrophic, acetoclastic, and methylotrophic, primarily producing CH_4 from acetate (Malyan *et al.*, 2016a). The CH_4 produced is either released into the atmosphere through three mechanisms, *viz.*, (i) diffusion loss of dissolved CH_4 across the water-air and soil-water interfaces, (ii) ebullition loss by the release of gas bubbles, and (iii) Plant-mediated transport (PMT) - transport into the roots by diffusion and conversion to CH_4 gas within the aerenchyma and cortex of rice plants, followed by concurrent release to the atmosphere through stomata; or, it may undergo methanotrophy. In the rice-growing season, nearly 80 to 90% CH_4 produced in the soil is released by PMT, facilitated by specialized aerenchyma structures that provide oxygen for respiration and CH_4 for transport (Xie and Li, 2002). Additionally, it is observed that 90% of the CH_4 produced in rice soils escapes primarily through micropores in the leaf sheath of the lower leaf position, whereas the leaf blade stomata serve as the secondary site of emission (Islam *et al.*, 2020b). Furthermore, CH_4 may undergo biological oxidation by aerobic and anaerobic methanotrophs, referred to as methanotrophy (Conrad, 2007; Nazaries *et al.,* 2013), wherein aerobic oxidation transforms CH_4 to CO_2 by sequential enzyme activity, utilizing oxygen as an electron acceptor, mediated by CH_4 monooxygenases that can also oxidize substrates such as acetate, ethanol, malate, succinate, and pyruvate. On the other hand, anaerobic methanotrophy or sulphate-dependent CH_4 oxidation is accomplished through physical combination of anaerobic methanotrophic archaea and sulphate-reducing bacteria using sulphate as an electron acceptor, facilitated by metals like iron and manganese (Chowdhary and Dick 2013; Nazaries *et al.*, 2013; Malyan *et al.*, 2016a). However, methanotrophy is limited by rapid ebullition, which reduces the likelihood of CH_4 oxidation.

Nitrous oxide production and emission from rice fields

N_2O is a leading anthropogenic GHG and plays a key role in stratospheric ozone depletion. Agriculture sector is the largest source of N_2O among all the anthropogenic contributors (Reay *et al.*, 2012), particularly due to the significant share of water and N-based fertilizers usage in rice cultivation (Zhao *et al.,* 2019; Jiang *et al.,* 2019). Hence, the likelihood of increased global N_2O emissions from rice fields in the future is markedly elevated (Ussiri and Lal, 2012). N_2O is generated through microbial nitrogen transformations in soils, which has been related to two biological processes, *viz.,* (i) Nitrification of ammonium (NH_4^+) under aerobic conditions leading to the loss of N as N_2O, and (ii) Denitrification - the reduction of NO_3^- to N_2O and, ultimately, N_2 gas under anaerobic conditions. It is produced in rice soils after intermittent flooding during the transition from wet to dry soil conditions. N_2O emissions from traditional flooded paddy fields, with 100 % water-filled pore space are minimal, because nitrification cannot occur due to anaerobic conditions, which also precludes denitrification due to the lack of NO_3^- in the soil (Qin *et al.*, 2010), as the NO_3^- gets reduced to NH_4^+ under such anaerobic condition. When N-based fertilizer is applied to the paddy fields, within the oxidized layer at the water-soil interface, the NH_4^+-N gets nitrified to NO_3^-, facilitated by ammonia oxidising bacteria (AOB) and archaea (AOA), with the latter being predominantly accountable for the process (Ahmed *et al.*, 2023). The NO_3^- thus formed in the oxidized layer moves to the reduced layer, where anaerobic bacteria denitrify it, producing N_2O as an intermediary compound (Van Spanning *et al.*, 2005; Xing *et al.,* 2002; Xing *et al.,* 2009). As N_2O is water-soluble, in flooded soils, rice roots absorb and transmit it through leaves *via* the transpiration stream, while it mainly diffuses to the soil surfaces in the absence of flood water.

Carbon dioxide production and emissions from rice fields

Rice paddies emit less CO_2 compared to CH_4 and N_2O, stemming from biotic and abiotic processes, but are often overlooked in studies due to maintained soil organic matter (SOM). The generation and release of CO_2 are contingent upon soil dynamics, prevailing environmental conditions, and the SOM characteristics. Microbial decomposition of reintroduced organic matter drives soil carbon mineralization, making it a key process in the release of CO_2 from soils (Hossain *et al.*, 2017; Mohanty *et al.*, 2017; Rahman, 2013). Anaerobic condition in inundated paddies limits carbon oxidation, thereby accumulates soil organic carbon and results in lower CO_2 emissions while promoting methanogenesis. At the surface level of the soil, CO_2 is liberated through the respiration of roots alongside various forms of flora and fauna (Hossain *et al.,* 2017). Observations indicate that CO_2 flux in rice paddies vary throughout the growth cycle, peaking during flowering due to heightened photosynthesis, while nocturnal emissions are primarily respiration-driven (Wang *et al.*, 2024). Ebullition contributes 13-35 % of CO_2, modulated by the content of crop residue and litter, root activities, and microbial processes that transform the soil carbon reservoirs into CO_2 through the action of soil microorganisms. Additionally, practices like urea application, residue incineration particularly the in-field burning of rice straw, and tillage methodologies enhances CO_2 emissions in rice cultivation (Ngo *et al.*, 2018; Rahman *et al.*, 2017). Urea fertilizer in the presence of water and urease enzyme gets converted to ammonium (NH_4^+), hydroxide (OH^-) and bicarbonate (HCO_3), with the latter ultimately evolving into CO_2 and water (Hussain *et al.,* 2015). However, albeit low efficiency of CO_2 assimilation due to photorespiration, rising atmospheric CO_2 concentrations stimulate photosynthesis and productivity of C3 plants such as rice, a phenomenon known as the CO_2 fertilization effect.

Strategies to prevent rice from warming the planet

Field studies have shown that the changes in crop genetics and selecting suitable cultivar, tillage practices, cropping regime, proper management of irrigation, fertilizer use, use of nitrification inhibitors, crop residue management *etc*., have a significant influence on GHG emissions from rice (Gupta *et al.*, 2021; Yadav *et al.*, 2024; Wassmann *et al.*, 2000), which in turn influence the biogeochemical processes of C and N in the soil (Islam *et al.*, 2020a). Alleviating GHGs emission from agriculture can be achieved by sequestering C in soil and reducing emissions of CH_4 and N_2O from soil through changes in land-use management (Pathak *et al.*, 2014). Such options are important not solely for global warming mitigation but also for improving soil health and fertility, along with optimal yield and curtailing emissions; essentially a win-win sustainable scenario. As major emission-curtailing factors are water regimes and fertilizer management practices, implementing targeted agro-technologies and management practices is crucial for mitigating GHG emissions in rice cultivation.

(A) Reducing GHG emissions while saving water

1. Irrigation and drainage management

Rice, a water-guzzling crop cultivated mostly through suboptimal irrigation methods, suffers from low water efficiency and significant environmental repercussions. Research indicates that water stress, especially, drought adversely affects rice productivity, with yield reductions ranging from 21% to 52% across various cultivars under stress conditions (Hussain *et al.*, 2022). Paddy fields exhibit a comparatively lower level of CO_2 emissions in relation to CH_4 and

N_2O, attributable to the suboptimal conditions for C oxidation of inundated paddy soils. The process of ebullition accounts for approximately 13–35% of CO_2 and 94–97% of CH_4 emissions (Hussain *et al.*, 2015). Rice paddies predominantly contribute to CH_4 emissions; however, under flooded conditions, they also emit N_2O, although to a lesser extent, due to the denitrification process favoured in anaerobic environment (Pittelkow *et al.*, 2013). On the other hand, N_2O emissions experience a substantial increase under conditions of continuous inundation and cycles of drainage which enhances nitrification. Consequently, rice cultivation presents a notable trade-off between CH_4 and N_2O emissions, with the generation of both the gases being significantly affected by the availability of water within the root zone of the crop. Nonetheless, rice production is currently confronted with considerable challenges, including the scarcity of irrigation water, labour shortages, and high GHG emissions from traditional continuous flooding (CF) of rice fields, sometimes over 90% CH_4 emissions than non-flooded practices (Sanchis *et al.*, 2012).

The irrigation patterns employed throughout the rice cultivation process can exert a profound influence on GHG emissions due to their regulation of soil microbial activity and the availability of substrates for non CO_2 emissions. Variations in soil moisture resulting from irrigation directly affect soil redox potential, which can significantly regulate the rates of release and consumption of GHGs (Wang *et al.*, 2017). Numerous studies have underscored the efficacy of diverse water management strategies including alternate wetting and drying (AWD), controlled irrigation (CI), mid-season drainage (MSD) in diminishing CH_4 and N_2O emissions originating from rice fields. In Eastern India, hydrologic variability exerts a considerable influence on GHG emissions, with variables such as the duration of flooding and interactions with crop residues and nitrogen management serving as pivotal determinants (Arenas-Calle *et al.*, 2024).

The AWD irrigation system, developed by the International Rice Research Institute (IRRI) represents a promising, water-saving, and economically viable environmentally benign technique that entails intermittent drying and re-flooding of rice fields. It effectively reduces GHG emissions by 45-90%, enhances water utilization and sustains grain output by promoting non-flooded days throughout the crop cycle (Das *et al.*, 2016; Ogawa *et al.*, 2022). Global freshwater scarcity, labour shortages, and high GHG emissions from traditional continuous flooding (CF) of rice fields are driving the adoption of the AWD irrigation system (Lampayan *et al*., 2015). Conversely, AWD irrigation fosters an ideal environment for nitrification and ensuing denitrification upon re-hydration, which may emit N_2O gas (Jiang *et al.*, 2019). Consequently, a trade-off relationship between CH_4 and N_2O emissions has been identified through water management (Islam *et al.*, 2020b; Islam *et al.*, 2022a). While AWD decreases CH_2 emissions by up to 73% in certain conditions, with sustained rice yields comparable to CF systems (Prangbang *et al.*, 2020; Sander *et al.*, 2020) by enhanced diffusion of atmospheric oxygen into soil, it may also elevate N_2O emissions by 44% (Zhao *et al.*, 2024) due to increased nitrification of NH_4^+ during the dry episode and the subsequent denitrification of NO_3^- during re-wetting of dry soil; however, it still reduces total GHG emissions from rice fields mainly due to reduced CH_4 emissions. Furthermore, lysimeter studies by Phungern *et al.,* (2023) reported reduction of 55.6% for lowland and 59.6% for upland cultivars in GWP for AWD over CF practices, despite an increase in N_2O emissions attributable to higher dissolved oxygen levels. AWD can consistently reduce the amount of soil available P (Adhikary *et al.*, 2023), thereby boosts arbuscular mycorrhizal fungi (AMF) that help plants absorb nitrogen, leaving less for N_2O production and lowering emissions (Storer *et al.*, 2018). A thorough investigation by Aung *et al.,* (2018) further suggested that early-season AWD could effectively lower GHG emissions in contexts where the full-scale implementation of AWD is impractical, achieving CH_4 reductions up to 51.5% in the dry season and 20.1% in the wet season. However, full-AWD practices resulted in a

52.8% to 61.4% reduction compared to CI (controlled irrigation), significantly decreasing CH_4 emissions in the dry season and also reducing early season emissions in the following wet season. AWD and CI have demonstrated significant potential for mitigating CH_4 emissions by approximately 51.6% to 60.5% and reduce nutrient losses while maintaining rice yields (Lee *et al.*, 2023b; Zhao *et al.*, 2024). Additionally, CI and AWD practices effectively decrease N losses, particularly when soil desaturation occurs before re-irrigation, which is crucial for minimizing NO_3^- leaching (Gbedourorou *et al.*, 2024).

MSD (mid-season drainage) in flooded rice systems slashes seasonal CH_4 emissions by an impressive 20-77% averaging at 52% reduction, while the accompanying rise in N_2O emissions contributes only 3% to overall GWP (Perry *et al.*, 2024). In Japan, MSD is widely employed to augment rice yields and conserve water, and its application in areas characterized by high CH_4 emitting soils can lead to a significant reduction in national CH_4 emission estimates (Leon *et al.*, 2017). Liu *et al.,* (2019a), in a meta-analysis focused on MSD, reported 47% reductions in GWP. A global meta-analysis by Wu *et al.*, (2022) revealed that drainage in rice cultivation reduced CH_4 emissions by 57.8%, increased N_2O emissions by 149.9%, and CO_2 emissions by 27.7%, with negligible impact on yield (+0.3%), ultimately decreasing the GWP index by 57.7%.

Furthermore, studies indicate that while CF generally leads to lower N_2O emissions, the implementation of intermittent flooding can paradoxically increase N_2O emissions significantly, sometimes up to three times higher than those from CF fields (Akiyama *et al.*, 2005; Kritee *et al.*, 2018). The adoption of CI methods, such as controlled intermittent flooding (CIF), helps reduce emissions while enhancing water-use-efficiency (Rajasekar and Selvi, 2022). Intermittent wetting and drying (IWD) can lower CH_4 emissions without reducing yields, as observed in the Brahmaputra valley (Rajbonshi *et al.*, 2024). Additionally, the management of fallow periods between rice crops, including practices such as soil drying and aerobic tillage, can impact CH_4 and N_2O emissions, with soil drying treatments resulting in elevated N_2O emissions due to the accumulation of NO_3^- (Sander *et al.*, 2018). Collectively, these studies emphasize the critical importance of tailored water management practices that take into account local hydrologic conditions, soil types, and socio-economic factors to effectively mitigate GHG emissions in rice cultivation.

2. Alternate rice production systems

The conventional wetland rice cultivation methods of puddled transplanted rice (PTR) are both water-intensive and labour-demanding, necessitating the development of water-efficient rice production systems that enhance water productivity in light of the impending water crisis. Soil puddling induces oxygen-deficient conditions that intensify GHG release and nitrogen depletion, ultimately amplifying the environmental footprint of rice cultivation. The choice of rice establishment method, such as transplanted rice versus direct seeding, also affects emissions, with transplanted rice generally producing higher GHG emissions across various fertilizer methods (Tin *et al.*, 2022). However, Moe *et al.,* (2024) found lower GHG emissions in transplanting compared to broadcasting method, without reducing grain yield. Advanced resource conservation methodologies such as direct seeded rice (DSR), system of rice intensification (SRI), and aerobic rice present opportunities to optimize water utilization with reduced environmental footprint and enhanced productivity (Mallareddy *et al.*, 2023; Sultan *et al.*, 2024).

DSR is increasingly favoured over traditional PTR methods, offering benefits like reduced water use, lower labour costs, early crop maturity, and decreased GHG outputs, particularly CH_4 and N_2O, making it environmentally and economically appealing (Mishra *et al.*, 2023). The DSR technique involves sowing pre-germinated seeds in puddled soil (wet-DSR), standing water (water seeding), or dry seeding on a prepared seedbed (dry-DSR), while significantly lowering input needs, conserving 12–35% of water and labour, and curbing methane emissions by up to 90%. (Singh *et al.*, 2024).

The SRI methodology, which integrates practices such as AWD, has been widely adopted and is recognized for its substantial reduction in CH_4 emissions (Uphoff, 2024) 885, with research suggesting a reduction of approximately 35-41% in GHG emissions per hectare relative to traditional methods, while, also enhancing yields by approximately 66%, further decreasing emissions per kilogram of rice produced and lowering production costs, making it a more attractive option for farmers (Dahlgreen and Parr, 2023; Dahlgreen and Parr, 2024). Additionally, SRI practices enhance soil C sequestration and lessen the reliance on chemical inputs, thereby contributing to environmental sustainability and CC mitigation (Hoang *et al.*, 2021). The practice also reduced CH_4 and CO_2 emissions by 59.8% and 20.1% compared to conventional practice, while emitting a small amount of N_2O (up to 0.0002 kg ha^{-1}), which was not detected in conventional methods, and achieved greater grains output with lower seasonal GWP and greenhouse gas emission intensity (GHGI) when coupled with 90 $kgNha^{-1}$ (Mboyerwa *et al.*, 2022).

Aerobic rice, which is cultivated in non-flooded, well-drained soils, not only significantly reduces water consumption and GHG emissions but also enhances water productivity compared to flooded rice, positioning it as a sustainable alternative to traditional methods, although challenges in achieving potential yields remain (George, 2018) Aerobic rice showed better GHG reduction, with CH_4 emissions nearly halved compared to flooded rice (Jinsy, 2014). Furthermore, a study by Ramesh and Rathika (2020) revealed that while transplanted rice exhibited higher CH_4 emissions, aerobic and drip-irrigated rice displayed markedly lower GHG outputs and improved water productivity. The aerobic rice system demonstrated notable environmental benefits, reducing the carbon footprint of rice production by 14.6 and 19.3% over shallow lowland rice and rice intensification systems, respectively (Dash *et al.*, 2023).

In Vietnam the package of improved cultivation techniques known as “1 Must-do, 5 Reductions” (1M5R) integrating AWD alongside other advanced techniques can save up to 11 tons of CO_2 equivalent per hectare annually compared to conventional farming. The approach promotes the use of certified seed and must achieve ‘5 reductions’ in seed rate, fertilizer rate (nitrogen), pesticide rate, water consumption through AWD irrigation, and post-harvest losses as a means to improve the overall sustainability of rice production (IRRI, 2024).

(B) GHG mitigation through fertilizer management

The on-going challenge of improper and non-judicious fertilizer application in agriculture has elicited significant concern. Rice represented 15% of global fertilizer use among the top three cereals (maize, wheat, and rice), with cereals overall accounting for 59% of nitrogen fertilizer consumption. Rice received approximately 16%, 13%, and 12% of the 59% N, 49 % P_2O_5, and 39 % K_2O used by the cereals, respectively (IFA, 2022). Nitrogen fertilization constitutes one of the strategies employed to improve crop yield and sustain soil fertility, though it significantly stimulates N_2O, CH_4 and CO_2 emissions, contributing to enhanced global warming (Menegat *et al.*, 2022). Methane fluxes are highly dependent on carbon availability, which is derived from the application of fertilizers, dead plant tissues, and organic exudates (Bhatia *et al.*, 2005). Nitrogen fertilizer’s impact on CH_4 emissions from rice fields is complex, influencing production, oxidation, and transport processes. It can either increase emissions by promoting rice growth and substrate C supply for methanogens or decrease emissions by enhancing CH_4 oxidation by stimulating growth of methanotrophs (Chen *et al.*, 2024). However, the net effect depends on nitrogen source and agronomic practices. Specifically, N fertilization enhances methanogen activity and accelerates organic matter decomposition, significantly increasing CH_4

emissions in acidic soils. Furthermore, approximately three-quarters of N_2O emissions from agricultural soils is from application of nitrogenous fertlizers, which enhances soil microbial activity, thus necessitating meticulous selection for effective mitigation strategies (Mohanty *et al.*, 2017). Additionally, rice plants themselves may contribute to N_2O emissions through a proposed mitochondrial pathway under hypoxic conditions, suggesting dual sources of N_2O in paddies *i.e.,* soil microorganisms and the plants (Timilsina *et al.*, 2020). However, research indicates that only 30-40% of the applied N is effectively absorbed by rice plants, while 60-70% is lost through processes such as ammonia volatilization, denitrification, surface runoff and NO_3^- leaching (Galloway *et al.*, 2003), necessitating improved nitrogen management strategies to enhance nitrogen use efficiency and eventually alleviate GHG emissions.

The effective management of fertilizers has a substantial effect on the reduction of the emissions of N_2O and CH_4, as it is largely affected by the type, rate, mode, timing, and method of fertilizer-N application. Enhancing nitrogen efficiency potentially mitigates N_2O emissions and residual NO_3^- in soil, while the 4R nutrient management approach *viz.*, right source, right time, right rate, and right placement successfully alleviates GHG emissions. Furthermore, promising results have been observed from sophisticated fertilizer management strategies designed to diminish GHG emissions from rice paddies, including the utilization of enhanced efficiency nitrogen fertilizers (EENFs), plant need-based application using leaf colour chart (LCC), precise incorporation into soil, tailored application rates and timings, and the avoidance of excessive use.

The type and amount of fertilizer material used can significantly affect soil microbial activity, thereby altering CH_4 and N_2O emissions. Researchers concluded after a meta-analysis of 155 studies that N fertilizer enhances CH_4 emissions, and the stimulatory effect of urea is more pronounced (2–3 times higher) than that of ammonium sulphate (AMS) (Banger *et al.*, 2012). Elevated levels of NH_4^+N in soil can significantly curb overall CH_4 emissions (Hussain *et al.*, 2015). Urea application enhances the soil NH_4^+N, and due to the structural parallels between CH_4 and NH_4^+ ion (Schimel, 2000), methanotrophs preferentially bind to NH_4^+; therefore limits methanotrophy, ultimately leading to increased CH_4 emission from soil (Malyan *et al.*, 2016a). On the other hand, AMS suppressed methanogens in rice soils. AMS application has been demonstrated to lower CH_4 emissions by 42% to 60% through the promotion of methanotrophic bacteria that oxidize CH_4. This is because the sulphate (SO_4^-) ions present in AMS can inhibit CH_4 production by fostering competition for resources between methanogens and sulphate-reducing bacteria. Ali *et al.,* (2012) and Malyan *et al.,* (2016b) observed 15% - 21% reduction in total seasonal CH_4 flux by AMS over urea. Applying phosphorus (P) and potassium (K) fertilizers reduces CH_4 emissions from rice fields, likely by promoting plant aerenchyma development and stimulating methanotrophic bacteria. Although N fertilizer increases CH_4 emissions, combining N, P, and K lowers the CH_4-to-grain yield ratio significantly (Datta *et al.*, 2013). Additionally, Slameto *et al.,* (2024) reported that combined application of NPKS fertilizer with manure fertilizer substantially increased rice yield while reduced CH_4 emissions and GWP values compared to alternative fertilizer formulations. Long-term P fertilizer input reduces CH_4 emissions in rice fields, mainly by improving CH_4 oxidation (Zhu *et al.*, 2022), which highlights the need for judicious P management to increase rice yield while reducing CH_4 emissions. Research by Kang *et al.,* (2024) suggest that the application of silicate fertilizer containing 2.5 % iron slag, particularly those enriched with electron acceptors such as oxidized iron (Fe^{3+}), show promise in reducing CH_4 emissions without compromising rice grain yield or soil characteristics. However, the dynamics of N_2O were questionable. Since the reduced iron (Fe^{2+}) can react as an electron donor, iron slag-based silicate fertilizer application might suppress N_2O emissions by progressing N_2O into N_2 gas during the denitrification process. In the Korean rice paddy, iron slag–based silicate fertilizer, enriched with Fe^{3+}, suppressed seasonal CH_4 emissions by 36–38 % through competition for electrons under anaerobic conditions, while reduces seasonal N_2O emissions by 49–56 % by donating electrons to drive denitrification toward N_2O gas rather than N_2O. It cuts net GWP by 37–40 %, and boosts grain yield by 22–25 % at an optimal soil SiO_2 level of ~183 mg/kg (Galgo *et al.*, 2024).

Microbial processes involved in N_2O production are typically related to the amount of N available in the soil, highlighting N fertilizer rate as the key determinant for N_2O emissions. Meta-analyses by Linquist *et al.,* (2012a) and Zheng *et al.,* (2014) revealed that unlike CH_4 emissions, which rise under low-to-moderate N levels but decline with excessive N, N_2O emissions increase with higher nitrogen input. Notably, at optimal application rate of 150-200 kg N ha^{-1}, yield benefits of nitrogen fertilization surpassed its GWP impact (Zheng *et al.*, 2014). Zhong *et al.,* (2016) reported the same trend with N_2O emissions and N-fertilizer rates, peaking at reproductive phase of rice growth, and suggested 225 kg N/ha as optimal. Regardless of N fertiliser type and biochar rates, increasing N rates increased rice yield and N_2O emissions (Iboko *et al.*, 2023). Thus, decreasing N input in rice soils is a promising strategy to mitigate GHG emissions, particularly N_2O. This is because lower N inputs enhance competition between plants and soil microbes, leading to improved N assimilation by plants and hence reduced N_2O emissions. However, applying less than the optimal amount can deplete SOC and reduce soil productivity.

Enhanced efficiency nitrogen fertilizers (EENFs) such as polymer-coated slow or control release fertilizer (S/CRF) and common N-fertilizer combined with nitrification inhibitor (NI), urease inhibitor (UI), and double inhibitors of UI + NI (DI) are designed to optimize nitrogen use by crops, reducing environmental losses. EENFs reduce CH_4 emissions by boosting oxidation and cut N_2O emissions by limiting N availability for nitrification and denitrification processes (Qian *et al.*, 2023). Compared to conventional N fertilizer, EENFs significantly reduced CH_4 emission by 16.2% and increased rice yield by 7.3%, leading to a 21.7% decline in yield-scaled N_2O emissions (Yang *et al.*, 2022). They further found that Nitrapyrin, DMPP (3, 4-dimethylpyrazole phosphate), and HQ (Hydroquinone) + Nitrapyrin were more effective in reducing CH_4 emissions, while HQ alone had less impact on rice yield than other EENFs. According to Shakoor *et al.,* (2018), N_2O emissions peaked with conventional fertilizer applications, while optimized and slow-release fertilizers reduced emissions by up to 21% in rice-wheat cropping system. Kuchi *et al.,* (2024) reported that coating urea with urease inhibitors conserves 20-25% N and ensures slow, gradual release throughout the crop growth, helping reduce pollution in soil, water, and the environment. Additionally, plant-derived materials such as neem cake, neem oil, and karanja seed extract are potential NIs (Gupta *et al.*, 2021). Biological nitrification inhibitors (BNIs) enhance nitrogen utilisation efficiency, reduce leaching, lower N_2O emissions and boost crop yields. Studies have proved that application of BNIs can decrease N_2O emissions by up to 90% compared to non-BNI producing plants (Saud *et al.*, 2022). Improved rice quality indices have also been observed, indicating that BNIs not only mitigate emissions but also enhance agricultural productivity, with 15.45% yield increase when BNIs are applied alongside conventional fertilizer (Huang *et al.*, 2023). Compounds such as syringic acid derived from rice root exudates inhibit *Nitrosomonas* strains leading to improved nitrogen utilization, and significant reductions in N_2O emissions by 69.1-79.3% in paddy soils and by 40.8%-46.4% from red soil, respectively (Lu *et al.*, 2022). They further found that the nitrification inhibitory efficacy of syringic acid was strongest in acidic red soil, followed by weakly acidic paddy soil, with no significant effect in an alkaline calcareous soil. Additionally, syringic acid addition possessed dual inhibition of both AOA and AOB abundance in paddy and red soil, linked to soil NH_4^+ and dissolved organic carbon.

Nano-fertilizer technology presents a viable approach to reduce agricultural emissions and mitigates climate change through controlled or slow-release of the nutrients (Saraiva *et al.*, 2023; Srivastava *et al.*, 2023). A greenhouse study by Mohanraj *et al.,* (2017) showed that nano-zeolite fertilizers containing NO_3^-N and NH_4^+N facilitate prolonged nutrient release, extending availability up to 11.6 and 20 days, respectively. They further found that while NH_4^+based nano-fertilizer reduced N_2O emissions, NO_2^- based nano-fertilizers decreased CH_4 emissions compared to conventional methods, showcasing enhanced nitrogen management and environmental benefit. Additionally, applying 75 kg N/ha through urea along with three nano-urea foliar sprays at 20, 40 and 60 days after transplanting halved CH_4 and N_2O emissions compared to 150 kg N/ha through urea in conventional split application, while maintaining or boosting yields (Anushka *et al.*, 2024). Moreover, Borah and Baruah (2016) assessed the impact of foliar application of plant growth hormones on CH_4 emission reduction from rice paddies. The results indicated that treatments with indole-3-acetic acid and kinetin (in 20 mg L^{-1} concentration) significantly decreased cumulative CH_4 emissions while enhancing grain productivity, thus presenting a viable approach for both emission regulation and economic yield improvement in rice cultivation.

Nitrogen topdressing in irrigated Eastern India rice fields can be guided by LCC (≥5) and soil plant analysis development (SPAD) or chlorophyll meter (≥37) thresholds, saving 20–47.5 kg N/ha over fixed-timing methods (Maiti *et al.*, 2004). Split application synchronize nutrient supply with crop demand and minimizes N losses to the environment, but show inconsistent effects on N_2O emissions over the course of a season depending on soil properties and water management (Slayden *et al.*, 2022). Typically, N_2O emissions spike shortly after fertilization due to heightened nitrification and denitrification (Gaihre *et al.*, 2020; Gogoi and Baruah, 2014; Shakoor *et al.*, 2018). Urea deep placement (UDP) significantly enhanced rice yield and nitrogen uptake by increasing panicle production per hill and improving nitrogen recovery efficiency (Gaihre *et al.*, 2020), aligning with earlier findings that reported 15%–20% yield gains and 25%–50% urea savings compared to broadcast urea due to targeted nitrogen placement in the root zone (Huda *et al.*, 2016; Islam *et al.*, 2018). However, further investigations are needed before endorsing deeper placement as a sustainable method farming practice as indicated by (Rychel *et al.*, 2020).

(C) Other Agronomic management practices

1. Tillage management

Soil tillage practices exert a considerable influence on GHG emissions during rice cultivation, by altering both the physicochemical and biological characteristics of the soil, thereby enhancing microbial production of CH_4 and N_2O (Oorts *et al.*, 2007). When considering GHGs collectively, soil tillage resulted in a 20 % increase in net global warming relative to NT, underscoring the CC mitigation potential inherent in a NT system. Conventional tillage practices, characterised by extensive soil disturbance, disrupts soil structure, leading to erosion, nutrient depletion, and reduced soil fertility over time. Contrastly, conservation tillage methods such as no-till (NT) and reduced tillage (RT) minimize soil disturbance, helping maintain structure, increase organic matter content, and improve moisture retention (Derpsch *et al.*, 2010). These practices enhance drought resilience and soil health, while lowering GHG emissions and boosting carbon sequestration, thereby supporting climate mitigation and long-term agricultural sustainability (Lal, 2018). In comparison to CT systems, the adoption of NT or RT practices markedly diminished the total GWP (by 6.6 %) linked to CH_4 and N_2O emissions, with NT showing greater mitigation effectiveness under crop rotation, straw removal, specific nitrogen application rates, and land-use conditions; while RT's impact varied widely, often increasing GHG emissions except in upland monoculture systems (Feng *et al.*, 2018). The consistent implementation of NT practices may enhance CH_4 oxidation and, in turn, reduce CH_4

emissions. Omonode *et al.,* (2007) articulated that NT practices limit CH_4 oxidation by compacting soil, thus reducing CH_4 uptake by rice soils. Moreover, research suggests that reducing tillage frequency in rice paddies could lead to diminished CH_4 emissions, attributable to an increase in soil bulk density under NT methodologies, which subsequently reduces soil porosity and ultimately lowers the decomposition rate of organic matter (Ahmad *et al.*, 2009; Pandey *et al.*, 2012). However, some researchers contend that NT practices may intensify N_2O emissions from rice soils (Zhang *et al.*, 2011; Nyamadzawo *et al.*, 2013). Bordoloi *et al.,* (2019) reported that a 25% reduction in N fertilizer application rates significantly curbed N_2O emissions from CT and RT agricultural systems. Given the potential for carbon sequestration and CH_4 mitigation, NT practices possess the potential to counterbalance overall GHG emissions. NT cultivation emitted 16.5% less GHGs in terms of CO_2-equivalent compared to conventional tillage practices (Yadav *et al.*, 2020). The potential regulatory influence of RT on CH_4 oxidation may facilitate the mitigation of CH_4 emissions. The reduced GWP associated with NT or RT compared to CT practices in rice agricultural settings (Ahmad *et al.*, 2009) suggests that the implementation of RT could confer significant benefits for GHG mitigation and carbon-smart agricultural practices, warranting endorsement within rice-based cropping systems. Overall, NT or RT practices can mitigate GHG emissions and enhance carbon sequestration, although their effectiveness depends on specific tillage methods and other management practices (Feng *et al.*, 2018).

2. *Selection of suitable rice cultivars*

The selection of rice varieties that enhance resource use efficiency while minimizing GHG emissions is essential for improving yields and addressing CC and associated abiotic stresses. There exists inherent variability in plant morphology, metabolic processes, and gas transport capabilities among distinct rice cultivars, with traits such as reduced number of sterile tillers, the number of plant tillers, above- and below-ground biomass, root exudates and root aerenchyma, a shorter root system, smaller xylem vessels, an elevated rhizospheric oxidation potential, an optimized harvest index, and a reduced propensity for root excretion, in conjunction with timely maturation traits (Aulakh *et al.*, 2000; Aulakh *et al.*, 2001; Gupta *et al.*, 2021; Bharali *et al.*, 2017; Hussain *et al.*, 2015; Linquist *et al.*, 2018; Oo *et al.*, 2016; Rajendran *et al.*, 2024; Wang and Adachi, 2000; Win *et al.*, 2021) are optimally suited for the reduction of CH_4 emissions from rice soils, highlighting the potential for selective breeding to enhance sustainability in rice cultivation amid GHG concerns (Bhattacharyya *et al.*, 2012). A positive correlation between rice biomass and CH_4 flux has been documented (Khosa *et al.*, 2010; Lee *et al.*, 2023a; Su *et al.*, 2015) , although outcomes from varietal comparisons have been inconsistent (Jiang *et al.*, 2013; Qin *et al.*, 2014). Moreover, a comprehensive meta-analysis by Zheng *et al.,* (2014) demonstrated that while potentially having higher yields, *indica* cultivars display a markedly elevated GWP per unit of yield, measured at 1101.72 kg CO_2 equivalent per Mg, in contrast to 711.38 kg CO_2 equivalent per Mg for *japonica* cultivars. This disparity underscores the significance of considering rice races in alleviating GHG emissions in rice production systems.

Studies indicate that CH_4 emissions from various rice varieties can range significantly, with values reported between 157.05 to 470.73 kg ha^{-1} during the main season, while N_2O emissions were notably lower, peaking at 0.94 kg ha^{-1} (Yadav *et al.*, 2024). The fluctuations in these non-CO_2 emissions may be contingent upon the physiological and anatomical attributes of various rice cultivars. Rice plants are vital for the production, oxidation, and emission of CH_4, serving as the principal conduit for over 90% CH_4 gas stemming from soil to atmosphere. Rice plays a dual role in CH_4 dynamics *viz.*, i) it enhances emissions through pathways like aerenchyma, and substrates (rhizodeposition, providing 40% to 60% of the organic C) for methanogens from the booting stage onwards; ii) it suppresses emissions by facilitating oxygen pathways that inhibit methanogenesis or promote methanotrophy (Conrad, 2007; Yuan *et al.*, 2012).

Furthermore, the overall contribution of rice cultivation to global GHG emissions underscores the importance of adopting low-emission rice varieties and sustainable agricultural practices to balance food security with environmental sustainability (Chirinda *et al.*, 2018; Chen *et al.*, 2024; Yadav *et al.*, 2024). Recent efforts to mitigate emissions include the promotion of submergence-tolerant varieties, drought-tolerant aerobic rice, short-duration varieties, high-yielding hybrids, and transgenic lines tailored for reduced methanogenic activity. Short duration varieties have demonstrated significantly low CH_4 emissions and GWP while exhibited elevated cumulative N_2O emissions (Win *et al.*, 2021). Furthermore, high-yielding and drought-resistant rice varieties can lower GHG emissions by 3.7% to 21.5% through optimized agronomic practices (Ji *et al.*, 2024). Flood-tolerant rice like MTU 1184 may cut irrigation needs, and thereby may potentially influence CH_4 emissions, and stabilize yields in flood-prone areas (Charumathi *et al.*, 2024). Selecting varieties with physiological traits that correlate with lower CH_4 emissions, such as smaller xylem vessels, further supports this mitigation strategy (Bharali *et al.*, 2017). High-yielding short duration hybrids which can minimize the time fields remain flooded, are emerging as a transformative approach to reducing GHG emissions (Hosseiniyan Khatibi *et al.*, 2025). Research shows that hybrid rice can emit 19% less CH_4, often exhibit enhanced nitrogen-use efficiency, reducing nitrogen emissions associated with excessive fertilizer application, compared to traditional inbred varieties under similar conditions (IRRI, 2025).

Research indicates that specific rice varieties exhibit significant differences in CH_4 emissions due to their root microbiomes and genetic traits. For instance, low-methane emitting cultivars like CLXL745 have been shown to have reduced methanogenic activity compared to high-emitting varieties (Hu, 2023; Liechty *et al.*, 2020). The effect of rice varieties on CH_4 emissions depends significantly on the colonization of methanogenic bacteria in roots as documented in Heijing 5 variety (Hu *et al.*, 2023). Additionally, a 70% reduction in CH_4 emissions with sustained yields was achieved when Heijing 5 was hybridized with elite high-yielding varieties, due to improved carbon partitioning and enhanced sugar transporters that optimize above-ground carbon allocation and limited CH_4-promoting root exudates (Hu *et al.*, 2024).

Notably, the cultivar Cliangyouhuazhan (CLYHZ) demonstrated high yield alongside the lowest GWP and GHGI in ratoon rice systems, making it a promising option for reducing CH_4 emissions (Zhang *et al.*, 2024). Genetically engineered rice varieties have shown significant potential in mitigating both CH_4 and N_2O emissions from paddy fields. For instance, transgenic lines with overexpressed nitrate transporters have demonstrated reductions in CH_4 emissions by up to 60% and also reduced total cumulative N_2O compared to their wild types, attributed to decreased root aerenchyma formation and lower methanogen populations in the rhizosphere (Iqbal *et al.*, 2023). India has launched two genome-edited rice varieties, 'Kamala' (DRR Dhan 100) and 'Pusa DST Rice 1', using Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR-Cas) technology. These offer higher yields, climate resilience, and reduced environmental impact, marking a breakthrough in sustainable agriculture (GOI, 2025). Additionally, rice varieties engineered for enhanced root traits, such as gas-tight barriers, facilitate better oxygen diffusion, promoting CH_4 oxidation and nitrification, which further reduces GHG emissions (Jiménez and Pedersen, 2023). Breeding rice to channel more photosynthates to grains instead of roots can cut CH_4 emissions and boost yields (Das and Kim, 2024). A genetically modified rice strain with increased starch content has been linked to lower methanogen levels, thereby contributing to reduced CH_4 emissions (Bodelier, 2015). The root development of a particular rice variety may influence the sequestration of SOC within the soil matrix. Furthermore, this aspect affects microbial activity by providing the carbon sources requisite for the processes of nitrification and denitrification (Borah and Baruah, 2016). Additionally, both qualitative and quantitative modifications in the profile of root exudates among various rice cultivars can significantly alter the rate of CH_4 production (Jia *et al.*, 2002). Varietal selection, along with irrigation management techniques such as AWD, can further mitigate CH_4 emissions (Asch *et al.*, 2023). According to Pramono *et al.,* (2020), the low-emission cultivar Inpari 32 when paired with AWD techniques, achieved a 46% reduction in CH_4 emissions.

3. Rice straw/residues management

Globally, the annual rice straw output ranges between 800 and 1,000 million tonnes, with 600 to 800 million tonnes, primarily from Asia (IRRI, 2018). The straw-to-paddy ratio varies significantly, ranging from 1.0 to 4.3 (Nguyen *et al.,* 2016; Zafar, 2015). Anaerobic decomposition of paddy straw and crop residue under CF conditions is a major contributor of CH_4 emissions from lowland rice fields (Liu *et al.*, 2014). Consequently, managing rice straw emerges as a critical consideration in the effort to regulate GHG emissions associated with lowland rice cultivation. Moreover, the effective management of straw is integral to the functioning of global carbon cycles, particularly through the sequestration of soil organic carbon (SOC).

Off-field practices such as composting, compost application, and bioenergy production offer greater mitigation potential than in-field practices. Proper straw management via surface retention/mulching or converting it into biochar or compost rather than burning or incorporation showed potential to curtail GHG discharges from rice soils (Bhattacharyya and Barman, 2018; Hussain *et al.,* 2015). Composting can mitigate emissions associated with fresh straw, livestock manure, and fertilizers (Gummert *et al.,* 2020). Combining biochar and compost can further enhance mitigation (Allen *et al.,* 2020), while avoiding straw burning, and adopting late incorporation can further reduce GHG potential. These methods have been shown to reduce net GWP by up to 206% compared to conventional practices (Belenguer-Manzanedo *et al.,* 2022). The development of alternative uses for rice straw can foster sustainable value chains, benefiting rural communities while addressing environmental concerns (Prateep Na Talang *et al.,* 2024).

In-field practices

a) Open-field burning – pile burning and spread burning

Rice straw burning is preferred over residue management due to several interrelated factors, including time constraints, short window for sowing of subsequent crops (Parihar *et al.,* 2023; Zaidi *et al.,* 2021), lack of awareness about alternative residue management techniques (Kumar *et al.,* 2023a; Muliarta *et al.,* 2022; Sharma and Bhattu, 2015), and insufficient technological support. The high costs and limited access to alternative technologies further perpetuate this reliance on burning (Shyamsundar *et al.,* 2019). Burning 1 kg of dry rice straw emits 700-4100 mg CH_4, 19-57 mg N_2O, and about 7300 kg CO_2-equivalent per hectare (Bhattacharyya *et al.,* 2021). Studies suggest that the gross GHG emissions, excluding CO_2 as it is net neutral due to photosynthesis in the IPCC guidelines, from burning are up to 98% lower than those from fresh straw incorporation in flooded soils (Van Hung *et al.,* 2020). When CO_2 is included, combustion causes 90% carbon loss, reducing soil carbon sequestration potential of fresh straw incorporation (Chen *et al.,* 2019). When this is accounted for, the net GWP from burning aligns closely with that of complete fresh straw incorporation (Lu *et al.,* 2010). Despite the established negative long-term impacts of straw incineration on soil quality, SOC sequestration and air quality, intensive rice farmers still prefer burning rice straw for its cost-effectiveness, reduced weed and disease carryover, and ease of tillage. Additionally, rice straw is less nutritious as fodder due to its silica content, making it less desirable for livestock feed. Thus, open-field burning remains the preferred method for farmers over residue management.

b) Incorporation

Studies indicate that while straw incorporation generally improves SOC levels, it can significantly elevate CH_4 emissions, particularly when applied at inappropriate times or methods, especially before rice transplanting in spring, leading to a potential 120% rise in CH_4 flux compared to no straw application (Song *et al.*, 2019). Conversely, autumn incorporation with soil mixing can reduce CH_4 emissions by 24-43% (Song *et al.*, 2019). Furthermore, while long-term (5 years) straw incorporation tends to lower N_2O emissions by up to 73.1% compared to one-year incorporation, it may also elevate CH_4 emissions by over 100% particularly during tillering stage, necessitating careful management to balance productivity with environmental impacts (Huang *et al.*, 2022). Effective strategies, such as controlled irrigation combined with multi-year straw incorporation, can optimize yields while minimizing GHG emissions (Huang *et al.*, 2022). Therefore, the timing and method of straw incorporation are critical for achieving sustainable rice production and effective GHG management (Danso *et al.*, 2023; Vijayaprabhakar *et al.*, 2021). Nevertheless, the slow decomposition rate of rice straw due to high contents of recalcitrant components (12% Ca, 16% silica and 6%–7% lignin), low N content (< 1.0%), and high C/N ratio (Yadvinder-Singh *et al.*, 2005) leads some farmers to forgo its soil incorporation, particularly in intensive cropping systems with a three-week interlude. As a result, scientists have initiated research aimed at accelerating the decomposition of rice straw. Thailand promotes ploughing harvested paddy into soil with additives to speed up rice straw degradation. Yet, farmers hesitate due to the method's time demands and expensive machinery (Oanh, 2021).

Off-field practices

c) Composting

Straw composting with manure effectively mitigates CH_4 emissions associated with in-field straw incorporation along with CH_4 and N_2O emissions from manure management. Rice yield remained stable with 40-60% less chemical fertilizer when using rice straw manure (RSM). It also sustained soil silicon levels and boosted microbial activity and protein content compared to non-RSM soil (Man *et al.*, 2007). Petersen *et al.,* (2013) suggest that using aerated manure with straw can decrease CH_4 emissions up to 90% compared to anaerobic storage. Improper manure or compost application can lead to nearly total loss of manure N, impacting GHG emissions and fertilizer N supply. This often occurs when manure is applied to high pH, low CEC soils without incorporation. In such cases, composting manure with rice straw can significantly reduce emissions **(***Gummert et al., 2020).*

Rice straw, with its high C:N ratio, is an effective manure compost bulking agent that reduces nitrogen loss to as little as 13% of the initial feedstock nitrogen by enhancing immobilization and substrate adsorption (Chadwick *et al.,* 2011). Furthermore, Spaccini and Piccolo (2017) suggest that composting enhances the stabilized fraction of SOC and sequesters more carbon than in-field aerobic residue decomposition. The added step of producing mushrooms from straw compost may potentially lower N_2O emissions by promoting nitrogen immobilization through mushroom nutrient uptake (Gummert *et al.,* 2020). However, studies on composting show that adding biochar can cut total nitrogen losses by about 52% (Steiner *et al.,* 2010).

d) Biochar production and utilization

Biochar can be prepared from rice straw under controlled pyrolysis (Foong *et al.,* 2022). Biochar production stands out as the optimal approach for agricultural residue management, given the lowest GWP impact and the highest net cash flow (Prateep Na Talang *et al.,* 2024). According to Sun *et al.,* (2019), the application of rice straw-based biochar was more effective in curbing overall NH_3 volatilization compared to the direct incorporation of rice straw. Crop residue decomposition, whether through incorporation or composting, may result in over 80% loss of the initial carbon as CO_2, with rice residue reaching 32.8% oxidation (Sarma *et al.,* 2013). Biochar, by contrast, stabilizes straw carbon more effectively, retaining 40%-50% as long-term soil organic carbon, offering greater climate benefits (Bhattacharyya *et al.,* 2021; Lehmann *et al.,* 2006; Yin *et al.,* 2014). Jia *et al.,* (2025) recommends 30 t ha^{-1} biochar to optimize crop production, enhance carbon balance, and mitigate climate change impacts, highlighting biochar's potential as a sustainable soil amendment in arid ecosystems. Comprehensive meta-analyses revealed high GHGs mitigation potential of biochar application (Allen *et al.,* 2020) alongside up to 70% decrease in the overall carbon footprint associated with rice production (Mohammadi *et al.,* 2016). Liu *et al.,* (2019b) observed a 41% reduction in GHG intensity (yield-scaled emissions) in upland soils and a 17% reduction in paddy soils with use of biochar in different cropping systems. Furthermore, co-application of low biochar (≤9 tons/ha) and medium N (>140 and ≤240 kg N/ha) produced low GHGs emissions, high grain yield, and the lowest GHGI (Iboko *et al.,* 2023; Dong *et al.,* 2024). According to Shen *et al.,* (2024), incorporating biochar into tropical paddy soils can increase rice productivity and decrease N_2O emissions by modifying the genes linked to nitrogen metabolism.

Microbiota management

Soil microbial dynamics influence emissions of CO_2, N_2O and CH_4 from rice soils. In soil, plant root/rhizospheric respiration and microbial respiration significantly contribute to elevated CO_2 concentrations in soil air compared to atmospheric levels. Research highlights that probiotic modulation can lead to significant GHG emission reductions, with a particular study noting a 47.58% decrease in CO_2, 21.53% in CH_4, and 88.50% in N_2O emissions, while increasing rice yield by 27.75% (Pao *et al.*, 2025). Additionally, N-fixing and CH_4-oxidizing bacteria contribute to GHG mitigation by utilizing CH_4 as an energy source and reducing N_2O emissions, fostering sustainable agricultural practices (Minamisawa, 2022). Cable bacteria boost sulphate *via* electrogenic sulphide oxidation, suppressing methanogens and cutting rice soil CH_4 emissions by 93% after one-time inoculation of rice-vegetated soil (Scholz *et al.*, 2020). Inoculating rice seeds with Betaproteobacterium *Azoarcus* sp. KH32C bacteria reduced soil CH_4-producing microbes, cutting CH_4 emissions by 17.2% (no fertilizer) and 23.5% (with nitrogen fertilizer), while maintaining rice grain yield (Sakoda *et al.*, 2022). Furthermore, the integration of microbial bio-stimulants has also proven effective in enhancing grain yields and decreasing CH_4 emissions, which is crucial given that rice accounts for approximately 11% of global anthropogenic CH_4 emissions (Kumar *et al.*, 2024).

The use of man-made (*i.e.*, silicone tube-based) aerenchymatous tissues (MAT) has been demonstrated to enhance soil oxygenation, resulting significant abatement in CH_4 emissions by about 50% in various both in mesocosms and paddy field trials (Yuan *et al.*, 2023). Moreover, they showed that the performance of MAT can be further improved by simply increasing the air pressure in MAT (e.g., -74.2% CH_4 emission at 200 kPa air pressure). Studies demonstrate that Plant Microbial Fuel Cells (PMFCs) can lower CH_4 emissions by up to 57% compared to conventional rice cultivation, especially when integrated with biochar and other enhancements (Al Hussain *et al.*, 2024; Kumar *et al.*, 2023b). The competition for organic substrates between electrogens and methanogens in PMFCs further enhances this reduction (Arends *et al.*, 2014; Deng *et al.*, 2016), with notable studies reporting reductions ranging from 38% to 84% through advanced fertilization techniques (Al Hussain *et al.*, 2024).

Challenges in GHG mitigation from rice fields

The expected rise in both the global population and rice consumption has sparked major concerns about limiting GHG emissions to mitigate future global climate change. The challenge lies in producing more food using less land and fewer resources. Significant advancements in agricultural technology will be required, including the development of high yielding, stress tolerant, low emission rice varieties. Water and fertilizers are the major drivers of GHG emissions from rice fields, primarily CH_4 and N_2O. Research indicates that integrating AWD practices can lower CH_4 emissions, but widespread adoption remains a challenge due to varying farmer incentives and local conditions. Additionally, the variability in soil types and climatic conditions across different regions complicates the implementation of uniform mitigation strategies. Furthermore, a trade-off between CH_4 and N_2O emissions is established; while AWD effectively curtails CH_4, it raises concerns about increased N_2O emissions, necessitating careful management. The DSR, SRI, and aerobic rice production systems effectively mitigates GHG emissions. However, despite its potential benefits, the adoption of such methods has been limited due to several constraints, including lack of awareness among farmers, significant changes in crop management practices compared to traditional practices such as nutrient management, weed management, etc.

While various mitigation strategies have shown promise in reducing GHG emissions from rice fields, several challenges remain, including balancing emissions reduction with yield maintenance, addressing the trade-off between CH_4 and N_2O emissions, adapting mitigation strategies to diverse agroecological conditions, incentivizing farmer adoption of emission-reducing practices, and improving understanding of soil-plant-microbe interactions in GHG production and emission.

However, balancing GHG reduction with food security remains complex, as some mitigation efforts may inadvertently impact crop yields and food availability (Creason *et al.*, 2016). Thus, integrated approaches that combine effective water management, appropriate fertilization, and cultivar selection are essential for sustainable rice production and effective GHG reduction (Sander, 2017). Future research should focus on developing rice varieties with lower GHGE potential, improving models to predict GHG emissions under various management scenarios, exploring the potential of microbial interventions to reduce GHG production, investigating the long-term impacts of mitigation strategies on soil health and productivity, and assessing the economic feasibility of various mitigation options. Furthermore, rice farmers are unlikely to adopt a practice unless it offers higher net returns. Moreover, socio-economic factors, such as access to technology and financial resources, play a crucial role in the adoption of sustainable practices, highlighting the importance of targeted policies and support systems to facilitate change. Addressing these challenges require coordinated effort among researchers, policymakers, and farmers to develop and implement effective mitigation strategies.

Conclusion

Rice production system and its cultivation significantly contribute towards GHG (CH_4 and N_2O) releases and lead to global warming. Reducing GHG emissions from paddy fields is very important to stabilize atmospheric concentration of the GHGs, which can contribute significantly to mitigate global warming. Achieving the Paris Agreement's goal of restricting global warming to below 2°C calls for special focus on the rice sector. Increasing population and escalating rice demand in the future raise serious concerns to curtail GHG emissions from rice cultivation without compromising the yield. By understanding the production mechanisms of CH_4 and N_2O from paddy fields, proper management practices with prime focus on water and fertilizer may play a significant role in mitigating the anthropogenic GHGE from agricultural soil. Crop management practices such as AWD, DSR, SRI, aerobic rice, conservation tillage, addition of compost, integrated biological-chemical nutrient management, efficient crop residue management along with climate resilient varietal selection can mitigate GHG emissions without any yield penalty.

References

Abdo AI, Tian M, Shi Z, Sun D, Abdel-Fattah MK, Zhang J, Wei H and Abdeen MA. 2024. Carbon footprint of global rice production and consumption. *Journal of Cleaner Production*, 474: 143560.

Adhikary PP, Mohanty S, Rautaray SK, Manikandan N and Mishra A. 2023. Alternate wetting and drying water management can reduce phosphorus availability under lowland rice cultivation irrespective of nitrogen level. *Environmental Monitoring and Assessment*, 195(12): 1420.

Ahmad S, Li C, Dai G, Zhan M, Wang J, Pan S and Cao C. 2009. Greenhouse gas emission from direct seeding paddy field under different rice tillage systems in central China. *Soil and Tillage Research*, 106(1): 54-61.

Ahmed Z, Gui D, Qi Z, Liu J, Ali A, Murtaza G, Shabbir RN, Tariq M, Shareef M, Zafar S and Khan MS. 2023. Greenhouse gas emissions and mitigation strategies in rice production systems. In: *Global Agricultural Production: Resilience to Climate Change*. Springer zInternational Publishing, Cham, Switzerland. pp. 237-265.

Akiyama H, Yagi K and Yan X. 2005. Direct N2O emissions from rice paddy fields: summary of available data. *Global Biogeochemical Cycles*, 19(1): GB1005

Al Hussain MM, Al Harun MA, Bahar MM, Bhonni NA, Azad MJ and Islam SM. 2024. Enhancing bioelectricity generation and mitigating methane emissions in paddy fields: A novel approach using activated biochar in plant microbial fuel cells. *Energy Conversion and Management*, 307: 118327.

Ali MA, Farouque MG, Haque M and ul Kabir A. 2012. Influence of soil amendments on mitigating methane emissions and sustaining rice productivity in paddy soil ecosystems of Bangladesh. *Journal of Environmental Science and Natural Resources*, 5(1): 179-185.

Allen J, Pascual KS, Romasanta RR, Van Trinh M, Van Thach T, Van Hung N, Sander BO and Chivenge P. 2020. Rice straw management effects on greenhouse gas emissions and mitigation options. In: Gummert M, Hung NV, Chivenge P and Douthwaite B (eds.) *Sustainable Rice Straw Management*. Springer Nature. Cham, Switzerland. pp. 145-159.

Anushka AS, Nunavath U, Kumar GS, Kanade AK, Pradeepkumar S and Sritharan N. 2024. Effect of nano urea on greenhouse gas emissions in transplanted rice (*Oryza sativa* L.) ecosystems. *Plant Science Today*, 11(sp4): 01-07.

Arenas-Calle L, Sherpa S, Rossiter D, Nayak H, Urfels A, Kritee K, Poonia S, Singh DK, Choudhary A, Dubey R and Kumar V. 2024. Hydrologic variability governs GHG emissions in rice-based cropping systems of Eastern India. *Agricultural Water Management*, 301: 108931.

Arends JB, Speeckaert J, Blondeel E, De Vrieze J, Boeckx P, Verstraete W, Rabaey K and Boon N. 2014. Greenhouse gas emissions from rice microcosms amended with a plant microbial fuel cell. *Applied Microbiology and Biotechnology*, 98(7): 3205-3217.

Asch F, Johnson K, Vo TB, Sander BO, Duong VN and Wassmann R. 2023. Varietal effects on methane intensity of paddy fields under different irrigation management. *Journal of Agronomy and Crop Science*, 209(6): 876-886.

Aulakh MS, Bodenbender J, Wassmann R and Rennenberg H. 2000. Methane transport capacity of rice plants. II. Variations among different rice cultivars and relationship with morphological characteristics. *Nutrient Cycling in Agroecosystems*, 58(1): 367-375.

Aulakh MS, Wassmann R, Bueno C and Rennenberg H. 2001. Impact of root exudates of different cultivars and plant development stages of rice (*Oryza sativa* L.) on methane production in a paddy soil. *Plant and Soil*, 230(1): 77-86.

Balcombe P, Speirs JF, Brandon NP and Hawkes AD. 2018. Methane emissions: choosing the right climate metric and time horizon. *Environmental Science: Processes and Impacts*, 20(10): 1323-1339.

Banger K, Tian H and Lu C. 2012. Do nitrogen fertilizers stimulate or inhibit methane emissions from rice fields?. *Global Change Biology*, 18(10): 3259-3267.

Basheer S, Wang X, Farooque AA, Nawaz RA, Pang T and Neokye EO. 2024. A review of greenhouse gas emissions from agricultural soil. *Sustainability*, 16(11): 4789.

Belenguer-Manzanedo M, Alcaraz C, Camacho A, Ibáñez C, Català-Forner M and Martínez-Eixarch M. 2022. Effect of post-harvest practices on greenhouse gas emissions in rice paddies: flooding regime and straw management. *Plant and Soil*, 474(1): 77-98.

Bharali A, Baruah KK and Gogoi N. 2017. Potential option for mitigating methane emission from tropical paddy rice through selection of suitable rice varieties. *Crop and Pasture Science*, 68(5): 421-433.

Bhatia A, Pathak H, Jain N, Singh PK and Singh AK. 2005. Global warming potential of manure amended soils under rice–wheat system in the Indo-Gangetic plains. *Atmospheric Environment*, 39(37): 6976-6984.

Bhattacharyya P and Barman D. 2018. Crop residue management and greenhouse gases emissions in tropical rice lands. In: Munoz MA and Zornoza R (eds.) Soil Management and Climate Change: Effects on Organic Carbon, Nitrogen Dynamics, and Greenhouse Gas Emissions, Academic Press. pp. 323-335.

Bhattacharyya P, Bisen J, Bhaduri D, Priyadarsini S, Munda S, Chakraborti M, Adak T, Panneerselvam P, Mukherjee AK, Swain SL and Dash PK. 2021. Turn the wheel from waste to wealth: economic and environmental gain of sustainable rice straw management practices over field burning in reference to India. *Science of the Total Environment*, 775: 145896.

Bhattacharyya P, Nayak AK, Raja R and Rao K.S. (Eds.) 2012. *Climate Change: Greenhouse Gas Emission. In Rice Farming and Mitigation Options.* Central Rice Research Institute, Cuttack, Odisha, India. p.165.

Bhattacharyya P, Roy KS, Neogi S, Dash PK, Nayak AK, Mohanty S, Baig MJ, Sarkar RK and Rao KS. 2013. Impact of elevated CO_2 and temperature on soil C and N dynamics in relation to CH_4 and N_2O emissions from tropical flooded rice (*Oryza sativa* L.). *Science of the Total Environment*, 461: 601-611.

Bodelier PL. 2015. Bypassing the methane cycle. *Nature*, 523(7562): 534-535.

Borah L and Baruah KK. 2016. Effects of foliar application of plant growth hormone on methane emission from tropical rice paddy. *Agriculture, Ecosystems and Environment*, 233: 75-84.

Bordoloi N, Baruah KK, Bhattacharyya P and Gupta PK. 2019. Impact of nitrogen fertilization and tillage practices on nitrous oxide emission from a summer rice ecosystem. *Archives of Agronomy and Soil Science,* 65(11): 1493-1506.

Chadwick D, Sommer S, Thorman R, Fangueiro D, Cardenas L, Amon B and Misselbrook T. 2011. Manure management: Implications for greenhouse gas emissions. *Animal Feed Science and Technology,* 166: 514-531.

Charumathi M, Girija Rani M, Suneetha Y, Satish Y, Ramana Rao PV, Ravi Kumar BNVSR, Mahesh S, Dayal Prasad Babu J and Srinivas T. 2024. Development of high yielding deep water rice variety MTU 1184 suitable for semi-deep flooded ecosystem of South Eastern region of India. *Journal of Rice Research*, 17(1): 72–80.

Chen J, Gong Y, Wang S, Guan B, Balkovic J and Kraxner F. 2019. To burn or retain crop residues on croplands? An integrated analysis of crop residue management in China. *Science of the Total Environment*, 662: 141-150.

Chen Y, Guo W, Ngo HH, Wei W, Ding A, Ni B, Hoang NB and Zhang H. 2024. Ways to mitigate greenhouse gas production from rice cultivation. *Journal of Environmental Management*, 368: 122139.

Chirinda N, Arenas L, Katto M, Loaiza S, Correa F, Isthitani M, Loboguerrero AM, Martínez-Barón D, Graterol E, Jaramillo S and Torres CF. 2018. Sustainable and low greenhouse gas emitting rice production in Latin America and the Caribbean: A review on the transition from ideality to reality. *Sustainability*, 10(3): 671.

Chowdhury TR and Dick RP. 2013. Ecology of aerobic methanotrophs in controlling methane fluxes from wetlands. *Applied Soil Ecology*, 65: 8-22.

Christensen TR. 2024. Wetland emissions on the rise. *Nature Climate Change*, 14(3): 210-211.

Conrad R. 2007. Microbial ecology of methanogens and methanotrophs. *Advances in Agronomy*, 96: 1-63.

Copernicus Climate Change Service. 2024. [Online] Available: https://climate.copernicus.eu/copernicus - 2024 -world -experienced -warmest-january-record [07 July 2024].

Creason J, Beach R, Hussein Z, Ragnauth S, Ohrel S and Li C. 2016. Crop yields, food security, and GHG emissions: An analysis of global mitigation options for rice cultivation. Presented at the 19th Annual Conference on Global Economic Analysis, Washington DC, USA.

Dahlgreen J and Parr A. 2023. The impact on greenhouse gas emissions of rice crop management under the system of rice intensification: a review. *Preprints.org*., [online] Available at: https://doi.org/10.20944/preprints202310.1922.v1 [Accessed 6 February. 2024].

Dahlgreen J and Parr A. 2024. Exploring the impact of alternate wetting and drying and the system of rice intensification on greenhouse gas emissions: a review of rice cultivation practices. *Agronomy*, 14(2): 378.

Danso F, Bankole OO, Zhang N, Dong W, Zhang K, Lu C, Shang Z, Li G, Deng A, Song Z and Zheng C. 2023. Plough tillage maintains high rice yield and lowers greenhouse gas emissions under straw incorporation in three rice-based cropping systems. *Agronomy*, 13(3): 880.

Das S and Kim PJ. 2024. Rice breeding for low methane and high yields. *Plant Communications*, 5(5): 100924.

Das S, Chou ML, Jean JS, Liu CC and Yang HJ. 2016. Water management impacts on arsenic behavior and rhizosphere bacterial communities and activities in a rice agro-ecosystem. *Science of the Total Environment*, 542: 642-652.

Dash PK, Bhattacharyya P, Padhy SR, Nauak AK, Poonam A and Mohanty S. 2023. Life cycle greenhouse gases emission from five contrasting rice production systems in the tropics. *Pedosphere*, 33(6): 960–971.

Datta A, Santra SC and Adhya TK. 2013. Effect of inorganic fertilizers (N, P, K) on methane emission from tropical rice field of India. *Atmospheric Environment*, 66: 123-130.

Deng H, Cai LC, Jiang YB and Zhong WH. 2016. Application of microbial fuel cells in reducing methane emission from rice paddy. *Huanjing kexue*, 37(1): 359-365.

Derpsch R, Friedrich T, Kassam A and Li H. 2010. Current status of adoption of no-till farming in the world and some of its main benefits. *International Journal of Agricultural and Biological Engineering*, 3(1): 1-25.

Dhillon BS and Sohu VS. 2024. Climate change shocks and crop production: The foodgrain bowl of India as an example. *Indian Journal of Agronomy*, 69(1): 1-10.

Dong W, Danso F, Tang A, Zhang J, Liu Y, Meng Y, Zhang X, Wang L and Yang Z. 2024. Biochar: An Option to Maintain Rice Yield and Mitigate Greenhouse Gas Emissions from Rice Fields in Northeast China. *Agronomy*, 14(12): 3050.

EEA [European Environment Agency]. 2025. https://www.eea.europa.eu/en/analysis/indicators/atmospheric-greenhouse-gas-concentrations.

Etminan M, Myhre G, Highwood EJ and Shine KP. 2016. Radiative forcing of carbon dioxide, methane, and nitrous oxide: A significant revision of the methane radiative forcing. *Geophysical Research Letters*, 43(24): 12-614.

Fahad S, Adnan M, Hassan S, Saud S, Hussain S, Wu C, Wang D, Hakeem KR, Alharby HF, Turan V and Khan MA. 2019. Rice responses and tolerance to high temperature. In: *Advances in Rice Research for Abiotic Stress Tolerance,* Woodhead Publishing, pp. 201-224.

Fahad S, Adnan M, Saud S and Nie L. (eds.). 2022. Climate Change and Ecosystems: Challenges to Sustainable Development. CRC Press, Boca Raton, 278p.

Fazli P, Man HC, Shah UK and Idris A. 2013. Characteristics of methanogens and methanotrophs in rice fields: a review. *Asia-Pacific Journal of Molecular Biology and Biotechnology*, 21(1): 3-17.

Feng J, Li F, Zhou X, Xu C, Ji L, Chen Z and Fang F. 2018. Impact of agronomy practices on the effects of reduced tillage systems on CH_4 and N_2O emissions from agricultural fields: a global meta-analysis. *PLos One*, 13(5): e0196703.

Feng L, Palmer PI, Parker RJ, Lunt MF and Bösch H. 2023. Methane emissions are predominantly responsible for record-breaking atmospheric methane growth rates in 2020 and 2021. *Atmospheric Chemistry and Physics*, 23(8): 4863-4880.

Foong SY, Chan YH, Chin BL, Lock SS, Yee CY, Yiin CL, Peng W and Lam SS. 2022. Production of biochar from rice straw and its application for wastewater remediation− An overview. *Bioresource Technology*, 360: 127588.

Gaihre YK, Singh U, Bible WD, Fugice Jr J and Sanabria J. 2020. Mitigating N_2O and NO emissions from direct-seeded rice with nitrification inhibitor and urea deep placement. *Rice Science*, 27(5): 434-444.

Galgo SJ, Canatoy RC, Lim JY, Park HC and Kim PJ. 2024. A potential of iron slag-based soil amendment as a suppressor of greenhouse gas (CH_4 and N_2O) emissions in rice paddy. *Frontiers in Environmental Science*, 12: 1290969.

Galloway JN, Aber JD, Erisman JW, Seitzinger SP, Howarth RW, Cowling EB and Cosby BJ. 2003. The nitrogen cascade. *Bioscience*, 53(4): 341-356.

Gbedourorou SK, Tovihoudji PG, Vanclooster M and Akponikpe IP. 2024. Mitigation of nitrogen loss in rice fields through soil desaturation prior to re-irrigation and the application of controlled-release nitrogen fertilizer: a meta-analysis (No. EGU24-15361). Copernicus Meetings.

George D. 2018. Aerobic rice: Rice for future. *International Journal of Chemical Studies*, 6(6): 481-485.

Gogoi B and Baruah KK. 2014. Seasonal and temporal changes in nitrous oxide emission with fertilizer application in rice ecosystem of North Bank Plain Agroclimatic Zone of North East India. *International Journal of Environmental. Monitoring and Analysis*, 2(5): 289-296.

GOI [Government of India]. Ministry of Agriculture & Farmers Welfare. 2025. 'Union Agriculture Minister Shri Shivraj Singh Chouhan Announces Two Genome-Edited Rice Varieties Developed in India', Press Information Bureau, Government of India, 4 May. Available at: https://pib.gov.in/PressReleasePage.aspx?PRID=2126802 (Accessed: 28 July 2025).

Gummert M, Hung NV, Chivenge P and Douthwaite B (eds.). 2020. Sustainable rice straw management. Springer Nature, Cham, Switzerland. 192p.

Gupta K, Kumar R, Baruah KK, 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): 30551-30572.

Hoang VP, Ha XL and Le TT. 2021. The advantages of the system of rice intensification (SRI) in environmental protection and climate change mitigation in rice production–a review. *TNU Journal of Science and Technology*, 226(09): 11-21.

Holmes CD. 2018. Methane feedback on atmospheric chemistry: Methods, models, and mechanisms. *Journal of Advances in Modeling Earth Systems*, 10(4): 1087-1099.

Hossain MB, Rahman MM, Biswas JC, Miah MM, Akhter S, Maniruzzaman M, Choudhury AK, Ahmed F, Shiragi MH and Kalra N. 2017. Carbon mineralization and carbon dioxide emission from organic matter added soil under different temperature regimes. *International Journal of Recycling of Organic Waste in Agriculture*, 6(4): 311-319.

Hosseiniyan Khatibi SM, Adviento-Borbe MA, Dimaano NG, Radanielson AM and Ali J. 2025. Advanced technologies for reducing greenhouse gas emissions from rice fields: Is hybrid rice the game changer?. *Plant Communications*, 6(2): 101224.

Hu J, Bettembourg M, Moreno S, Zhang A, Schnürer A, Sun C, Sundström J and Jin Y. 2023. Characterisation of a low methane emission rice cultivar suitable for cultivation in high latitude light and temperature conditions. *Environmental Science and Pollution Research*, 30(40): 92950-92962.

Huang J, Nie T, Li T, Chen P, Zhang Z, Zhu S, Sun Z and E L. 2022. Effects of straw incorporation years and water-saving irrigation on greenhouse gas emissions from paddy fields in cold region of northeast China. *Agriculture*, 12(11): 1878.

Huang X, Zou Y, Qiao C, Liu Q, Liu J, Kang R, Ren L and Wu W. 2023. Effects of biological nitrification inhibitor on nitrous oxide and nosZ, nirK, nirS denitrifying bacteria in Paddy soils. *Sustainability*, 15(6): 5348.

Huda A, Gaihre YK, Islam MR, Singh U, Islam MR, Sanabria J, Satter MA, Afroz H, Halder A and Jahiruddin M. 2016. Floodwater ammonium, nitrogen use efficiency and rice yields with fertilizer deep placement and alternate wetting and drying under triple rice cropping systems. *Nutrient Cycling in Agroecosystems*, 104(1): 53-66.

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. In: *Environment, Climate, Plant and Vegetation Growth*: Springer International Publishing. pp. 659-686.

Hussain S, Peng S, Fahad S, Khaliq A, Huang J, Cui K and Nie L. 2015. Rice management interventions to mitigate greenhouse gas emissions: a review. *Environmental Science and Pollution Research*, 22(5): 3342-3360.

Hussain T, Hussain N, Tahir M, Raina A, Ikram S, Maqbool S, Fraz Ali M and Duangpan S. 2022. Impacts of drought stress on water use efficiency and grain productivity of rice and utilization of genotypic variability to combat climate change. *Agronomy*, 12(10): 2518.

Iboko MP, Dossou-Yovo ER, Obalum SE, Oraegbunam CJ, Diedhiou S, Brümmer C and Témé N. 2023. Paddy rice yield and greenhouse gas emissions: Any trade-off due to co-application of biochar and nitrogen fertilizer? A systematic review. *Heliyon*, 9(11): e22132.

IFA [International Fertilizer Association]. 2022. Fertilizer use by crop and country for the 2017-2018 period. International Fertilizer Association (IFA), Paris, France; [Available at https://www.ifastat.org/consumption/fertilizeruse-by-crop].

IPCC [Intergovernmental Panel on Climate Change]. 2023. *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. [Core Writing Team, Lee, H. and Romero, J. (eds.)]. IPCC, Geneva, Switzerland.184p.

Iqbal MF, Zhang Y, Kong P, Wang Y, Cao K, Zhao L, Xiao X and Fan X. 2023. High-yielding nitrate transporter cultivars also mitigate methane and nitrous oxide emissions in paddy. *Frontiers in Plant Science*, 14: 1133643.

IRRI [International Rice Research Institute]. 2024. GHG mitigation in rice - Vietnam. GHG Mitigation in Rice. Retrieved from https://ghgmitigation.irri.org/focus-countries/vietnam.

IRRI [International Rice Research Institute]. 2025. Hybrid rice innovations: A path forward for climate-smart agriculture. https://www.irri.org/news-and-events/news/hybrid-rice-innovations-path-forward-climate-smart-agriculture

IRRI. [International Rice Research Institute]. 2018. Rice Straw Management. https://www.irri.org/rice-straw-management

Islam SFU, Sander BO, Quilty JR, De Neergaard A, Van Groenigen JW and Jensen LS. 2020a. Mitigation of greenhouse gas emissions and reduced irrigation water use in rice production through water-saving irrigation scheduling, reduced tillage and fertiliser application strategies. *Science of the Total Environment*, 739: 140215.

Islam SMM, Gaihre YK, Biswas JC, Jahan MS, Singh U, Adhikary SK, Satter MA and Saleque MA. 2018. Different nitrogen rates and methods of application for dry season rice cultivation with alternate wetting and drying irrigation: Fate of nitrogen and grain yield. *Agricultural Water Management*, 196: 144–153.

Islam SMM, Gaihre YK, Islam MR, Ahmed MN, Akter M, Singh U and Sander BO. 2022a. Mitigating greenhouse gas emissions from irrigated rice cultivation through improved fertilizer and water management. *Journal of Environmental Management*, 307: 114520.

Islam SMM, Gaihre YK, Islam MR, Akter M, Al Mahmud A, Singh U and Sander BO. 2020b. Effects of water management on greenhouse gas emissions from farmers' rice fields in Bangladesh. *Science of the Total Environment*, 734: 139382.

Islam SMM, Gaihre YK, Islam MR, Khatun A and Islam A. 2022b. Integrated plant nutrient systems improve rice yields without affecting greenhouse gas emissions from lowland rice cultivation. *Sustainability*, 14(18): 11338.

Jackson RB, Saunois M, Bousquet P, Canadell JG, Poulter B, Stavert AR, Bergamaschi P, Niwa Y, Segers A and Tsuruta A. 2020. Increasing anthropogenic methane emissions arise equally from agricultural and fossil fuel sources. *Environmental Research Letters*, 15(7): 071002.

Ji Y, Zhou Y, Li Z, Feng K, Sun X, Xu Y, Wu W and Zou H. 2024. Carbon footprint research and mitigation strategies for rice-cropping systems in China: a review. *Frontiers in Sustainable Food Systems*, 8: 1375092.

Jia Y, Sun Y, Zhang D, Yang W, Pang J, Siddique KH and Qu Z. 2025. Mitigation of Greenhouse Gas Emissions Using Straw Biochar in Arid Regions of Northwest China: Evidence from Field Experiments. *Agronomy*, 15(5): 1007.

Jia ZJ, Cai ZC, Xu H and Tsuruta H. 2002. Effects of rice cultivars on methane fluxes in a paddy soil. *Nutrient Cycling in Agroecosystems*, 64(1): 87-94.

Jiang Y and Zhang WJ. 2013. Super rice cropping will enhance rice yield and reduce CH_4 emission: a case study in Nanjing, China. *Rice Science*, 20(6): 427-433.

Jiang Y, Carrijo D, Huang S, Chen JI, Balaine N, Zhang W, van Groenigen KJ and Linquist B. 2019. Water management to mitigate the global warming potential of rice systems: A global meta-analysis. *Field Crops Research*, 234: 47-54.

Jiménez JDLC and Pedersen O. 2023. Mitigation of greenhouse gas emissions from rice via manipulation of key root traits. *Rice*, 16(1): 24.

Jinsy VS. 2014. Productivity analysis of aerobic rice (*Oryza sativa* L.) and its impact on greenhouse gas emission. Ph D. Thesis. Kerala Agricultural University, Thrissur, 183p.

Kang YG, Lee JY, Cho G, Yun Y and Oh TK. 2024. Synergy effect of silicate fertilizer and iron slag: A sustainable approach for mitigating methane emission in rice farming. *Science of the Total Environment*, 935: 173392.

Khosa MK, Sidhu BS and Benbi DK. 2010. Effect of organic materials and rice cultivars on methane emission from rice field. *Journal of Environmental Biology*, 31(3): 281-285.

Kritee K, Nair D, Zavala-Araiza D, Proville J, Rudek J, Adhya TK, Loecke T, Esteves T, Balireddygari S, Dava O and Ram K. 2018. High nitrous oxide fluxes from rice indicate the need to manage water for both long-and short-term climate impacts. *Proceedings of the National Academy of Sciences*, 115(39): 9720-9725.

Kuchi S, Manasa V, Gobinath R, Rao DVKN, Kumar MR, Brajendra P. 2024. Assessment of genotypic variability for nitrogen use efficiency (NUE) and improving NUE through urease inhibitors in irrigated rice. *Journal of Rice Research*, 17(1): 81-89.

Kumar A, Nayak AK, Sharma S, Senapati A, Mitra D, Mohanty B, Prabhukarthikeyan SR, Sabarinathan KG, Mani I, Garhwal RS and Thankappan S. 2023a. Rice straw recycling: A sustainable approach for ensuring environmental quality and economic security. *Pedosphere*, 33(1): 34-48.

Kumar K, Manju P and Gajalakshmi S. 2023b. Harnessing plant microbial fuel cells for resource recovery and methane emission reduction in paddy cultivation. *Energy Conversion and Management*, 294: 117545.

Kumar SR, David EM, Pavithra GJ, Sajith GK, Lesharadevi K, Akshaya S, Bassavaraddi C, Navyashree G, Arpitha PS, Sreedevi P, Zainuddin K, Saiyyeda F, Ravindra BB, Udagatti PM, Ganesan R, Palabhanvi B, CS, Kumar VMLD, Theivasigamani P and Subbian E. 2024. Methane-derived microbial biostimulant reduces greenhouse gas emissions and improves rice yield. *Frontiers in Plant Science*, 15: 1432460.

Kumar V. 2024. The Physics Behind Climate Change: Understanding Greenhouse Gases. *International Journal of Innovations in Science, Engineering and Management*, 3(4): 21-25.

Kuypers MM, Marchant HK and Kartal B. 2018. The microbial nitrogen-cycling network. *Nature Reviews Microbiology*, 16(5): 263-276.

Lal R. 2018. Digging deeper: A holistic perspective of factors affecting soil organic carbon sequestration in agroecosystems. *Global Change Biology*, 24(8): 3285-3301.

Lamb WF, Wiedmann T, Pongratz J, Andrew R, Crippa M, Olivier JG, Wiedenhofer D, Mattioli G, Al Khourdajie A, House J and Pachauri S. 2021. A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018. *Environmental Research Letters*, 16(7): 073005.

Lampayan RM, Rejesus RM, Singleton GR and Bouman BA. 2015. Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. *Field Crops Research*, 170: 95-108.

Lee JH, Lee JY, Kang YG, Kim JH and Oh TK. 2023a. Evaluating methane emissions from rice paddies: A study on the cultivar and transplanting date. *Science of the Total Environment*, 902: 166-174.

Lee JM, Jeong HC, Lee HS, Park HR, Kim GS and Lee SI. 2023b. Effects of water management practices on methane emissions and rice yields in East Asian paddy fields: A regional-scale meta-analysis. *Korean Journal of Soil Science and Fertilizer*, 56(4): 313-324.

Lehmann J, Gaunt J and Rondon M. 2006. Bio-char sequestration in terrestrial ecosystems–a review. *Mitigation and Adaptation Strategies for Global Change*, 11(2): 403-427.

Leon A, Kohyama K, Yagi K, Takata Y and Obara H. 2017. The effects of current water management practices on methane emissions in Japanese rice cultivation. *Mitigation and Adaptation Strategies for Global Change*, 22(1): 85-98.

Linquist B, Van Groenigen KJ, Adviento-Borbe MA, Pittelkow C and Van Kessel C. 2012b. An agronomic assessment of greenhouse gas emissions from major cereal crops. *Global Change Biology,* 18(1): 194-209.

Linquist BA, Adviento-Borbe MA, Pittelkow CM, van Kessel C and van Groenigen KJ. 2012a. Fertilizer management practices and greenhouse gas emissions from rice systems: a quantitative review and analysis. *Field Crops Research,* 135: 10-21.

Linquist BA, Marcos M, Adviento-Borbe MA, Anders M, Harrell D, Linscombe S, Reba ML, Runkle BR, Tarpley L and Thomson A. 2018. Greenhouse gas emissions and management practices that affect emissions in US rice systems. *Journal of Environmental Quality*, 47(3): 395-409.

Liu C, Lu M, Cui J, Li B and Fang C. 2014. Effects of straw carbon input on carbon dynamics in agricultural soils: a meta-analysis. *Global Change Biology,* 20(5): 1366-1381.

Liu X, Mao P, Li L and Ma J. 2019b. Impact of biochar application on yield-scaled greenhouse gas intensity: a meta-analysis. *Science of the Total Environment*, 656: 969-976.

Liu X, Zhou T, Liu Y, Zhang X, Li L and Pan G. 2019a. Effect of mid-season drainage on CH_4 and N_2O emission and grain yield in rice ecosystem: A meta-analysis. *Agricultural Water Management*, 213: 1028-1035.

Liu Y, Wan KY, Tao Y, Li ZG, Zhang GS, Li SL and Chen F. 2013. Carbon dioxide flux from rice paddy soils in central China: effects of intermittent flooding and draining cycles. *PLos One*, 8(2): e56562.

Lu F, Wang X, Han B, Ouyang Z, Duan X and Zheng H. 2010. Net mitigation potential of straw return to Chinese cropland: estimation with a full greenhouse gas budget model. *Ecological Applications*, 20(3): 634-647.

Lu Y, Hua Y, Lv N, Zu W, Kronzucker HJ, Dong G and Shi W. 2022. Syringic acid from rice roots inhibits soil nitrification and N_2O emission under red and paddy soils but not a calcareous soil. *Frontiers in Plant Science*, 13: 1099689.

Maiti D, Das DK, Karak T and Banerjee M. 2004. Management of nitrogen through the use of leaf color chart (LCC) and soil plant analysis development (SPAD) or chlorophyll meter in rice under irrigated ecosystem. *The Scientific World Journal*, 4(1): 838-846.

Mallareddy M, Thirumalaikumar R, Balasubramanian P, Naseeruddin R, Nithya N, Mariadoss A, Eazhilkrishna N, Choudhary AK, 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): 1802.

Malyan SK, Bhatia A, Kumar A, Gupta DK, Singh R, Kumar SS, Tomer R, Kumar O and Jain N. 2016a. Methane production, oxidation and mitigation:

a mechanistic understanding and comprehensive evaluation of influencing factors. *Science of the Total Environment*, 572: 874-896.

Malyan SK, Bhatia A, Kumar O and Tomer R. 2016b. Impact of nitrogen fertilizers on methane emissions from flooded rice. *Current World Environment*, 11(3): 846-850.

Man LH, Khang VT and Watanabe T. 2007. Improvement of soil fertility by rice straw manure. In: Development of Technologies and Sustainable Farming Systems in the Mekong Delta of Vietnam, JIRCAS Working Report, Japan International Research Center for Agricultural Sciences -Tsukuba, Japan, 55: pp.76-77.

Maraseni TN, Deo RC, Qu J, Gentle P and Neupane PR. 2018. An international comparison of rice consumption behaviours and greenhouse gas emissions from rice production. *Journal of Cleaner Production*, 172: 2288-2300.

Mboyerwa PA, Kibret K, Mtakwa P and Aschalew A. 2022. Greenhouse gas emissions in irrigated paddy rice as influenced by crop management practices and nitrogen fertilization rates in eastern Tanzania. *Frontiers in Sustainable Food Systems*, 6: 868479.

Menegat S, Ledo A and Tirado R. 2022. Greenhouse gas emissions from global production and use of nitrogen synthetic fertilizers in agriculture. *Scientific Reports*, 12(1): 14490.

Minamisawa K. 2023. Mitigation of greenhouse gas emission by nitrogen-fixing bacteria. *Bioscience, Biotechnology, and Biochemistry*, 87(1): 7-12.

Mishra S, Chaubey AK and Pathak J. 2023. Direct seeded rice: Prospects, constraints and future research work. *Indian Farming,* 73(9): 11–14.

Moe MM, Bunyasiri I and Sirisupluxna P. 2024. Quantifying and comparing greenhouse gas emissions in monsoon rice production: A comprehensive analysis of transplanting and broadcasting sowing methods in Myanmar. *The Open Agriculture Journal,* 18(1): e18743315290024.

Mohammadi A, Cowie A, Mai TL, de la Rosa RA, Kristiansen P, Brandao M and Joseph S. 2016. Biochar use for climate-change mitigation in rice cropping systems. *Journal of Cleaner Production*, 116: 61-70.

Mohanraj J, Lakshmanan A and Subramanian K. 2017. Nano-zeolite amendment to minimize greenhouse gas emission in rice soil. *Journal of Environment and Nanotechnology*, 6(3): 73-76.

Mohanty S, Swain CK, Sethi SK, Dalai PC, Bhattachrayya P, Kumar A, Tripathi R, Shahid M, Panda BB, Kumar U and Lal B. 2017. Crop establishment and nitrogen management affect greenhouse gas emission and biological activity in tropical rice production. *Ecological Engineering*, 104: 80-98.

Muliarta IN, Sukmadewi DKT, Selangga DGW, Kariasa IG, Prawerti DAD, Parwata IKA and Landra IW. 2022. Implementation of LEISA Concept through composting rice straw waste in Subak Telun Ayah, Tegallalang. *Abdimas: Jurnal Pengabdian Masyarakat Universitas Merdeka Malang*, 7(4): 663-675.

Nazaries L, Murrell JC, Millard P, Baggs L and Singh BK. 2013. Methane, microbes and models: fundamental understanding of the soil methane cycle for future predictions. *Environmental Microbiology*, 15(9): 2395-2417

Ngo TT, Ho VK, Tran SN, Duong VC, Nguyen VC and Nguyen VH. (2018). Quantification of direct and indirect greenhouse gas emissions from rice field cultivation with different rice straw management practices–A study in the autumn-winter season in An Giang Province, Vietnam. *Journal of Vietnamese Environment*, 10(1): 49-55.

Nguyen VH, Topno S, Balingbing C, Nguyen VC, Röder M, Quilty J, Jamieson C, Thornley P and Gummert M. 2016. Generating a positive energy balance from using rice straw for anaerobic digestion. *Energy Reports*, 2: 117–122.

Nyamadzawo G, Wuta M, Chirinda N, Mujuru L and Smith JL. 2013. Greenhouse gas emissions from intermittently flooded (Dambo) rice under different tillage practices in chiota smallholder farming area of Zimbabwe. *Atmospheric and Climate Sciences*, 3(4):13-20

Oanh NTK. 2021. Rice straw open burning: emissions, effects and multiple benefits of non-burning alternatives. Vietnam *Journal of Science, Technology and Engineering*, 63(4): 79-85.

Ogawa S, Yamamoto K, Uno K, Thuan NC, Togami T and Shindo S. 2022. Optimal water level management for mitigating GHG emissions through water-conserving irrigation in an giang province, Vietnam. *Sensors*, 22(21): 8418.

Omonode RA, Vyn TJ, Smith DR, Hegymegi P and Gál A. 2007. Soil carbon dioxide and methane fluxes from long–term tillage systems in continuous corn and corn–soybean rotations. *Soil and Tillage Research,* 95: 182-195.

Oo AZ, Sudo S, Inubushi K, Chellappan U, Yamamoto A, Ono K, Mano M, Hayashida S, Koothan V, Osawa T and Terao Y. 2018. Mitigation potential and yield-scaled global warming potential of early-season drainage from a rice paddy in Tamil Nadu, India. *Agronomy*, 8(10): 202.

Oo AZ, Win KT, Motobayashi T and Bellingrath-Kimura SD. 2016. Effect of cattle manure amendment and rice cultivars on methane emission from paddy rice soil under continuously flooded conditions. *Journal of Environmental Biology*, 37(5): 1029.

Oorts K, Merckx R, Gréhan E, Labreuche J and Nicolardot B. 2007. Determinants of annual fluxes of CO_2 and N_2O in long–term no tillage and conventional tillage systems in northern France. *Soil and Tillage Research*, 95(2): 133-148.

Panchasara H, Samrat NH and Islam N. 2021. Greenhouse gas emissions trends and mitigation measures in Australian agriculture sector-A review. *Agriculture*. 11(2): 85.

Pandey D, Agrawal M and Bohra JS. 2012. Greenhouse gas emissions from rice crop with different tillage permutations in rice–wheat system. *Agriculture, Ecosystems & Environment*, 159: 133-144.

Pao SH, Wu H, Hsieh HL, Chen CP and Lin HJ. 2025. Effects of modulating probiotics on greenhouse gas emissions and yield in rice paddies. *Plant, Soil and Environment*, 71(1): 21-35.

Parihar DS, Narang MK, Dogra B, Prakash A and Mahadik A. 2023. Rice residue burning in northern India: an assessment of environmental concerns and potential solutions–a review. *Environmental Research Communications*, 5(6): 062001.

Pathak H, Bhatia A and Jain N. 2014. *Greenhouse Gas Emission from Indian Agriculture: Trends, Mitigation and Policy Needs*. Indian Agricultural Research Institute, New Delhi - 110012, pp15-17.

Patterson J. 2012. Exploitation of unconventional fossil fuels: Enhanced greenhouse gas emissions. In: Liu G. (ed.) Greenhouse Gases-Emission, Measurement and Management, InTech, Janeza Tridine 9, 51000 Rijeka. Croatia, pp. 147-170.

Peng S, Huang J, Sheehy JE, Laza RC, Visperas RM, Zhong X, Centeno GS, Khush GS and Cassman KG. 2004. Rice yields decline with higher night temperature from global warming. *Proceedings of the National Academy of Sciences,* 101(27): 9971-9975.

Penning H and Conrad R. 2007. Quantification of carbon flow from stable isotope fractionation in rice field soils with different organic matter content. *Organic Geochemistry*, 38(12): 2058-2069

Perry H, Carrijo DR, Duncan AH, Fendorf S and Linquist BA. 2024. Mid-season drain severity impacts on rice yields, greenhouse gas emissions and heavy metal uptake in grain: evidence from on farm studies. *Field Crops Research,* 307: 109248.

Petersen SO, Blanchard M, Chadwick D, Del Prado A, Edouard N, Mosquera and Sommer SG. 2013. Manure management for greenhouse gas mitigation. *Animal*. 7(s2): 266-282.

Phungern S, Azizan SN, Yusof NB and Noborio K. 2023. Effects of water management and rice varieties on greenhouse gas emissions in central Japan. *Soil Systems*, 7(4): 89.

Pittelkow CM, Adviento-Borbe MA, Hill JE, Six J, van Kessel C and Linquist BA. 2013. Yield–scaled global warming potential of annual nitrous oxide and methane emissions from continuously flooded rice in response to nitrogen input. *Agriculture, Ecosystems and Environment*, 177: 10-20

Pramono A, Adriany TA and Susilawati HL. 2020. Mitigation scenario for reducing greenhouse gas emission from rice field by water management and rice cultivars. *Journal of Tropical Soils*, 25(2): 53-60.

Prangbang P, Yagi K, Aunario JK, Sander BO, Wassmann R, Jäkel T, Buddaboon C, Chidthaisong A and Towprayoon S. 2020. Climate-based suitability assessment for methane mitigation by water saving technology in paddy fields of the central plain of Thailand. *Frontiers in Sustainable Food Systems*, 4: 575823.

Prateep Na Talang R, Na Sorn W, Polruang S and Sirivithayapakorn S. 2024. Alternative crop residue management practices to mitigate the environmental and economic impacts of open burning of agricultural residues. *Scientific Reports*, 14(1): 14372. https://doi.org/10.1038/s41598-024-65389-3.

Qian H, Zhu X, Huang S, Linquist B, Kuzyakov Y, Wassmann R, Minamikawa K, Martinez-Eixarch M, Yan X, Zhou F and Sander BO. 2023. Greenhouse gas emissions and mitigation in rice agriculture. *Nature Reviews Earth & Environment*, 4(10): 716-732.

Qin X, Li YE, Wan Y, Liao Y, Fan M, Gao Q, Liu S and Ma X. 2014. Effect of tillage and rice residue return on CH_4 and N_2O emission from double rice field. *Transactions of the Chinese Society of Agricultural Engineering*, 30(11): 216-224.

Qin Y, Liu S, Guo Y, Liu Q and Zou J. 2010. Methane and nitrous oxide emissions from organic and conventional rice cropping systems in Southeast China. *Biology and Fertility of Soils*, 46(8): 825-834.

Rahman MM, Biswas JC, Maniruzzaman M, Choudhury AK and Ahmed F. 2017. Effect of tillage practices and rice straw management on soil environment and carbon dioxide emission. *The Agriculturists*, *15*(1): 127-142.

Rahman MM. 2013. Carbon dioxide emission from soil. *Agricultural Research*, 2(2): 132-139. https://doi.org/10.1007/s40003-013-0061-y.

Rajasekar P and Selvi JAV. 2022. Sensing and analysis of greenhouse gas emissions from rice fields to the near field atmosphere. *Sensors*, 22(11): 4141. https://doi.org/10.3390/s22114141

Rajbonshi MP, Mitra S and Bhattacharyya P. 2024. Agro-technologies for greenhouse gases mitigation in flooded rice fields for promoting climate smart agriculture. *Environmental Pollution*, 350: 123973. https://doi.org/10.1016/j.envpol.2024.123973.

Rajendran S, Park H, Kim J, Park SJ, Shin D, Lee JH, Song YH, Paek NC and Kim CM. 2024. Methane emission from rice fields: Necessity for molecular approach for mitigation. *Rice Science*, 31(2): 159-178.

Ramesh T and Rathika S. 2020. Evaluation of rice cultivation systems for greenhouse gases emission and productivity. *International Journal of Ecology and Environmental Sciences*, 2: 49-54. https://www.researchgate.net/publication/342347798.

Ravishankara AR, Daniel JS and Portmann RW. 2009. Nitrous oxide (N_2O): the dominant ozone-depleting substance emitted in the 21st century. *Science*. 326(5949): 123-125.

Reay DS, Davidson EA, Smith KA, Smith P, Melillo JM, Dentener F and Crutzen PJ. 2012. Global agriculture and nitrous oxide emissions. *Nature Climate Change*, 2(6): 410–416.

Rychel V, Meurer KH, Börjesson G, Strömgren M, Getahun GT, Kirchmann H and Kätterer T. 2020. Deep N fertilizer placement mitigated N_2O emissions in a Swedish field trial with cereals. *Nutrient Cycling in Agroecosystems,* 118(1): 133–148.

Sakoda M., Tokida, T., Sakai, Y., Senoo, K. and Nishizawa, T., 2022. Mitigation of paddy field soil methane emissions by betaproteobacterium *Azoarcus* inoculation of rice seeds. *Microbes and Environments*, 37(4): ME22052. doi: 10.1264/jsme2.ME22052.

Sanadya A, Yadu A, Raj J, Chandrakar H and Singh R. 2023. Effect of Temperature on Growth, Quality, Yield Attributing Characters and Yield of Rice–A Review. *International Journal of Environment and Climate Change*, 13(8): 804-814.

Sanchis E, Ferrer M, Torres AG, Cambra-López M and Calvet S. 2012. Effect of water and straw management practices on methane emissions from rice fields: a review through a meta-analysis. *Environmental Engineering Science*, 29(12): 1053-1062.

Sander BO, Samson M, Sanchez PB, Valencia KP, Demafelix EA and Buresh RJ. 2018. Contribution of fallow periods between rice crops to seasonal GHG emissions: effect of water and tillage management. *Soil Science and Plant Nutrition*, 64(2): 200-209.

Sander BO, Schneider P, Romasanta R, Samoy-Pascual K, Sibayan EB, Asis CA and Wassmann R. 2020. Potential of alternate wetting and drying irrigation practices for the mitigation of GHG emissions from rice fields: two cases in Central Luzon (Philippines). *Agriculture*, 10(8): 350. https://doi.org/10.3390/agriculture10080350.

Sander BO. 2017. From Research to Implementation: IRRI’s Activities on GHG Mitigation in Rice Cultivation, 1-16 pages.

Sandford C, Dunn R, Titchner H, Kendon M, Rayner N, Morice C, Palmer M, McCarthy M and Kaye N. 2024. Global and regional climate in 2023. *Weather*, 79(12): 400-412. DOI: 10.1002/wea.7636.

Saraiva R, Ferreira Q, Rodrigues GC and Oliveira M. 2023. Nanofertilizer use for adaptation and mitigation of the agriculture/climate change dichotomy effects. *Climate*, 11(6): 129. ; https://doi.org/10.3390/cli11060129.

Sarma UJ, Chakravarty M and Bhattacharyya HC. 2013. Emission and sequestration of carbon in soil with crop residue incorporation. *Journal of the Indian Society of Soil Science*, 61(2): 117-121.

Saud S, Wang D and Fahad S. 2022. Improved nitrogen use efficiency and greenhouse gas emissions in agricultural soils as producers of biological nitrification inhibitors. *Frontiers in Plant Science*, 13: 854195. doi: 10.3389/fpls.2022.854195.

Saxena R and Naresh Kumar S. 2022: Simulating the impact of climate change on rice yield and adaptation strategies in major rice growing regions of India. *Journal of Agrometeorology*, 16(1): 18-25. https://doi.org/10.54386/jam.v16i1.1481.

Schimel J. 2000. Rice, microbes and methane. *Nature*, 403(6768): 375-377. ttps:// doi.org/10.1038/35000325.

Scholz VV, Meckenstock RU, Nielsen LP and Risgaard-Petersen N. 2020. Cable bacteria reduce methane emissions from rice-vegetated soils. *Nature Communications*, 11(1): 1878. https://doi.org/10.1038/s41467-020-15812-w.

Shahbandeh M. 2025. *World Rice Acreage. 2023*. https://www.statista.com/statistics/ 271969/world-rice-acreage-since-2008/.

Shakoor A, Xu Y, Wang Q, Chen N, He F, Zuo H, Yin H, Yan X, Ma Y and Yang S. 2018. Effects of fertilizer application schemes and soil environmental factors on nitrous oxide emission fluxes in a rice-wheat cropping system, east China. *PLos One*, 13(8): e0202016. https://doi.org/10.1371/journal.pone.0202016.

Sharma A and Bhattu BS. 2015. Baler technology for the paddy residue management–Need of the hour. *International Journal of Computer Applications*, 975(1): 22-23.

Shen Q, Wang H, Lazcano C, Voroney P, Elrys A, Gou G, Li H, Zhu Q, Chen Y, Wu Y and Meng L. 2024. Biochar amendments to tropical paddy soil increase rice yields and decrease N_2O emissions by modifying the genes involved in nitrogen cycling. *Soil and Tillage Research,* 235: 105917. https://doi.org/10.1016/j.still.2023.105917.

Shyamsundar P, Springer NP, Tallis H, Polasky S, Jat ML, Sidhu HS, Krishnapriya PP, Skiba N, Ginn W, Ahuja V and Cummins J. 2019. Fields on fire: Alternatives to crop residue burning in India. *Science*, 365(6453): 536-538. DOI: 10.1126/science.aaw4085.

Singh SK, Monu Kumar HJ, Maurya S, Kumar A, Yadav S and Sah D. 2024. Direct-seeded rice: potential benefits, constraints and prospective. *Journal of Scientific Research and Reports*, 30(7): 272-280.

Slameto, Fahrudin DE and Saputra MW. 2024. Effect of fertilizer composition and different varieties on yield, methane and nitrous oxide emission from rice field in East Java Indonesia. *Frontiers in Agronomy*, 6: 1345283. doi: 10.3389/fagro.2024.1345283

Slayden JM, Brye KR, Della Lunga D, Henry CG, Wood LS and Lessner DJ. 2022. Site position and tillage treatment effects on nitrous oxide emissions from furrow-irrigated rice on a silt-loam Alfisol in the Mid-south, USA. *Geoderma Regional*, 28: e00491. https://doi.org/10.1016/j.geodrs.2022.e00491

Song HJ, Lee JH, Jeong HC, Choi EJ, Oh TK, Hong CO and Kim PJ. 2019. Effect of straw incorporation on methane emission in rice paddy: conversion factor and smart straw management. *Applied Biological Chemistry*, 62(1): 70. https://doi.org/10.1186/s13765-019-0476-7

Sonwani, S. and Saxena, P. 2022. Greenhouse gases: sources, sinks, and mitigation. *Springer Nature*, Singapore, 257p.

Spaccini R and Piccolo A. 2017. Soil organic carbon stabilization in compost amended soils. Global Symposium on Soil Organic Carbon. 21st–23rd March 2017. Rome, Italy.

Srivastava P, Das A, Gupta K, Muthukumaran M, Kurdekar AK, Sharma U and Zaman MI. 2023. Impact of nano and non-nano fertilizers on rice quality and productivity: a review. *International Journal of Environment and Climate Change*, 13(8): 973-987.

Steiner C, Das KC, Melear N and Lakly D. 2010. Reducing nitrogen loss during poultry litter composting using biochar. *Journal of Environmental Quality,* 39(4): 1236-1242.

Su J, Hu C, Yan X, Jin Y, Chen Z, Guan Q, Wang Y, Zhong D, Jansson C, Wang F and Schnürer A. 2015. Expression of barley SUSIBA2 transcription factor yields high-starch low-methane rice. *Nature*, 523(7562): 602-606.

Sultan M, Imran M, Ahmad F and Grichar WJ. (eds.). 2024. Irrigation systems and applications. *Agricultural Sciences*. Intech Open. Available at: http://dx.doi.org/10.5772/intechopen.107802.

Sun X, Zhong T, Zhang L, Zhang K and Wu W. 2019. Reducing ammonia volatilization from paddy field with rice straw derived biochar. *Science of the Total Environment*, 660: 512-518.

Tian H, Xu R, Canadell JG, Thompson RL, Winiwarter W, Suntharalingam P, Davidson EA, Ciais P, Jackson RB, Janssens-Maenhout G and Prather MJ. 2020. A comprehensive quantification of global nitrous oxide sources and sinks. *Nature*, 586(7828): 248-256.

Timilsina A, Bizimana F, Pandey B, Yadav RK, Dong W and Hu C. 2020. Nitrous oxide emissions from paddies: understanding the role of rice plants. *Plants*, 9(2): 180. https://doi.org/10.3390/plants9020180.

Tin MT, Chidthaisong A, Pumijumnong N, Arunrat N and Yuttitham M. 2022. Methane and Nitrous Oxide Emissions from Lowland Rice as Affected by Farmers' Adopted Fertilizer Applications under Two Crop Establishment Methods in Myanmar. *Environment and Natural Resources Journal*, 20(6): 621-633. 10.32526/ennrj/20/202200095.

Trang VH, Nelson KM, Rose S, Khatri-Chhetri A, Wollenberg EK and Sander BO. 2022. Rice cultivation ambition in the new and updated Nationally Determined Contributions: 2020-2021: Analysis of agricultural sub-sectors in countries' climate change strategies. CCAFS Info Note, CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Wageningen, Netherlands, 9p.

Umali-Deininger D. 2022. Greening the rice we eat. *East Asia and Pacific on the rise.* [Online] Available: https://blogs.worldbank.org/en/eastasiapacific/greening-rice-we-eat [07 July. 2024].

Umarani E, Hemalatha V, Saritha A and Ramanjaneyulu AV. 2020. Impact of high temperature stress in rice. *International Journal of Economic Plants*, 7(3): 108-110.

UNFCC [United Nations Framework Convention on Climate Change]. 2015. Paris Agreement. [Online] Available: https://unfccc.int/process-and-meetings/the-paris agreement?gad_source=1&gclid=Cj0KCQjwiOy1BhDCARIsADGvQnBntTHqiclzFcNdkBYJLbt-zN6LeUVVI8oDpNxiX5TmDiqluAeaA-EaAqt1EALw_wcB [07 July. 2024]

Uphoff N. 2024. The principles that constitute System of Rice Intensification (SRI) and the practices for applying them at field level. *Journal of Rice Research*, 17(1): 1-19.

USDA [United States Department of Agriculture]. 2023. Rice sector at a glance. Economic research service. [Online] Available: https://www.ers.usda.gov/topics/crops/rice/rice-sector-at-a-glance [10 July. 2024].

Ussiri D and Lal R. 2012. Soil emission of nitrous oxide and its mitigation. *Springer* Science and Business Media, 369-378.

Van Hung N, Maguyon-Detras MC, Migo MV, Quilloy R, Balingbing C, Chivenge P and Gummert M. 2020. Rice straw overview: availability, properties, and management practices. In: Gummert M, Hung NV, Chivenge P and Douthwaite B. (eds.) *Sustainable rice straw management, Springer Nature* Switzerland AG, Switzerland. pp.1-13.

Van Spanning RJ, Delgado MJ and Richardson DJ. 2005. The nitrogen cycle: denitrification and its relationship to N2 fixation. In: Nitrogen fixation in agriculture, forestry, ecology, and the environment (pp. 277-342). Dordrecht: *Springer* Netherlands.

Vijayaprabhakar A, Durairaj SN, Hemalatha M and Joseph M. 2021. Study on residue management options in combine harvested rice field in relation to yield and economic benefits of succeeding rice crop. *Agricultural Science Digest-A Research Journal*, 41(1): 85-88.

Wang B and Adachi K. 2000. Differences among rice cultivars in root exudation, methane oxidation, and populations of methanogenic and methanotrophic bacteria in relation to methane emission. *Nutrient Cycling in Agroecosystems,* 58(1): 349-356.

Wang C, Lai DY, Sardans J, Wang W, Zeng C and Peñuelas J. 2017. Factors related with CH_4 and N_2O emissions from a paddy field: clues for management implications. *PLos One*. 12(1): 0169254. https://doi.org/10.1371/journal.pone.0169254.

Wang J, Ciais P, Smith P, Yan X, Kuzyakov Y, Liu S, Li T and Zou J. 2023. The role of rice cultivation in changes in atmospheric methane concentration and the Global Methane Pledge. *Global Change Biology,* 29(10): 2776–2789.

Wang J, Wang J, Zhao H and Zheng Y. 2024. Observation and Simulation of CO2 Fluxes in Rice Paddy Ecosystems Based on the Eddy Covariance Technique. *Atmosphere*, 15(5): 517. https://doi.org/10.3390/atmos15050517.

Wassmann R, Lantin RS, Neue HU, Buendia LV, Corton TM and Lu Y. 2000. Characterization of methane emissions from rice fields in Asia. III. Mitigation options and future research needs. *Nutrient Cycling in Agroecosystems*, 58(1): 23-36.

Win EP, Win KK, Bellingrath-Kimura SD and Oo AZ. 2021. Influence of rice varieties, organic manure and water management on greenhouse gas emissions from paddy rice soils. *PLos One*. 17(1): e0263554. https://doi.org/10.1371/journal.pone.0263554 .

WMO [World Meteorological Organization]. 2023. *State of the Global Climate Report 2023*. WMO-No. 1347, Genewa, Switzerland, 53p.

Wu Q, He Y, Qi Z and Jiang Q. 2022. Drainage in paddy systems maintains rice yield and reduces total greenhouse gas emissions on the global scale. *Journal of Cleaner Production*, 370: 133515. https://doi.org/10.1016/j.jclepro.2022.133515.

Xie JF and Li Y.E. 2002. A review of studies on mechanism of greenhouse gas (GHG) emission and its affecting factors in arable soils. *Chinese Journal of Agrometerology,* 23: 47-52. https://doi.org/10.3390/su16114789.

Xing G, Zhao X, Xiong Z, Yan X, Xu H, Xie Y and Shi S. 2009. Nitrous oxide emission from paddy fields in China. *Acta Ecologica Sinica,* 29(1): 45-50.

Xing GX, Cao YC, Shi SL, Sun GQ, Du LJ and Zhu JG. 2002. Denitrification in underground saturated soil in a rice paddy region. *Soil Biology and Biochemistry*, 34(11): 1593-1598.

Xu Y, Zhan M, Cao C, Tian S, Ge J, Li S, Wang M and Yuan G. 2016. Improved water management to reduce greenhouse gas emissions in no-till rapeseed–rice rotations in Central China. *Agriculture, Ecosystems and Environment*, 221: 87-98. https://doi.org/10.1016/j.agee.2016.01.021.

Yadav GS, Babu S, Das A, Mohapatra KP, Singh R, Avasthe RK and Roy S. 2020. No-till and mulching enhance energy use efficiency and reduce carbon footprint of a direct-seeded upland rice production system. *Journal of Cleaner Production*, 271: 122700. https://doi.org/10.1016/j.jclepro.2020.122700.

Yadav SP, Ghimire NP, Paudel P, Mehata DK and Bhujel S. 2024. Advancing effective methods for mitigating greenhouse gas emissions from rice (*Oryza sativa* L.) fields. *Journal of Sustainable Agriculture and Environment*, 3(4): e70012. https://doi.org/10.1002/sae2.70012.

Yadvinder-Singh YS, Bijay-Singh BS and Timsina J. 2005. Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the tropics. *Advances in Agronomy*, 85: 269–407. DOI: 10.1016/S0065-2113(04)85006-5.

Yang T, Wang M, Wang X, Xu C, Fang F and Li F. 2022. Product type, rice variety, and agronomic measures determined the efficacy of enhanced-efficiency nitrogen fertilizer on the CH_4 emission and rice yields in paddy fields: A meta-analysis. *Agronomy*, 12(10): 2240. https://doi.org/10.3390/agronomy12102240.

Yin Y-F, He X-H, Gao R, Ma H-L and Yang Y-S. 2014. Effects of rice straw and its Biochar addition on soil labile carbon and soil organic carbon. *Journal of Integrative Agriculture*, 13(3): 491-498.

Yuan Q, Pump J and Conrad R. 2012. Partitioning of CH_4 and CO_2 production originating from rice straw, soil and root organic carbon in rice microcosms. *PLos One*, 7(11): e49073. https://doi.org/10.1371/journal.pone.0049073.

Yuan S, Linquist BA, Wilson LT, Cassman KG, Stuart AM, Pede V, Miro B, Saito K, Agustiani N, Aristya VE and Krisnadi LY. 2021. Sustainable intensification for a larger global rice bowl. *Nature Communications*, 12(1): 7163. https://doi.org/10.1038/s41467-021-27424-z.

Yuan ZF, Zhou Y, Chen Z, Tang X, Wang Y, Kappler A and Xu J. 2023. Reduce methane emission from rice paddies by man-made aerenchymatous tissues. *Carbon Research*, 2(1): 17. https://doi.org/10.1007/s44246-023-00049-1.

Zafar S. 2018. Rice straw as bioenergy resource. *Bio Energy Consult. Retrieved from the World Wide Web: https://www.bioenergyconsult.com/rice-straw-as-bioenergy-resource*.

Zaidi ST. 2021. Rice Crop Residue burning and alternative measures by India: A Review. *Journal of Scientific Research*, 65(1): 132-137.

Zhang W, Du B, Duan X, Liang Z, Tang Y, Li J and Yao X. 2024. Effects of different rice varieties and water management practices on greenhouse gas (CH_4 and N_2O) emissions in the ratoon rice system in the upper yangtze river region, China. *Agriculture*, 14(12): 2251. https://doi.org/10.3390/agriculture14122251.

Zhang W, Yu Y, Huang Y, Li T and Wang P. 2011. Modeling methane emissions from irrigated rice cultivation in China from 1960 to 2050. *Global Change Biology*, 17(12): 3511-3523.

Zhao C, Liu B, Piao S, Wang X, Lobell DB, Huang Y, Huang M, Yao Y, Bassu S, Ciais P and Durand JL. 2017. Temperature increase reduces global yields of major crops in four independent estimates. *Proceedings of the National Academy of Sciences*, 114(35): 9326-9331.

Zhao C, Qiu R, Zhang T, Luo Y and Agathokleous E. 2024. Effects of alternate wetting and drying irrigation on methane and nitrous oxide emissions from rice fields: A meta-analysis. *Global Change Biology*, 30(12): e17581. doi: 10.1111/gcb.17581. PMID: 39625221.

Zhao X, Pu C, Ma ST, Liu SL, Xue JF, Wang X, Wang YQ, Li SS, Lal R, Chen F and Zhang HL. 2019. Management-induced greenhouse gases emission mitigation in global rice production. *Science of the Total Environment*, 649: 1299-1306.

Zheng H, Huang H, Yao L, Liu J, He H and Tang J. 2014. Impacts of rice varieties and management on yield-scaled greenhouse gas emissions from rice fields in China: A meta-analysis. *Biogeosciences*, 11(13): 3685-3693.

Zhong Y, Wang X, Yang J, Zhao X and Ye X. 2016. Exploring a suitable nitrogen fertilizer rate to reduce greenhouse gas emissions and ensure rice yields in paddy fields. *Science of the Total Environment*, 565: 420-426.

Zhu X, Li J, Liang X, Chen Y, Chen X, Ji J, Xia W, Lan X, Peng C and Chen J. 2022. Long-term P fertilizer application reduced methane emissions from paddies in a double-rice system. *Agronomy*, 12(9): 2166.

RESEARCH ARTICLE https://doi.org/10.58297/KTRB5141

Effect of Zinc Bio-Fortification on Yield and Quality of Pigmented Rice Varieties (*Oryza sativa* L.)

Himasri K[1], Anny Mrudhula K[2]*, Manukonda Srinivas[3], Sandeep Raja B[4] and Suvarna Latha AJ[5]

[1,5]Acharya N.G. Ranga Agricultural University (ANGRAU), Agricultural College, Bapatla

[2]ANGRAU - Saline Water Scheme, Bapatla, Andhra Pradesh, India

[3]ANGRAU – DAATT Centre, Rajahmundry, East Godavari District, Andhra Pradesh

[4]ANGRAU - Post Harvest Technology Centre, Bapatla, Andhra Pradesh, India

*Correspondence author email: anny.mrudhula1@gmail.com

Received: 8th August, 2025, Accepted: 5th October, 2025

Abstract

A field experiment was carried out during the *Kharif* season of 2023 at the Agricultural College Farm, Bapatla, to evaluate the influence of foliar zinc application on the yield and quality attributes of coloured rice (*Oryza sativa* L.). The study employed a split plot design (SPD) with four main plot treatments comprising coloured rice varieties M_1: Navara, M2: BPT-2858, M3: BPT-2841, and M_4: Kujipatalia and four sub-plot treatments involving foliar application of $ZnSO_4$ at 0.2% concentration at different growth stages: S_1 - no zinc application, S_2 - application at the tillering stage, S_3 - application at both tillering and panicle initiation stages, and S_4- application at tillering, panicle initiation, and booting stages. Each treatment combination was replicated thrice. The findings indicated that the Kujipatalia variety (M_4) produced the highest grain and straw yields. In terms of physical quality traits, milling percentage was maximized in Kujipatalia, kernel length in BPT-2841, kernel breadth in Navara, and overall physical quality was superior in BPT-2858. Regarding chemical quality parameters, BPT-2841 exhibited the highest levels of total phenols, carbohydrates, amylose, crude fiber, antioxidant activity, and anthocyanin content. BPT-2858 recorded the highest crude ash, crude fat, and zinc content in grain, whereas Kujipatalia showed the greatest crude protein and zinc content in straw. Among the zinc application treatments, the foliar application of $ZnSO_4$ at 0.2% during tillering, panicle initiation, and booting stages (S_4) consistently resulted in the most favourable outcomes across all measured parameters. Consequently, the combination of Kujipatalia, BPT-2841, and BPT-2858 varieties with the S_4 zinc application schedule proved to be the most effective in enhancing both yield and quality traits. In contrast, the Navara variety without zinc supplementation (S_1) demonstrated the lowest performance in yield and quality, although it recorded the highest kernel breadth.

Key words: Coloured rice, Zinc fertilization, yield, quality

Introduction

Rice serves as the primary food for more than half of the world's population and plays a critical role in meeting over 90% of the world's dietary energy needs. India is the world's second largest producer of rice, accounting for 20 percent of world rice production. Asia accounts for 60% of the total global population, approximately 92% of worldwide rice production, and 90% of global rice consumption (Anonymous, 2012). In 2023-24, projections indicate that the global rice market will produce 520.5 million metric tons of rice. In India, rice cultivation covers an extensive area of 46.3 million hectares, resulting in an annual yield of 1357.55 lakh tonnes. An area of 22.9 lakh hectares in Andhra Pradesh cultivates rice, yielding an annual production of 77.6 lakh metric tons and a productivity of 3,392 kilograms per hectare (Ministry of Agriculture and Farmer Welfare, GOI, 2022).

For people who rely on rice as their main source of sustenance, the quality of rice is critical. In the past few years, the demand for high-quality rice has risen as a result of social progress and improved living conditions. Consumers now prioritise high-quality rice above high-yielding varieties (Tang *et al.*, 2019). In addition to traditional criteria for selecting high-quality rice, such as ease of processing, nice appearance, and outstanding taste, the market and consumers also consider rich nutrition and robust flavour as crucial elements in assessing rice quality. As a result, there has been a surge in research focused on improving the nutritional content and fragrance, making it a popular subject of study. Contemporary nutritional research has demonstrated that coloured rice variants possess higher nutritional value compared to white rice, even after the milling process. Applying mineral elements in moderate amounts can increase the mineral content in rice grains, enhancing the nutritional quality of rice and meeting the mineral needs of the human body (Xu *et al.*, 2022). Consequently, some prominent rice research programmes are now shifting their attention to the matter of nutritional quality, which includes enhancing the levels of micronutrients and antioxidants.

Black rice is a type of rice that contains pigments called cyanidin-3-glucosidase and peonidin-3-glucosidase anthocyanin molecules, which give it its dark colour. Black rice has had a profound impact on culinary traditions and cultural activities, starting from its roots in Asia and continuing to its current comeback in world cuisine. Black rice has gained significant interest among coloured rice varieties due to its sensory attributes, high nutritional content, and particularly its advantageous health benefits (Kushwaha, 2016; Ito *et al.*, 2019). The substance is comprised of a variety of beneficial substances, such as vital amino acids, functional lipids, anthocyanins, phenolic compounds, γ-oryzanols, tocopherols, tocotrienols, phytosterols, and phytic acid. It is also abundant in antioxidants and has the ability to decrease chronic inflammation. Historically, the affluent enjoyed red rice as an exclusive type due to its exceptional nutritional content and distinct flavour. Additionally, it possesses a more pronounced nutty taste and a slightly resilient consistency, rendering it a preferred option in numerous customary recipes. The composition of this substance includes anthocyanins, proanthocyanidins, GABA (Gamma-Aminobutyric acid) and phytosterols. These components have the potential to decrease cholesterol levels and mitigate the likelihood of developing heart disease.

Conversely, rice has a naturally low content of micronutrients such as zinc. In developing nations where polished rice is the primary dietary staple, zinc deficiency poses a significant problem of malnutrition. Zinc is a crucial mineral for maintaining human health. Insufficient levels of zinc can lead to a range of illnesses, including a weakened immune system, stunted growth and development, and heightened susceptibility to cancer (Nriagu, 2019). Because the human body is unable to synthesize zinc, it must be obtained from external sources. Plant-based meals, such as rice, have a reduced zinc level compared to animal diets (Rahman *et al*., 2012). Indeed, rice has a notably lower zinc concentration compared to other plant-based meals like wheat, maize, and potatoes (Cakmak *et al.*, 2017). Long-term consumption of refined white rice may lead to an increased risk of insufficient zinc intake. Hence, the judicious utilisation of zinc fertiliser is vital for raising the quality of rice, specifically by augmenting the zinc concentration and fragrance of rice. Zinc (Zn) is the second most abundant trace element, and it is essential for the survival of all living species. Zinc (Zn) stimulates several enzymes and protein synthesis, as well as enhancing the breakdown of sugar, hence enhancing the overall quality of rice kernels (Kheyri *et al.*, 2019). Additionally, the outer layer of leaves rapidly detects zinc when administered through foliar feeding. The phloem transports the redistributed zinc to developing seeds (**Table 1**). This process ultimately leads to the formation of larger grains and increased grain yield (Hassan *et al.*, 2019).

Table 1: Yield of coloured rice varieties influenced by zinc fertilization

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Coloured rice varieties		
M_1:Navara	3318	4116
M_2: BPT-2858	3868	4801
M_3: BPT-2841	4187	5255
M_4: Kujipatalia	4480	5374
SEm(±)	100.9	94.6
CD (P=0.05)	349	327
CV (%)	8.8	8.9
Foliar application of $ZnSO_4$ @ 0.2%		
S_1: No zinc	3484	4559
S_2:Tillering stage	3869	4695
S_3:Tillering and PI stages	4172	5071
S_4:Tillering, PI and booting stages	4328	5221
SEm(±)	103.3	98.9
CD (P=0.05)	302	289
CV (%)	9.0	9.2
Interaction		
SEm (±)	178.0	169.4
CD (P=0.05)	493	470

Materials and Methods

The present experiment was conducted during *kharif,* 2023 at the Agricultural College Farm of Acharya N. G. Ranga Agricultural University (80.30˚E longitude and 15.54˚ N latitude with an altitude of 5.49 m above mean sea level) Bapatla, Andhra Pradesh. The soil of the experimental field was sandy clay loam, neutral in reaction (pH 7.2), normal in EC (0.21 dS/m), medium in organic carbon (0.45%), low in available nitrogen (235.2 kg/ha), medium in available phosphorus (38.2 kg/ha) and available potassium (309.12 kg/ ha) and low in available zinc (0.29 ppm). The mean maximum temperature during the cropping period was 33.2ºC and mean minimum temperature was 23.7ºC. The total rainfall received during the cropping period was 900.8mm, in 2023. The experiment was conducted in a split-plot design (SPD) with 3 replications. In main plot, coloured rice varieties: M_1- Navara, M_2- BPT-2858, M_3- BPT-2841 and M_4- Kujipatalia and in sub-plots – application of $ZnSO_4$ @ 0.2% at different stages: S_1- no zinc; S_2- application of $ZnSO_4$ @ 0.2% at tillering stage; S_3- application of $ZnSO_4$ @ 0.2% at tillering and panicle initiation stages and S_4- application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages were tested. The varieties had duration of (M_1)120, (M_2)130, (M_3)130-135 and (M_3)120-130 days and were sown on 8th August 2023. The seedlings were uprooted on 25th day in the nursery and transplanted into the main field with a row spacing of 20 cm × 15 cm. In order to facilitate the good seed germination, irrigation was provided immediately after sowing. The fertilizer schedule recommended for rice cultivation in Krishna Agro Climatic zone is 120:60:40 kg NPK/ha. Full dose of phosphorus was applied as basal. Nitrogen was applied in 3 split doses, 1/3rd at basal, 1/3rd at tillering and 1/3rd at panicle initiation stage and potassium was appliedin 2 split doses, half at basal and half at panicle initiation. Pre emergence herbicide pyrazosulfuran-ethyl @ 80 g ac^{-1} was applied followed by post emergence herbicide application of bispyribac sodium @ 30 g *a.i* ha^{-1} applied at 20 DAT and manual weeding was done at 45 DAS and 70 DAS. Need based irrigations were given throughout the crop period. Treatment with $ZnSO_4$ @ 0.2% was carried out based on the different stages in all the plots except in the control. The yield was recorded after the harvest of the crop while the physical quality parameters were recorded using the Satake huller, milling and head rice recovery machine and dial micrometer while chemical quality parameters were done in the laboratory by the standard procedures: The data are subjected to statistical analysis using Fisher's method of analysis of variance as outlined by Panse and Sukhatme (1978) for the design adopted in this research study and wherever statistical significance was observed, the critical difference (CD) at P=0.05 level of probability was calculated for comparison of mean data.

Results and Discussion

The grain and straw yields were significantly influenced by coloured rice varieties and zinc fertilization, and their interaction effect was also significantly affected by varieties and zinc fertilization. Data reveal that the Kujipatalia variety recorded significantly the highest grain yield (4480 kg ha^{-1}) and straw yield (5374 kg ha^{-1}) which was on par with BPT-2841 variety while the significantly lowest grain yield was recorded with Navara variety grain yield (3318 kg ha^{-1}) and straw yield (4116 kg ha^{-1}). The maximum grain and straw yield was recorded with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages. Grain yield (4328 kg ha^{-1}) and straw yield (5221 kg ha^{-1}) were found to be on par with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation grain yield (4172 kg ha^{-1}) and straw yield (5071 kg ha^{-1}). Minimum grain yield (3484 kg ha^{-1}) and straw yield (4559 kg ha^{-1}) were noticed with no zinc application. The highest grain and straw yield were recorded with the Kujipatalia variety coupled with application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages and the lowest grain yield was recorded with Navara variety combined with no zinc application. The foliar application of zinc (Zn) significantly improved grain yield by increasing number of spikelets per panicle, filled grain percentage and 1000 grain weight stated by Wang *et al.,* (2023). Similar findings were reported by Xia *et al*., (2018) and Chen *et al*., (2022).

Physical quality parameters

Results of the data on hulling percentage of coloured rice were found to be non-significant in both the varieties and upon zinc fertilization. There was also no significant interaction between varieties and zinc application at different stages on hulling percentage of coloured rice. The experimental data reveals that the milling percentage was found to be significant for coloured rice varieties and zinc fertilization. Significantly higher milling percentage was recorded with Kujipatalia variety (71.0%) which was on par with BPT-2841 (70.5%) and BPT-2858 (68.7%) variety and lowest was recorded with Navara variety (67.0%). Significantly higher milling percent was recorded with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages (71.1%) which was on par with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation stages (70.0%) and significantly lowest milling percent was recorded with no zinc application (67.3%). Data on head rice recovery of coloured rice was found to be non-significant among the varieties and zinc fertilization. The interaction effect among the two factors (varieties and zinc fertilization) was also found to be non-significant on head rice recovery percent of coloured rice. El-Hissewy *et al.,* (2016) stated that the effect of zinc fertilization on increased milling value may be due to improved growth, photosynthetic assimilates and grain filling (**Table 2**).

Table 2: Physical quality parameters of coloured rice varieties influenced by zinc fertilization

Physical quality parameters					
Treatments	**Hulling (%)**	**Milling (%)**	**Head rice recovery (%)**	**Kernel length (mm)**	**Kernel breadth (mm)**
Coloured rice varieties					
M_1:Navara	74.1	67.0	63.8	6.3	2.7
M_2: BPT-2858	75.8	68.7	65.0	6.5	2.2
M_3: BPT-2841	76.9	70.5	65.7	6.5	2.3
M_4:Kujipatalia	77.2	71.0	66.6	6.5	2.4
SEm(±)	1.24	1.02	0.96	0.03	0.01
CD (P=0.05)	NS	3.0	NS	0.09	0.03
CV (%)	5.6	5.1	5.1	1.4	1.2
Foliar application of $ZnSO_4$ @ 0.2%					
S_1: No zinc	75.1	67.3	63.7	6.4	2.4
S_2:Tillering stage	75.6	68.8	64.4	6.4	2.4
S_3:Tillering and PI stages	76.4	70.0	65.3	6.5	2.4
S_4:Tillering, PI and booting stages	6.8	71.1	67.7	6.5	2.4
SEm(±)	0.57	0.68	1.13	0.03	0.01
CD (P=0.05)	NS	1.9	NS	NS	NS
CV (%)	2.6	3.4	6.0	1.8	1.3
Interaction					
SEm (±)	5.6	1.35	1.89	0.70	0.01
CD (P=0.05)	NS	4..2	5.6	NS	0.03

Results of the experimental data on kernel length of coloured rice were significantly influenced by varieties. Significantly the highest kernel length was recorded with BPT-2858, BPT-2841 and Kujipatalia varieties (6.5 mm) and the lowest was recorded with Navara variety (6.3 mm). Experimental results showed that kernel length of coloured rice varieties was not significantly influenced by zinc fertilization. There was no significant interaction among the coloured rice varieties and zinc fertilization on kernel length. While the kernel breadth of coloured rice showed significant effect only for the varieties and non-significant for the zinc fertilization. Significantly the highest kernel breadth was achieved with Navara variety (2.7 mm) and the lowest was achieved with BPT-2858 variety (2.2 mm). There was no significant influence of coloured rice varieties with zinc fertilization. The interaction effect among these two factors was shown to be significant on the kernel breadth of coloured rice. Wahane *et al.,* (2022) reported that the kernel length and breadth were not affected by Zn fertilization.

Chemical quality parameters

Total phenols (mg/g):

The total phenol content was influenced significantly by both the coloured rice varieties and zinc fertilization. With respect to varieties, significantly the higher phenol content was recorded with BPT-2841 variety (74.2 mg/100g) which was found to be on par with Kujipatalia (71.6 mg/100g) variety and significantly the lower phenol content was recorded with Navara variety (65.7mg/100g). In the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages (73.8 mg/100g) has recorded significantly the higher phenol content which was on par with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation stages (70.2mg/100g) and lower phenol content was recorded with no zinc application (67.3mg/100g). There was significant interaction effect among the varieties and zinc application at different stages on total phenol content. The highest phenol content was recorded with BPT-2841 variety coupled with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages and the lower phenol content was recorded in Navara variety with no zinc application. Seleiman *et al.,* (2023) reported that the foliar application of Zn improved total phenol content by 30% compared to the control by enhancing the different enzymatic activity like superoxide-dismutase. Ali *et al.,* (2020) observed that the maximum phenol contents were found in foliar application compared with soil application which indicates that foliar zinc application increases the phenolic contents. Similar findings were corroborated by Bassi and Sharma (1993). Wahane *et al.,* (2022) observed that the amylose content was significantly influenced by Zn fertilization **(Table 3).**

Amylose content (%)

Data on amylose content of the grain reveals that the highest amylose content in the grain was recorded with BPT-2841 variety (23.2%) which was found to be on par with the BPT-2858 (22.9%) and Kujipatalia variety (22.4%) while, Navara variety (18.9%) recorded significantly lowest amylose content in the grain. In case of zinc fertilization, the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages (26.7%) has recorded significantly superior amylose content in the grain and the lowest was recorded with no zinc application (16.1%). There was significant interaction among the varieties and zinc application at different stages on amylose content of the grain. The highest amylose content was recorded with BPT-2858 variety combined with application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages and the lower amylose content was recorded with Navara variety combined with no zinc application **(Table 3).**

Carbohydrate content (%)

Carbohydrate content was significantly influenced with both the coloured rice varieties and zinc fertilization. Data indicated that significantly higher carbohydrate content was recorded with BPT-2841 variety (72.2%). Lower carbohydrate content was recorded with Navara variety (50.3%). Significantly superior carbohydrate content was recorded with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages (73.7%) and no zinc application recorded significantly lower carbohydrate (52.4%) content **(Table 3)**. Zn plays an important role in several plant physiological processes such as carbohydrate metabolism. Zn exerts a positive effect on carbohydrate metabolism through photosynthesis and sugar transformations (Alloway, 2004). Barak and Helmke (1993) reported that zinc is involved in starch formation.

Antioxidant activity (mg/100g)

The antioxidant activity was significantly influenced by coloured rice varieties and zinc fertilization. Significantly the higher antioxidant activity was recorded with BPT-2841 variety (76.6 mg/100g) followed by BPT-2858 variety (74.5 mg/100g) and Kujipatalia variety (72.9 mg/100g) while significantly lower antioxidant activity was recorded with Navara variety (60.5 mg/100g).With respect to zinc fertilization, significantly higher antioxidant activity was recorded with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages (81.3 mg/100g) which was found to be significantly superior over rest of the treatments **(Table 3).** Lower antioxidant activity was recorded with no zinc application (62.9 mg/100g). Seleiman *et al.,* (2023) reported that the foliar application of Zn facilitated antioxidant defence mechanisms.

Anthocyanin content (mg/g)

Experimental data on anthocyanin content of coloured rice was significantly influenced by the varieties but not with zinc fertilization. Among the varieties, the highest was recorded with BPT-2841 variety (1.02 mg/g) followed by BPT-2858 variety (1.01 mg/g) and the lowest was recorded with Navara variety (0.87 mg/g). There was significant interaction effect among the varieties and zinc fertilization on anthocyanin content of coloured rice (**Table 3**).

Table 3: Effect of zinc fertilization on total phenol content, amylose, carbohydrate, antioxidant and anthocyanin content of coloured rice

Chemical quality parameters					
Treatments	Total phenols (mg/g)	Amylose content (%)	Carbohydrates (%)	Antioxidants (mg/g)	Anthocyanin (mg/g)
Coloured rice varieties					
M_1:Navara	65.7	18.9	50.3	60.5	0.87
M_2: BPT-2858	69.0	22.9	57.8	74.5	1.01
M_3: BPT-2841	74.2	23.2	72.2	76.6	1.02
M_4:Kujipatalia	71.6	22.4	67.0	72.9	0.95
SEm(±)	1.28	0.65	1.28	1.91	0.04
CD (P=0.05)	4.4	2.3	4.4	6.6	0.12
CV (%)	6.3	10.4	7.2	9.3	12.6
Foliar application of $ZnSO_4$ @ 0.2%					
S_1: No zinc	67.3	16.1	52.4	62.9	0.95
S_2:Tillering stage	69.2	20.7	57.7	68.1	0.96
S_3:Tillering and PI stages	70.2	23.9	63.5	72.3	0.96
S_4:Tillering, PI and booting stages	73.8	26.7	73.7	81.3	0.97
SEm(±)	1.31	0.81	1.78	1.47	0.03
CD (P=0.05)	3.8	2.4	5.2	4.3	NS
CV (%)	6.5	12.8	10.0	8.2	12.2
Interaction					
SEm (±)	2.26	1.34	2.88	2.76	0.06
CD (P=0.05)	6.6	4.3	8.3	7.9	0.17

Crude fiber content (%)

Data reveals that the coloured rice varieties and zinc fertilization had significant impact on the crude fiber content of the grain. Among the varieties, BPT-2841 variety (4.68 %) has recorded the highest crude fiber content which was significantly superior over the rest of the varieties tested and Navara variety recorded significantly the lowest crude fiber (3.33 %) content. The highest crude fiber content attained with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages (4.55%) was statistically significant over the rest of the treatments studied in this experiment and the lowest crude fiber content was recorded with no zinc application (3.95 %). Rasheed *et al*., (2022) stated that crude fiber in rice with more strength has been observed with response to zinc application **(Table 4).**

Crude protein content (%)

The crude protein content in the coloured rice was influenced by varieties and zinc fertilization. The highest crude protein content was recorded with Kujipatalia variety (9.8 %) which was on par with BPT- 2841 variety (9.5 %) and the lower crude protein was recorded with Navara variety (7.9 %). Among the zinc fertilization at different stages, application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages (9.6 %) recorded significantly superior to other varieties and the lower crude protein content was recorded with no zinc application (7.9%). Humaira *et al.,* (2015) reported that Zn-superoxide dismutase enzymatic activity is enhanced with Zn application due to this, more protein is produced. Obata *et al*., (1999) and Awad-Allah *et al.,* (2022) reported similar result in their studies **(Table 4)**.

Table 4: Effect of zinc fertilization on crude protein, crude ash, crude fiber and crude fat content of coloured rice

Chemical quality parameters				
Treatments	**Crude protein (%)**	**Crude ash (%)**	**Crude fiber (%)**	**Crude fat (%)**
Coloured rice varieties				
M_1:Navara	7.9	1.61	3.33	1.99
M_2: BPT-2858	8.6	1.72	3.66	2.13
M_3: BPT-2841	9.5	1.60	4.68	1.93
M_4:Kujipatalia	9.8	1.42	4.56	1.78
SEm(±)	0.22	0.05	0.02	0.05
CD (P=0.05)	0.8	0.18	0.07	0.19
CV (%)	8.4	11.5	1.8	9.6
Foliar application of $ZnSO_4$ @ 0.2%				
S_1: No zinc	7.9	1.35	3.95	1.58
S_2:Tillering stage	8.9	1.55	3.78	1.95
S_3:Tillering and PI stages	9.5	1.70	3.96	2.01
S_4:Tillering, PI and booting stages	9.6	1.74	4.55	2.29
SEm(±)	0.25	0.05	0.04	0.07
CD (P=0.05)	0.7	0.14	0.11	0.20
CV (%)	9.7	10.5	3.1	12.4
Interaction				
SEm (±)	0.42	0.09	0.06	0.11
CD (P=0.05)	2.6	0.27	0.18	0.33

Crude fat content (%)

Experimental results reveal that the crude fat content of coloured rice was significantly influenced by varieties and zinc fertilization. With respect to varieties, the highest crude fat content was recorded with BPT-2858 variety (2.13 %) followed by Navara variety (1.99 %) while, Kujipatalia variety (1.78%) recorded the lowest. In case of zinc fertilization, application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages (2.29 %) recorded superior crude fat content while, the lowest was recorded with no zinc application (1.58 %). Dhaliwal *et al.,* (2020) observed that the foliar application of Zn improved the mineral contents **(Table 4).**

Crude ash content (%)

Data reveals that the crude ash content in the coloured rice was influenced by varieties and zinc fertilization. Among the varieties, the highest crude ash content was recorded with BPT-2858 variety (1.72%) and the lowest was recorded with Kujipatalia variety (1.42%). Results of the data with respect to zinc fertilization, revealed that the highest crude ash content was recorded with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages (1.74 %) which was on par with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation stages (1.70%). The lowest was recorded with no zinc application (1.35%) **(Table 4).**

Zinc content in grain (ppm)

Zinc content in the grain was influenced by coloured rice varieties and zinc fertilization. Data shows that the highest zinc content in the rice grain was recorded with BPT-2858 variety (34.2 ppm) which was found to be on par with BPT-2841 (33.9 ppm) and Kujipatalia (32.4 ppm) variety. Navara variety recorded the lowest zinc content in the grain (28.3 ppm). With respect to zinc fertilization, the highest zinc content in the grain was recorded with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages (33.2 ppm) while no zinc (31.3 ppm) applied treatment recorded the lowest zinc content in the grain. The interaction effect between the coloured rice varieties and zinc fertilization was found to have significant impact on the zinc content in the grain. The highest zinc in the grain was recorded with the combination of BPT-2858 variety with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages whereas the lowest was recorded with Navara variety coupled with no zinc application. Xu *et al.,* (2022) observed that zinc applied by foliar spray is readily absorbed by the leaf epidermis and after remobilization, it is transferred via the phloem to developing seeds. Zulfiqar *et al.,* (2020) stated that foliar application of Zn at the early reproductive stage results in the translocation of the Zn to the reproductive structures of the plant and it is then accumulated in grains. Saha *et al*., (2017) reported that foliar application of Zn at the reproductive stages yielded more **(Table 5)**. In foliar application, Zn^{2+} ions enter the plant (leaf apoplast) directly through stomatal pores and increase Zn concentration in the phloem tissue of leaves, from where it can be directly translocated to grains (Gupta *et al.,* 2017).

Table 5: Effect of zinc fertilization on zinc content in the grain and straw of coloured rice

Treatments	Zinc content in grain (ppm)	Zinc content in straw (ppm)
Coloured rice varieties		
M_1:Navara	28.3	25.6
M_2: BPT-2858	34.2	27.6
M_3: BPT-2841	33.9	27.5
M_4:Kujipatalia	32.4	28.1
SEm(±)	0.54	0.53
CD (P=0.05)	1.9	1.8
CV (%)	5.8	6.7
Foliar application of $ZnSO_4$ @ 0.2%		
S_1: No zinc	31.3	24.9
S_2:Tillering stage	31.8	26.5
S_3:Tillering and PI stages	32.4	28.4
S_4:Tillering, PI and booting stages	33.2	28.8
SEm(±)	0.34	0.69
CD (P=0.05)	1.0	2.0
CV (%)	3.7	8.8
Interaction		
SEm (±)	0.69	1.13
CD (P=0.05)	2.7	3.8

Zinc content (%) in straw

Experimental results on zinc content in straw of coloured rice was influenced by varieties and zinc fertilization. Among the varieties, the highest zinc content in straw was recorded with Kujipatalia variety (28.1 %) followed by BPT-2858 variety (27.6 %) and the lowest was recorded with Navara variety (25.6%). In case of zinc fertilization, the highest zinc content in straw was recorded with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages (28.8 %) which was on par with the application of $ZnSO_4$ @ 0.2% at tillering and panicle initiation stages (28.4 %). The interaction effect was found to be significant on zinc content in straw among the varieties and zinc fertilization **(Table 5).** The highest zinc content in straw was recorded with BPT-2858 variety coupled with the application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages and lowest was recorded with the Navara variety combined with no zinc application. High Zn application produced a considerable improvement in Zn uptake in shoots, regardless of genotype (Himasri *et al.,* 2025 and Fageria *et al.,* 1997). Li *et al.,* (1999) reported that Zn application increased Zn concentrations and uptake in shoot, grain and straw with foliar application being most effective.

Conclusion

The highest yield was observed highest with Kujipatalia variety and incase of quality parameters *viz.*, total phenols, carbohydrate, antioxidant activity, amylose content, crude fiber were realized highest with BPT-2841 variety; while crude ash, crude fat, Zn in grain with BPT-2858 variety and crude protein, Zn in straw with Kujipatalia variety. The application of $ZnSO_4$ at specific growth stages namely tillering and panicle initiation resulted in a statistically significant improvement in both yield and quality parameters. Bio-fortification of coloured rice with Zn fertilization significantly influenced all the quality parameters which influences the overall health of an individual. Zinc content in grain reduces the problem of micronutrient malnutrition in the developing nations.

References

Ali S, Azorji JN, Rasheed D, Wisal and Khan S. 2020. Effect of foliar and soil application zinc on biochemical contents, macro nutrients and growth performance of *Triticum aestivum* L. *Amazonian Journal of Plant Research.* 4(2): 542-548.

Alloway B. 2004. The determination of zinc in agricultural materials by atomic-absorption spectrophotometry. *Analyst*. 86(1025): 530-534.

Anonymous. 2012. Agricultural Statistics at a Glance, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India. 359.

Awad-Allah M, Shehzad MA, Bashir F, Tasneem M, Yasin G and Iqbal M. 2022. Boron, zinc and microtone effects on growth, chlorophyll contents and yield attributes in rice (*Oryza sativa* L.) cultivar. *African Journal of Biotechnology.* 11(48):10851-858.

Barak H and Helmke SK. 1993. Response of wetland rice to nitrogen and zinc. *Oryza.* 44(1): 31-34.

Bassi R and Sharma SS. 1993. Proline accumulation in wheat seedlings exposed to zinc and copper. *Phytochemistry*. 33(6): 1339-1342.

Cakmak I, Gulut KY and Kutman UB. 2017. Agronomic biofortification of cereals with zinc: a review. *Europian Journal of Soil Science.* 69(1): 172-180.

Chen MR, White PJ, Hammond JP, Zelko I and Lux A. 2022. Zinc in plants. *New Phytologist.*173(4): 677-702.

Dhaliwal S, Sadana US, Manchanda JS and Dhadli HS. 2020. Biofortification of wheat grains with zinc and iron in typic ustochrept soils of Punjab. *Indian Journal of Fertilizers.*5(11): 13-20.

El-Hissewy AA, Mohammed AE, El-Tantawi SA and Aamer SM. 2016. A study on the effect of different zinc fertilizer levels on rice grain quality traits. *Journal of Sustainable Agricultural Sciences.*42: 58-70.

Fageria NK, Dos Santos AB and Cobucci T. 1997. Zinc nutrition of lowland rice. *Communications in Soil Science and Plant Analysis.* 42(14): 1719- 1727.

Gupta N, Ram H and Kumar B. 2017. Mechanism of zinc absorption in plants: uptake, transport, translocation and accumulation. *Environmental Science and Biotechnology.*15:89-109.

Himasri K, Anny Mrudhula K, Manukonda Srinivas and Suvarna Latha AJ. 2025. Effect of Zinc Bio-fortification on yield and nutrient uptake of Pigmented Rice. Souvenir cum Extended Summaries of National Seminar on *"Climate Smart Innovations to Address the current agronomic challenges"* held from 27-28 June, 2025 at ANGRAU-RARS, Tirupati, Andhra Pradesh. Pp: 357-359.

Humaira TS, Muhammad J, Muhammad A, Hmid US, Saleem U and Sahib A. 2015. Effect of zinc on physico–chemical parameters of hydroponically grown rice varieties. *Middle East Journal of Agricultural Research.*4(3): 395-403.

Ito VC and Lacerda LG. 2019. Black rice (*Oryza sativa* L.): A review of its historical aspects, chemical composition, nutritional and functional properties and applications and processing technologies. *Food Chemistry*. 301: 125304.

Kheyri N, Norouzi HA, Mobasser HR and To*Rabi* B. 2019. Effect of silicon and zinc nanoparticles on growth, yield, and biochemical characteristics of rice. *Agronomy.* 111(6):3084–3090.

Kushwaha UKS. 2016. Black rice research, history and development. Springer *International Cham, Switzerland. Pp:* 21-47.

Li, Yan, Qin, Suichu, Li Y and Qin SC. 1999. Effect of rice metabolism and the diagnosis of hidden zinc deficiency in rice. *Journal of Fujian Agriculture and Forestry University.* 28 (1): 66-67.

Ministry of Agriculture, Govt. of India, 2022.*https://www.statista.com*

Nriagu XX. 2019. Research on genotypic difference in zinc nutrition of rice. *Trace Element Science*.10: 6-9.

Obata H, Kawamura S, Senoo K and Tanaka A. 1999. Changes in the level of protein and activity of Cu/Zn superoxide dismutase in zinc deficient rice plant (*Oryza sativa* L.). *Soil Science and Plant Nutrition.*45(4): 891-896.

Panse VG and Sukhatme VG. 1978. Statistical methods for agricultural workers, 2nd edition. *Indian Council of Agricultural Research.*

Rahman A, Ram H, Zou CQ, Rerkasem B, Duarte AP, Simunji S, Yazici A, Guo S and Rizwan M. 2012. Effect of zinc-biofortified seeds on grain yield of wheat, rice, and common bean grown in six countries. *Journal of Plant Nutrition and Soil Science.*182 (5):791-804.

Rasheed F, Aslam A, Aftab M, Sarwar G, Naz R, Rafique A. 2022. Prospective of use of phosphorus and zinc at tillering and booting stages of rice. *Pakistan Journal of Agricultural Research, .*35(2): 394.

Saha S, Chakraborty M, Padhan D, Saha B, Murmu S, Batabyal K, Seth A, Hazra GC, Mandal B and Bell RW. 2017. Agronomic biofortification of zinc in rice: Influence of cultivars and zinc application methods on grain yield and zinc bioavailability. *Field Crops.* 210: 52-60.

Seleiman M, Zahida TM, Uddin R, Sajjid I, Akhlaq A, Moheyuddin K, Salahuddin J, Mari AH and Panhwar RN. 2023. Effect of zinc and boron fertilizers application on some physicochemical attributes of five rice varieties grown in agro-ecosystem of Sindh, Pakistan. American-Eurasian *Journal of Agricultural and Environmental Sciences*. 13(4):433.

Tang A, Ltekin M, Kalayci A, Yilmaz S, Eker and Cakmak I. 2019. Effects of zinc fertilization on grain yield and shoot concentrations of zinc, boron, and phosphorus of 25 wheat cultivars grown on a zinc-deficient and boron-toxic soil. *Journal of Plant Nutrition.* 24(11): 1817-1829.

Wahane MR, Bedse TJ, Jondhale, DG, Khobragade NH and Deface SB. 2022. Effect of zinc application on yield, nutrients uptake and biochemical properties of rice under Inceptisols. *Oryza*. 59(4): 434-442.

Wang RMK, YuanX, Chen J, Pu J, ShiX, Yang Y, Zhang H and Zhang H. 2023. Zinc oxide nanoparticles foliar application effectively enhanced zinc and aroma content in rice (*Oryza sativa* L.). *Rice.* 16: 36.

Xia H, Xue Y, Liu D, Kong W, Xue Y, Tang Y, Li J, Li D and Mei P. 2018. Rational application of fertilizer nitrogen to soil in combination with foliar Zn spraying improved Zn nutritional quality of wheat grains. *Frontier in Plant Sciences.* 9: 677.

Xu M, Liu M, Liu F, Zheng N, Tang S, Zhou J, Ma Q and Wu L. 2022. A safe, high fertilizer-efficiency and economical approach based on a low-volume spraying UAV loaded with chelated-zinc fertilizer to produce zinc-bio-fortified rice grains. *Journal of Clean Production.*323: 12900.

Zulfiqar Y, Zhang H, WangL, Pu X, Du J, Yang S and Liu J. 2020. Genotypic variation in element concentrations in brown rice from Yunnan landraces in China. *Environmental Geochemistry and Health.* 32(3):165-77.

RESEARCH ARTICLE https://doi.org/10.58297/HMBP7222

Optimizing Yield and Profitability in Wet Direct-Seeded Rice: Comparative Analysis of Sowing Time and Establishment Methods in South-Eastern Rajasthan

Sharma KM[1]*, Meena SN[1], Manoj Kumar[1], Chandra Prakash[1] and Mahendra Kumar R[2]

[1]Agricultural Research Station, Ummedgaj Farm, Kota

Agriculture University, Kota (Rajasthan)

[2]ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad

*Corresponding author Email: kmsharma.kvk@gmail.com

Received: 5th July 2025 Accepted: 30th August 2025

Abstract

A field experiment was carried out at Agricultural Research Station, Kota during *Kharif* 2019 and 2020 to evaluate the yield and profitability of different crop establishment methods under wet direct seeded system in comparison to the transplanting method. The experiment was laid out in split plot design where treatments comprised of two sowing times (normal and late sown) in main plots and four establishment methods in sub-plots (broadcasting, manual line sowing, drum seeding and transplanting). Results revealed that delayed sowing by 30 days reduced panicles/m^2, panicle weight and grain yield by 8.81, 16.42 and 15.87 respectively as compared to normal sowing. Transplanting method recorded maximum and significantly higher panicles/m^2 (307), panicle weight (4.13 g), test weight (25.08 g), grain yield (5.73 t/ha) and straw yield (8.09 t/ha) over wet direct seeded methods. Among wet-direct seeded methods, drum seeding method recorded maximum panicles/m^2 (286), panicle weight (3.78) and test weight (24.54) and grain yield (5.33) and was found at par with manual line sowing. Economic analysis reveals that the highest net returns (Rs. 87833/ha) was obtained under transplanting while drum seeding method (Rs. 85649/ha) was found at par with it. Drum seeding method reduced the cost of cultivation by Rs.7065/ha in comparison to the transplanting method (Rs. 45949/ha) and gave highest B:C ratio (3.22) which was statistically superior to transplanting (2.92) as well as manual line sowing (3.03) and broadcasting (2.85) methods. Use of a drum seeder for direct seeding of paddy under puddled conditions is found to be an alternative option to the transplanting in present study.

Keywords: B:C ratio, drum seeding, establishment methods, net returns, profitability, sowing time, wet direct seeded rice.

Introduction

Rice is India's leading staple food crop of which is consumed by about 65 percent of the population (Singh and Singh, 2020). India has the largest area (47.8 million hectares) under rice cultivation in the worlds and is the second largest producer (137.8 million tonnes) after China (Anonymous, 2025). In Rajasthan, paddy is cultivated in an area of 0.234 million hectare with an annual production of 0.57 million tonnes and average productivity of 2.46 t/ha. Kota zone comprising of 'Humid South-Eastern Plain Zone' contributes to nearly one-half of the rice area and production in Rajasthan (Anonymous, 2023).

Rice is mostly cultivated through the transplanting method. Due to labour shortages and rising labour costs in many regions, the need for alternatives to the conventional transplanting approach has grown in recent years. Higher costs and limited supply of farm labour often delays transplanting. When over-aged seedlings are transplanted, it results in lower rice yield and delays the planting of the succeeding crop which ultimately produces lower system yield. Growing labour demand in non-agricultural sectors is causing labour shortages in agriculture, so it is necessary to achieve more yield with less labour (Chakraborty *et al*., 2017). The shortage of irrigation water jeopardizes the sustainability of the production of rice in irrigated situations (Chauhan *et al*., 2014). To deal with these problems associated with transplanting especially scarcity of labour and to save water and energy input under nursery raising system, wet direct seeded rice (Wet-DSR) is increasingly being recognised as an alternative to transplanting. The wet direct seeding technique, which aims to realize labour saving in paddy cultivation, has continued to gain popularity in recent years (Ryma Labad *et al.,* 2020).

The wet DSR is a system in which pre-germinated seeds are directly sown either by broadcasting or manual line sowing or by using the drum seeder in well puddled main field. Rice crop grown by DSR methods matures 7-10 days earlier compared to puddled transplanting, which allows timely sowing of the succeeding crop (Mishra *et al.*, 2023). Wet-DSR is also recommended when a late monsoon delays sowing, where after applying irrigation water and sprouted seeds, farmers can ensure timely planting through the direct seeding method (Kumar *et al.*, 2024).

Direct-seeded rice yield is reduced when seeds are sown too soon or too late. Numerous studies have reported that planting rice after onset of the monsoon season increased grain output because weed infestation was reduced (Mane and Raskar, 2002). On the other hand, extremely late seeding may shorten rice's vegetative and reproductive growth cycle, which would diminish crop yield. Therefore, research is required for optimizing the sowing window for wet DSR especially in areas where rice-wheat cropping system is dominates. The rising cost and scarcity of labour at peak periods demand to develop alternative methods to transplanting. However, yield levels and profitability of different crop establishment methods of wet DSR in comparison to the transplanting needed to be evaluated before promoting in the South-Eastern Rajasthan conditions. Therefore, a field experiment was carried out to evaluate the yield levels and profitability under different crop establishment methods of wet DSR in comparison to the transplanting under normal and late sown conditions.

Materials and Methods

A field experiment was conducted at the Research Farm of Agricultural Research Station, (25° 10' 57'' North Latitude, 75°50' 20'' East Longitude and 267 m above MSL) of Agriculture University, Kota, Rajasthan during two consecutive *Kharif* seasons of the 2019 and 2020 to study the effect of sowing time and different crop establishment methods under wet direct seeded rice system and its comparison with normal transplanting system. The region falls under agro-climatic zone V 'Humid South-Eastern Plain Zone' of Rajasthan. Soil of the experimental field was clay (Vertisols), alkaline in reaction (pH 7.40), medium in organic carbon (0.60%), low in available nitrogen (235 kg/ha), medium in phosphorus (24 kg/ha) and high in potassium (433 kg/ha).

The experiment was laid out in split plot design with three replications. Treatments consisted of two sowing times in main plots (S_1-Normal sowing, S_2-late sowing) and four crop establishment methods in sub-plots (M_1-Broadcasting of seeds, M_2-Manual line sowing of seeds with 20 cm row spacing, M_3-Line sowing of seeds using Drum seeder at 20 cm row spacing, M_4-Normal transplanting at 20x15 cm spacing.

Well levelled field was selected for the experimentation and it was well prepared by ploughing, harrowing and puddling. Further, after preparing plots as per design, individual plots were also levelled manually as per requirement of the Wet DSR. Rice variety Pusa Sugandha-5 was sown on 29th June and 30th July during *Kharif* 2019 and on 15th July and 16th August during *Kharif* 2020 as normal and late sown respectively.

Seeds of the rice were pre-germinated by soaking for 24 hours in water and after draining out the water the seeds were kept in and covered with wet gunny bags for 24-36 hours to get sprouted seeds. Pre-germinated seeds were sown directly in the main field as per the treatments of wet DSR while for transplanting, seeds were sown in the nursery on the same day. After puddling of main field, soil was allowed to settle down and excess water was drained out one day before direct sowing to maintain thin layer of about 2-3 cm water in plots at the time of sowing. In broadcasting method, pre-germinated seeds were broadcasted in the main field. In manual line sowing, seeds were dropped manually in lines 20 cm apart. In Drum seeding method, the sprouted seeds were sown through drum seeder. Drum seeder is a low-cost (around Rs. 5000) piece of equipment that is used to directly plant pre-germinated (sprouted) paddy seeds in a field that has been puddled and leveled after the excess water has been drained. It typically consists of four hyperboloid-shaped drums that can plant eight lines in a single pass with a 20 cm row-to-row spacing (Singh *et al.,* 2016). Seed rate was kept 50 kg/ha for broadcasting method and 30 kg/ha for other methods. In transplanting treatment, 25 days old seedlings were transplanted at spacing of 20x15 cm row and plant spacings. To enable proper germination of seeds and establishment of seedlings, irrigation and drainage were managed for the next 8-10 days after sowing to maintain a thin film of water. After seedling establishment, the crop was irrigated to 5 cm depth at required intervals as per rainfall.

Recommended doses of fertilizers @ 120-60-40 kg/ha NPK were applied through urea, DAP, and MOP. Full quantity of phosphorous and potassium were applied as a basal dose. While nitrogen was applied in three splits, with half as a basal dose and the one-fourth doses each at tillering and panicle initiation stages. Weed management was common in all experimental plots *i.e.,* application of Bispyribac sodium @ 350 g ai/ha at 15-20 DAS followed by two hand weeding. Plant-protection measures were taken as per need.

The total rainfall received during crop season was 1366 mm and 641 mm during 2019 and 2020, respectively. The maximum temperature raged from 29.3°C to 39.6°C and 31.3°C to 38.9°C and minimum temperature from 17.4°C to 26.7°C and 15.3°C to 24.0°C during crop seasons of 2019 and 2020, respectively. While relative humidity values ranged from 55.6 to 92.9 and 39.7 to 89.6 percent during 2019 and 2020, respectively. The numbers of panicles were counted from a one-meter row length from two random rows in each plot, which was then expressed as number of panicles m^2. The above ground portion of plants of net plot area (17.28 m^2) was sun dried after harvest and then weighed to work out biological yield. Grain yield of net plots was recorded after manual threshing of harvested produce and then expressed as tonnes/ha. Straw yield was worked out by subtracting the grain yield from the biological yield. Based on prevailing market price of input used (seed, fertilizers, agrochemical etc.) and operational cost (nursery, field preparation, sowing/transplanting, irrigation, interculture, sprays, harvesting and winnowing etc.) and the output obtained from each treatment, economic analysis was done to workout net returns and B:C ratio. The data collected on different parameters were statistically analyzed using the Analysis of Variance approach, and the significant differences were assessed at 5% level of significance (Gomez and Gomez, 1984).

Results and Discussion

Yield attributes

Yield attributes were significantly influenced by the sowing time and crop establishment methods (**Table 1**). Crop sown on normal sowing time recorded significantly higher panicles/m^2, panicle weight and test weight over delayed sowing. Pooled data of two years shows that delayed sowing of crop by 30 days resulted in 8.81, 16.42 and 3.40 per cent reduction in panicles/m^2, panicle weight and test weight, respectively as compared to the normal sowing. In addition to reducing weed crop competition, normal sowing increased the availability of all growth components, particularly light and nutrients, which is advantageous for improved growth and yield characteristics (Nazir *et al.,* 2022).

Table 1: Effect of sowing time and establishment methods on yield attributes and yield of wet-direct seeded rice (pooled data of two years)

Treatments	Panicles/ m^2	Panicle weight (g)	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	Harvest index (%)
Sowing time							
S_1-Normal Sowing	295	4.08	24.98	5.68	5.04	13.72	41.29
S_2- Delayed sowing	269	3.41	24.13	4.80	7.13	11.92	39.94
SEm±	3.908	0.048	0.111	0.047	0.07	0.117	0.026
CD (P=0.05)	13.52	0.164	0.38	0.163	0.244	0.406	0.08
Establishment methods							
M_1-Broadcasting	257	3.38	24.13	4.72	7.07	11.79	39.78
M_2-Manual line sowing	277	3.68	24.47	5.16	7.53	12.69	40.44
M_3-Drum seeding	286	3.78	24.54	5.33	7.65	12.98	40.89
M_4-Normal transplanting	307	4.13	25.08	5.73	8.09	13.83	41.34
SEm±	3.910	0.066	0.154	0.072	0.100	0.157	0.277
CD (P=0.05)	11.21	0.19	0.44	0.207	0.286	0.450	0.79

SEm =Standard Error of the Mean CD (P=0.05): Critical difference at 5% level of significance

Among establishment methods, transplanting method recorded maximum panicles/m^2 (307), panicle weight (4.13g) and test weight (25.08) which were found significantly higher over all three Wet-DSR methods. Several workers have also reported higher yield attributes under transplanted rice in comparison to wet DSR (Kumar *et al.,* 2018, Ramesh *et al.,* 2023). Among Wet DSR methods, drum seeding treatment resulted in maximum panicles/m^2 (286), panicle weight (3.78) and test weight (24.54), however, manual line sowing was found at par with it. On the other hand, broadcasting method resulted in significantly lowest values of panicles/m^2 (257) and panicle weight (3.38 g) than other establishment methods. It might be due to higher competition among the plants under the broadcasting where plants had uneven stand geometry. Also, more uniform seedling establishment and deep penetration of roots might have facilitated efficient nutrient uptake in line sowing methods. These results are in close conformity with those reported by Kumar and Chinnamuthu (2022). Further, manual line sowing and drum seeding treatments were found to be statistically at par in this respect. Results shows that test weight of grains did not differ significantly among all three wet-DSR methods.

Yield

The results presented in **Table 1** reveal that that normal sown crop recorded significantly higher grain (5.70 t/ha), straw (8.04 t/ha) and biological (13.74 t/ha) yields over delayed planting. It was observed that on a pooled basis; grain and straw yields were reduced to the extent of 15.87 and 12.85 per cent, respectively due to 30 days of delayed sowing. This might be attributed to a relatively longer vegetative phase, better growth and yield attributes under normal sown crop than late sown as also reported by Dileep *et al*., (2018).

Among crop establishment methods, transplanting method recorded maximum grain (5.73 t/ha), straw (8.09 t/ha) and biological (13.83 t/ha) yields, which were found significantly higher over direct seeded methods. The higher number of panicles/m^2, panicle weight/plant, and test weight of rice might be the primary causes of the maximum grain yield under transplanting. Optimum plant population and uniform crop geometry under the transplanting might have facilitated better nutrient uptake of plants. The outcome closely matched the findings of Netam *et al.,* (2016). According to Miller *et al.,* (1991), panicles/m² were found to be the most significant component among the yield attributes, explaining 89% of the yield variation. Samra and Dhillon (2000) and Prasad *et al.,* (2001) also reported that puddled transplanted rice produced a higher yield than line sowing of sprouted seed and puddling with disseminating sprouted seed.

Among Wet DSR methods, drum seeding treatment recorded maximum grain (5.33 t/ha), straw (7.65 t/ha) and biological (12.98 t/ha) yields, however, manual line sowing was found at par with it. On the other hand, broadcasting method recorded lowest grain (4.72 t/ha) and straw yields (7.07 t/ha) which were found statistically lower than other methods. The lower yields in the broadcasting as compared to line sowing methods could be ascribed to the reason that plants sown in broadcasting did not have a specific distance and uniform space which might have caused higher competition among the plants. Further, greater developments of yield attributes under line sowing might be the primary cause for higher grain and straw yields. Chinnam *et al.,* (2018) and Deksha *et al.,* (2021) also reported better results with drum seeding method.

Data analysis also reveals that harvest index was recorded maximum under transplanting (41.34), which was found at par with drum seeding method (40.89). Relatively more improvement in yield attributes might have increased grain yield and corresponding high harvest index under transplanting and drum seeding methods. While, broadcasting method recorded lowest harvest index (39.78) which might be ascribed to poor development of yield attributes under uneven crop geometry.

Economic returns

Economic analysis of two years pooled data (**Table 2**) reveals that significantly higher net returns (Rs. 132564/ha) and B:C ratio (3.25) were obtained under normal sowing time as compared to the delayed sowing time. Among the different establishment methods, transplanting method fetched the highest net returns (Rs. 87833/ha) which was significantly higher over broadcasting (Rs. 71156/ha) and manual line sowing (Rs.80467/ha) methods, however, drum seeding method (Rs. 85649/ha) was found at par with it. The higher net income in the transplanting and drum seeding methods were attributed to the higher yields. Broadcasting method fetched significantly lowest net returns due to reduced grain and straw yield.

Table 2: Effect of sowing time and establishment methods on economic returns of wet-dry direct seeded rice (pooled data of two years)

Treatments	Gross cost of cultivation (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C ratio
Sowing time				
S_1-Normal Sowing	40933	132564	91631	3.25
S_2- Delayed sowing	40933	111879	70946	2.76
SE m±	-	1090.6	1090.6	0.027
CD (P=0.05)	-	3774	3774	0.09
Establishment methods				
M_1-Broadcasting	38984	110140	71156	2.85
M_2-Manual line sowing	39914	120381	80467	3.03
M_3-Drum seeding	38884	124533	85649	3.22
M_4-Normal transplanting	45949	133832	87883	2.92
SE m±	-	1650.8	1650.8	0.041
CD (P=0.05)	-	4735	4735	0.12

Further economic analysis reveals that drum seeding method reduced the average cost of cultivation by Rs.7065/ha in comparison to the transplanting method. As a result, drum seeding fetched the highest B:C ratio (3.22) which was found statistically superior over transplanting (2.92), broadcasting (2.85) as well as manual line sowing (3.03) methods. Singh and Singh (2010) also found that the drum seeding strategy increased net returns and the B:C ratio. Lower B:C ratio in manual line sowing as compared to drum seeding is ascribed to the greater number of labour needed for manual planting. These outcomes are consistent with the research conducted by Gill and Walia (2013) and Deksha *et al.,* (2021).

Conclusion

Based on the findings of the present experiment, it may be concluded that sowing in wet-direct seeded methods should be completed preferably up to 15th July. Use of a drum seeder for direct sowing of pre-germinated paddy seeds under puddled conditions may be an alternative option to the transplanting method. Direct seeding through drum seeder fetched equivalent net returns to the transplanting. Drum seeding reduced the cost of cultivation by Rs.7065/ha in comparison to the transplanting and fetched maximum B:C ratio (3.22). Therefore, wet direct seeding techniques may be useful for the farmers under labour scarcity situations and need upscaling among the farmers through field demonstrations.

Acknowledgments

The authors are highly thankful to the Director, ICAR-IIRR, Hyderabad; Zonal Director Research, ARS, Kota and Director Research, Agriculture University Kota for providing the necessary facilities as well as rendering moral support during the entire research work.

References

Anonymous. 2023. Third Advance Estimates Directorate of Economics and Statistics, Department of Agriculture and Farmer Welfare, Ministry of Agriculture and Farmers Welfare, Government of India.

Anonymous. 2025. USDA Foreign Agriculture Services: India Rice Area, Yield and Production available at URL https://www/fas.usda.gov/regions/india.

Chakraborty D, Ladha JK, Rana DS, Jat ML, Gathala MK, Yadav S, Rao AN, Ramesha MS and Raman A. 2017. A global analysis of alternative tillage and crop establishment practices for economically and environmentally efficient rice production. *Scientific Reports*, 7(1): 9342. https://doi.org/10.1038/s41598-017-09742-9.

Chauhan BS, Kaur P, Mahajan G, Randhawa RK, Singh H and Kang MS. 2014. Global warming and its possible impact on agriculture in India. *Advances in Agronomy*, 123:65-121. https://doi.org/10.1016/B978-0-12-420225-2.00002-9

Chinnam ND, Lakshmana K and Kiranmai K. 2018. Adoption of recommended practices of drum seeder technology in paddy. *International Journal of Agricultural Sciences*, 10(24): 7628-7630.

Deeksha Kumar M, Thakur AK, Chandrakar T and Singh DP. 2021. Effect of different crop establishment methods on growth and yield of rice under normal and delay sowing conditions. *International Journal of Current Microbiology and Applied Sciences*. 10(01): 3165-3173.

Dileep K, Pasupalak S and Baliarsingh A. 2018. Effect of establishment methods and sowing time on growth and yield of rice varieties (*Oryza sativa* L.). *The Pharma Innovation Journal,* 7, 904-907. e Journal ,9 (23). http://dx.doi.org/10.2139/ssrn.3517106

Gill JS and Walia SS. 2013. Effect of establishment methods on nitrogen levels of basmati rice (*Oryza sativa*). *Indian Journal of Agronomy*, 58(4): 506-511.

Gomez KA and Gomez AA. 1984. *Statistical procedures for agricultural research* -II Edition John Wiley & Sons, New York.

Kumar A, Verma RL, Sah RP, Satapathy BS, Mohanty S, Tripathi R, Chattopadhyay K, Samantaray S and Nayak AK. 2024. Direct seeded rice: a technology for enhancing climate resilience. *NRRI research Bulletin No. 50*, ICAR-National Rice Research Institute, Cuttack-753006, Odisha, India. pp. 32.

Kumar V, Singh S, Sagar V and Maurya ML. 2018. Evaluation of different crop establishment method of rice on growth, yield and economics of rice cultivation in agro-climatic condition of eastern Uttar Pradesh, *Journal of Pharmacognosy and Phytochemistry,* 7(3): 2295-2298.

Kumar Senthil G and Chinnamuthu CR. 2022. Effect of time and method of sowing in wet direct seeded rice. *Agricultural Science Digest*. 42(3): 327-331.

Mane RB and Raskar BS. 2002. Effect of sowing dates and weed control measures on drilled rice. *Indian Journal of Weed Science,* 34 (3 and 4): 282-284.

Miller BC, Hill JE and Roberts SR. 1991. Plant population effect on growth and yield in water-seeded rice. *Agronomy Journal,* 83(2): 291-297.

Mishra Suraj, Chaubey A.K. and Pathak J. 2023. Direct seeded rice: Prospects, constraints and future research work. *Indian Farming,* 79(9): 11–14.

Nazir A, Bhat MA, Bhat TA, Fayaz S, Mir MS, Basu U, Ahanger SA, Altaf S, Jan B, Lone BA, Mushtaq M, Sharnuby ME, Skalicy M, Brestic M and Sabagh ME. 2022. Comparative analysis of rice and weeds and their nutrient partitioning under various establishment methods and weed management practices in temperate environment. *Agronomy,* 12(4):816(1-21).

Netam CR, Singh R, Thakur AK and Netam AK. 2016. Effect of crop establishment methods and weed management options on weed dynamics and productivity of rice (*Oryza sativa L*). *Indian Journal of Agronomy*, 61(3):326- 330.

Prasad SM, Mishra SS and Singh SJ. 2001. Effect of establishment methods, fertility levels and weed-management practices on rice (*Oryza sativa* L). *Indian Journal of Agronomy,* 46(2):216-221.

Ramesh T, Rathika S, Subramanian E and Vijayakumar S. 2023. Water productivity, economic viability and yield of rice under different rice establishment methods. *Journal of Rice Research* 16(1): 99-104.

Ryma Labad T, Hartani G and Uttamaro S. 2020. Effect of weed treatment on cereal yield in direct seeding: A challenge between soil pollution and seeds. *Indian Journal of Agricultural Research*, 54(1):101-106.

Samra JS and Dhillon SS, 2000. Production potential of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system under different methods of crop establishment. *Indian Journal of Agronomy,* 45(1): 21-24.

Singh M and Singh RP. 2010. Influence of crop establishment methods and weed management practices on yield and economics of direct-seeded rice (*Oryza sativa*). *Indian Journal of Agronomy,* 55 (3):224-229.

Singh UV, Kumar D and Moses SC. 2016. Performance evaluation of manually operated paddy drum seeder in puddle field. *Journal of Agriculture and Veterinary Science*, 9(6):69-83.

Singh KM and Singh P. 2020. Challenges of ensuring food and nutritional security in Bihar. Development economics: macroeconomic issues in developing economies. *SSRN Electronic Journal*, 1-13 pp. DOI: 10.2139/ssrn.3517106.

RESEARCH ARTICLE https://doi.org/10.58297/CHES6229

Genetic Variability and Association Studies in F_2 Population of *Indica-Japonica* Crosses of Rice

Kundan Bedwa, Neelam Bhardwaj * and Surbhi Patyal

Department of Genetics and Plant Breeding, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur-176062

*Corresponding author Email: neenabhardwaj@gmail.com

Received: 2nd July, 2025; Accepted: 25th September, 2025

Abstract

The present experiment was conducted to evaluate genetic variability among 12 *indica-japonica* crosses and their parents during *kharif*, 2023. Analysis of the variance revealed presence of significant variability among the genotypes for all the characters studied in F_2 population. High phenotypic coefficient of variance (PCV) and genotypic coefficient of variance (GCV) were observed for spikelets per panicle (19.75%, 17.76%) and grain yield per plant (18.89%, 16.28%) suggesting presence of high variability among the lines that can be exploited for improvement of these traits through selection in advanced generations. High heritability coupled with high genetic advance were observed for spikelets per panicle (80.93%, 32.93%) and 1000 grain weight (80.34%, 21.10%). Based upon the correlation studies grain yield per plant was positively and significantly correlated with effective tillers per plant, panicle length, spikelets per panicle and 1000 grain weight, both at phenotypic and genotypic level. Path coefficient analysis showed that high positive direct effects were exhibited by effective tillers per plant and spikelets per panicle.

Keywords: *Indica-japonica* crosses, Heritability, Variability, Correlation

Introduction

Rice (*Oryza sativa* L.) is a monocotyledonous angiospermic plant of the *Poaceae* family and *Oryzoideae* subfamily and is commonly classified into three subspecies: *indica*, *japonica* and *javanica* (Choi and Jung, 2018). As the staple food for 2.7 billion people, rice's significance led to the declaration of 2004 as the International Year of Rice. India ranks as the world's second-largest producer of rice following China and is also the largest exporter (Khan*,* 2018). The country cultivates rice across 48 million hectares of land achieving an annual production of 134 million metric tons and a productivity of 2.79 tons per hectare (USDA, 2023-24). *Indica* and *japonica* are the two primary subspecies of cultivated Asian rice. *Indica* varieties typically feature taller plants with light green, longer leaves and exhibit tolerance to heat and moisture but are sensitive to low temperatures. They are commonly cultivated in humid regions and lower latitudes. On the other hand, *japonica* varieties are characterized by shorter plant heights and darker green, shorter leaves compared to *indica*. They are known for their tolerance to low temperatures and are suitable for cultivation in both high latitudes and lower latitudes at high altitudes. Genetic variability within and between *indica* and *japonica* rice subspecies has been extensively studied, driven by the quest to enhance grain yield and tolerance to biotic and abiotic stresses including cold stress. The genetic interactions between these two subspecies, particularly in F_2 populations resulting from crosses, offers an unique opportunity to explore the genetic basis of complex traits such as grain yield.

The F_2 derived lines constitute a segregating population that is far from being homozygous and early generation selection in such populations depends on the assumption that the performance of a line at an early generation of selfing is predicative of its performance at homozygosity (Chahota *et al.,* 2007). Understanding the genetic variability present in the germplasm, the degree to which the desired traits are heritable and associations between traits and both direct and indirect effects on yield and its attributes is crucial for improving the yield through selection. Therefore, the present study was aimed at finding out nature and magnitude of genetic variability present in F_2 population of the rice for grain yield and other yield component traits to select the transgressive segregants for further breeding programmes.

Materials and Methods

The present study was conducted at Rice and Wheat Research Centre, Malan (RWRC) during *kharif*, 2023. The experimental material comprised of 12 *indica-japonica* rice crosses along with eight parents and two checks *viz.,* HPR-2143 and HPR-2880. The detail of parents and checks used in the present study is given in **Table 1**. These crosses and their parents along with two checks were evaluated in Randomized Block design with three replications. Each entry was grown in plots with a spacing of 15 cm between plants and 20 cm between rows (two rows per genotype) across three replications within plot size of 0.81 m^2. The observations were recorded for eight yield and its related characters *viz.,* days to 50% flowering, days to 75% maturity, plant height, effective tillers per plant, spikelets per panicle, panicle length, 1000 grain weight and grain yield per plant. 20 plants were randomly selected and tagged for data collection on various traits excluding phenological characteristics such as days to 50% flowering and days to 75% maturity, which were recorded based on the entire plot. The analysis of variance and test of significance was calculated as per the method of Panse and Sukhatme, (1985). The genotypic coefficient of variance (GCV), phenotypic coefficient of variance (PCV), heritability and genetic advance were calculated by the formula given by Burton and De Vane, (1953) and Johnson *et al.,* (1955). Phenotypic and genotypic coefficients of correlation were computed by the formula given by Al-Jibouri *et al.,* (1958). Path coefficient analysis was done by using standard procedure given by Dewey and Lu (1959) in order to estimate the extent of genetic variability present among the parents and crosses.

Table 1: List of cross combinations, parents and checks used in this study

Sl. No.	Cross Combinations
1	HPR 2143 × Naggardhan
2	HPR 2143 × Giza 14
3	HPR 2143 × Koshihikari
4	HPR 3106 × Hinohikari
5	Giza 14 × HPR 2143
6	Giza 14 × HPR 3106
7	Pusa Basmati 1509 × Hinohikari
8	Hinohikari × HPR 2143
9	Bhrigudhan× HPR 2143
10	Koshihikari× HPR 2143
11	HPR 3106 × Koshihikari
12	HPR 2143 × Hinohikari

Sl. No.	Parents and Checks
1	Pusa Basmati 1509 (*indica*)
2	HPR 3106 (*indica*)
3	Hinohikari (*japonica*)
4	Bhrigudhan (*japonica*)
5	Naggardhan (*japonica*)
6	Giza14 (*japonica*)
7	Koshihikari (*japonica*)
8	HPR 2143 (*indica*) (Check)
9	HPR 2880(*indica*) (Check)

Results and Discussion

Variability Parameters

Assessing variability parameters is essential for any breeding programme to assess the nature and magnitude of existing variability (Begna and Teressa, 2024). Estimated values phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability (h^2_{bs}) and expected genetic advance as a percentage of the mean for various traits are presented in **Table 2**. In the present study, results showed significant genetic variation for all traits studied in the F_2 population. All the characters studied exhibited low, moderate and high PCV and GCV values. PCV estimates were higher than the corresponding GCV for all the traits studied, indicating that the apparent variation is not only due to genotypes but also due to the influence of the environment (Gupta *et al.,* 2022). Highest PCV (>15%) was obtained for spikelets per panicle (19.75%) followed by grain yield per plant ((18.89%) and effective tillers per plant (15.88%). Moderate PCV (10-15%) was obtained for 1000-grain weight (12.75%), panicle length (11.74%) and plant height (11.17%). On the other hand, low PCV (<10%) was obtained for days to 50% flowering (5.26%) and days to 75% maturity (4.15). High GCV (>15%) was obtained for spikelets per panicle (17.76%) and grain yield per plant (16.28%) followed by moderate GCV obtained for effective tillers per plant (13.54%), 1000-grain weight (11.43%) and low GCV (<10%) for plant height (9.94%), panicle length (7.27%), days to 50% flowering (5.13%) and days to 75% maturity (4.01%). El-malky and Al-Dahej, (2023), Surjaye *et al.,* (2022), Kurmanchali *et al.,* (2019) and Rachappanavar, (2017) also reported similar results, with higher phenotypic coefficient of variation (PCV) compared to genotypic coefficient of variation (GCV) in their studies.

Table 2: Estimated parameters of variability for yield and its related traits in *indica-japonica* crosses and the parents

Traits	Mean ±SE(m)	Range	PCV (%)	GCV (%)	Heritability (h^2_{bs}) (%)	Genetic advance (as % of mean)
Days to 50% flowering	85.48 ±0.81	80.00-98.00	5.26	5.13	95.14	10.31
Days to 75% maturity	112.49 ±1	107.00-126.00	4.15	4.01	93.12	7.96
Plant height	129.45 ±5.39	101.13-146.47	11.17	9.94	79.15	18.22
Effective tillers per plant	9.71 ±0.66	7.47-11.87	15.88	13.54	72.68	23.78
Panicle length	23.53 ±1.77	20.05-27.32	11.74	7.27	38.33	9.27
Spikelets per panicle	144.19 ±10.15	103.27-192.97	19.75	17.76	80.93	32.93
1000-grain weight	20.77 ±0.96	16.17-26.46	12.75	11.43	80.34	21.10
Grain yield per plant	17.13 ±1.11	9.13-26.19	18.89	16.28	74.21	28.82

Heritability estimates serve as an anticipating tool to quantify the accuracy of phenotypic values. For a given character, greater heritability thus aids in efficient selection. High heritability was observed for the traits *viz;* days to 50% flowering (95.14%), days to 75% maturity (93.12%), spikelets per panicle (80.93%) and 1000-grain weight (80.34%). High heritability suggests that these traits are minimally affected by environmental factors, making selection for their improvement potentially more effective based only on the phenotypic expression of these traits. Low heritability was shown by only one trait *i.e.*, panicle length (38.33%) suggesting significant environmental influence on the expression of this particular trait. Research findings of Tuwar *et al.*, (2013), Srivastava *et al.,* (2017), Srujana *et al.,* (2017) and Tiwari *et al.,* (2019) provides additional support to the findings of the present investigation.

Genetic advance in conjunction with heritability would give a more reliable index of selection value (Johnson *et al.,* 1955). Genetic advance was highest for spikelets per panicle (32.93%) followed by grain yield per plant (28.82%), effective tillers per plant (23.78%) and 1000-grain weight (21.10%). The high value of genetic advance indicated that the inheritance of these traits is under the influence of additive genes, suggesting selection would be effective and beneficial for improving these traits. The knowledge of genetic variability, heritability and genetic advance aids in anticipating the potential genetic gain in subsequent generations when selection methods are used to improve the specific traits (Saha *et al.,* 2019). High heritability coupled with high genetic advance was observed for spikelets per panicle and 1000-grain weight indicating that the heritability was due to additive gene effects making selection potentially effective for given traits.

Correlation analysis

Correlation analysis revealed significant associations among yield along with its component traits at both the genotypic and phenotypic levels (**Table 3**) offering insights into associations among yield and component traits that may guide effective selection. Grain yield showed correlations that were strongly positive for effective tillers for each plant (r = 0.992 genotypic; 0.950 phenotypic), for panicle length (r = 0.989; 0.854), for spikelets per panicle (r = 0.988; 0.956), and for 1000-grain weight (r = 0.757; 0.652) suggesting that these traits contribute to total grain yield and can function as reliable indices for selection. Grain yield exhibited negative correlation to plant height (r = –0.795 genotypic; –0.670 phenotypic), this suggests that taller genotypes are potentially less efficient for yield performance and for yield-related traits, shorter plants are more favourable. Effective tillers per plant correlated positively to panicle length (r = 0.987; 0.895), spikelets per panicle (r = 0.980; 0.938) and 1000-grain weight (r = 0.743; 0.581) emphasizing role of tillering in improving grain productivity. Association studies indicated that simultaneous selection will be useful for these traits with respect to yield improvement. Similar kind of association was revealed by Bose *et al.,* (2024), Billa *et al*., (2024), Prajapati *et al.,* (2022) and Dinesh *et al.,* (2023).

Table 3: Estimates of genotypic (G) and phenotypic (P) correlation coefficients among yield and its related traits

Traits	Correlation coefficient	Days to 75% maturity	Plant height	Effective tillers per plant	Panicle length	Spikelets per panicle	1000-grain weight	Grain yield per plant
Days to 50% flowering	**G**	0.987*	-0.137	-0.183	-0.118	-0.117	-0.006	-0.090
	P	0.979*	-0.091	-0.138	-0.043	-0.095	0.020	-0.081
Days to 75% maturity	**G**		-0.149	-0.166	-0.110	-0.115	0.004	-0.087
	P		-0.088	-0.114	-0.038	-0.092	0.054	-0.077
Plant height	**G**			-0.833*	-0.979*	-0.844*	-0.763*	-0.795*
	P			-0.623*	-0.534*	-0.658*	-0.565*	-0.670*
Effective tillers per plant	**G**				0.987*	0.980*	0.743*	0.992*
	P				0.895*	0.938*	0.581*	0.950*
Panicle length	**G**					0.972*	0.912*	0.989*
	P					0.862*	0.528*	0.854*
Spikelets per panicle	**G**						0.739*	0.988*
	P						0.585*	0.956*
1000-grain weight	**G**							0.757*
	P							0.652*

Path coefficient analysis

Path coefficient analysis revealed the magnitude and direction of both direct and indirect effects of yield-related traits on grain yield per plant at genotypic and phenotypic levels. The association among phenotypic characters and their effect on yield is highly beneficial for selecting desired lines that can integrated in breeding programme in later generations. Perusal of the data revealed that at genotypic level, spikelets per panicle (1.194) exhibited the highest positive direct effect on grain yield, followed by plant height (0.208), 1000-grain weight (0.180), effective tillers per plant (0.172), days to 75% maturity (0.056), and days to 50% flowering (0.020), whereas panicle length showed a negative direct effect (–0.303). Various traits also contributed indirectly to grain yield, with effective tillers per plant showing high positive indirect effects via spikelets per panicle (1.171) and 1000-grain weight (0.134), and panicle length contributing indirectly through spikelets per panicle (1.169), effective tillers (0.170), and 1000-grain weight (0.164) suggesting that the direct selection for these traits will lead to overall improvement in grain yield per plant (**Table 4**). The significant negative correlation of plant height with grain yield per plant was due to high negative indirect effect *via* spikelets per panicle at genotypic level and high negative indirect effect *via* effective tillers per plant at phenotypic level. At genotypic level, positive correlation of panicle length with grain yield per plant was due to high indirect effect of spikelets per panicle and at phenotypic level, *via* high indirect effect of effective tillers per plant. Positive direct effects of selected traits on grain yield observed in the present experiment are in accordance with Priya *et al.,* (2017), Francis *et al.,* (2018), Nithya *et al.,* (2021), Chavan *et al.,* (2022) and Goud *et al.,* (2022).

Table 4: Estimates of genotypic and phenotypic path coefficients among yield and its related traits

Traits	Correlation coefficient	Days to 50% flowering	Days to 75% maturity	Plant height	Effective tillers per plant	Panicle length	Spikelets per panicle	1000-grain weight	Grain yield per plant
Days to 50% flowering	G	**0.020**	0.055	-0.028	-0.032	0.036	-0.140	-0.001	-0.090
	P	**0.330**	-0.305	0.001	-0.071	0.003	-0.042	0.003	-0.081
Days to 75 % maturity	G	0.020	**0.056**	-0.031	-0.029	0.033	-0.137	0.001	-0.087
	P	0.323	**-0.311**	0.001	-0.059	0.002	-0.041	0.007	-0.077
Plant height	G	-0.003	-0.008	**0.208**	-0.144	0.296	-1.007	-0.137	-0.795*
	P	-0.030	0.027	**-0.015**	-0.321	0.035	-0.294	-0.072	-0.670*
Effective tillers per plant	G	-0.004	-0.009	-0.173	**0.172**	-0.299	1.171	0.134	0.992*
	P	-0.046	0.035	0.009	**0.515**	-0.058	0.420	0.074	0.950*
Panicle length	G	-0.002	-0.006	-0.203	0.170	**-0.303**	1.169	0.164	0.989*
	P	-0.014	0.012	0.008	0.461	**-0.065**	0.385	0.067	0.854*
Spikelets per panicle	G	-0.002	-0.006	-0.175	0.169	-0.324	**1.194**	0.133	0.988*
	P	-0.031	0.029	0.010	0.484	-0.056	**0.447**	0.074	0.956*
1000-grain weight	G	0.000	0.000	-0.158	0.128	-0.276	0.883	**0.180**	0.757*
	P	0.007	-0.017	0.008	0.299	-0.034	0.261	**0.127**	0.652*

Conclusion

In summary, the results of this investigation indicated that effective tillers per plant, panicle length, spikelets per panicle and 1000-grain weight could be considered as critical criteria for yield improvement in segregating generations of rice. The study exhibited high genetic variation in the F_2 population from *indica* × *japonica* crosses for grain yield and its component traits, suggesting a broad range of opportunity for selection and genetic enhancement. High heritability in association with high genetic advance for characters like spikelets per panicle and 1000-grain weight supports the dominance of additive gene action, which renders them suitable candidates for early generation selection. Correlation and path coefficient analyses indicated that effective tillers per plant, spikelets per panicle, panicle length, and 1000-grain weight had significant positive association and direct or indirect effects on grain yield, making them important yield-contributing traits. The results suggest that selection on these identified traits in segregating populations can be extremely effective in separating transgressive segregants with superior yield potential. The outcome of this research offers a useful basis for future breeding programs to develop high-yielding, climate-resistant rice varieties through strategic hybridization and selection.

References

Al-Jibouri HA, Miller PA and Robinson HF. 1958. Genotypic and environment variances and covariances in upland cotton cross of interspecific origin. *Agronomy Journal*, 50(10): 633-636.

Begna T and Teressa T. 2024. Genetic variability and its benefits in crop improvement: A review. *Middle East Journal of Agriculture Research*, 13(01): 128-136.

Billa SC, Haritha T, Krishna VB, Swapna M and Tushara M. 2024. Character association studies for yield, nutritional and cooking quality characters in coloured rice (*Oryza sativa* L.). *Journal of Rice Research,* 17(1): 65-71.

Bose CGS, Krishna Veni B, Rani Ch, Tushara M and Ramesh D. 2024. Genetic parameters and association studies for yield and grain quality traits in rice genotypes derived from distant crosses. *Journal of Rice Research,* 17(1): 57-64.

Burton GW and De Vane EH. 1953. Estimating heritability in tall Fescue (*Festuca arundinacea*) from replicated colonal material. *Agronomy Journal*, 45(10): 478-481.

Chahota RK, Kishore N, Dhiman KC, Sharma TR, Sharma SK. 2007. Predicting transgressive segregants in early generation using single seed descent method derived micro-macrosperma gene pool of lentil. *Euphytica,* 156: 305-310.

Chavan BR, Dalvi VV, Kunkerkar RL, Mane AV and Gokhale NB. 2022. Study of correlation and path analysis in aromatic rice genotypes (*Oryza sativa* L.). *The Pharma Innovation Journal*, 11(2): 1704-1707.

Choi HS and Jung SK. 2018. Review of various issues and productivity of organic rice paddy in South Korea. *Research on Crops*, 19(1): 28-33.

Dewey DR and Lu KH. 1959. A correlation and path coefficient analysis of components of crested wheat grass seed production. *Agronomy Journal,* 51(9): 515-518.

Dinesh K, Devi MS, Sreelakshmi C and Paramasiva I. 2023. Exploring the genetic diversity for yield and quality traits in indigenous landraces of rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding,* 14(2): 502-510.

El-Malky MM and Al-Dahej MI. 2023. Assessment of inbreeding depression genetic variability and genetic diversity in rice (*Oryza sativa* L.) based on agro-morphological traits. *Fresenius Environmental Bulletin,* 32(4): 2067-2077.

Francis N, Packiaraj D, Geethanjali S and Hemaprabha K. 2018. Correlation and path coefficient analysis for yield contributing characters in rice (*Oryza sativa* L.) cultivars. *International Journal of Current Microbiology and Applied Science,* 7(06): 2292-2296.

Goud GB, Naik DS, Fiyaz RA, Azam MM, Reddy SN and Naik BB. 2022. Phenotypic correlation between morphological and yield related traits of rice (*Oryza sativa* L.). *International Journal of Agriculture, Environment and Biotechnology,* 15(Special Issue): 515-520.

Gupta H, Purushottam GY, Yadav SK, Singh S and Kumar S. 2022. Genetic variability, heritability and genetic advance for yield and its related traits in rainfed upland rice (*Oryza sativa* L.) genotypes. *The Pharma Innovation Journal*, 11(2): 2520-2524.

Johnson HW, Robinson HF and Comstock RE. 1955. Estimates of genetic and environmental variability in soybeans. *Agronomy Journal,* 47(7): 314-318.

Khan M. 2018. Evaluation of various rice (*Oryza sativa* L.) genotypes for yield and yield characters under agro ecological conditions of Peshawar. *Advances in Plants and Agriculture Research*, 8(6): 491-494.

Kurmanchali M, Kurmanchali N, Kukreti A, Sihag N, Chaudhary H and Karnwal MK. 2019. Study of genetic variability, heritability and genetic advance for various yield attributing and quality traits in basmati rice (*Oryza sativa* L.). *International Journal of Chemical Sciences,* 7(1): 2486-2489.

Nithya N, Beena R, Abida PS, Sreekumar J, Stephen R, Jayalekshmi VG, Manju RV and Viji MM. 2021. Genetic diversity and population structure analysis of bold type rice collection from Southern India. *Cereal Research Communications,* 49: 311-328.

Panse VG and Sukhatme PV. 1985. Statistical Methods for Agricultural Workers. ICAR, New Delhi.

Prajapati MR, Bala M, Patel VP, Patel RK, Sushmitha US, Kyada AD, Patel DP, Pranati J and Kumar SB. 2022. Analysis of genetic variability and correlation for yield and its attributing traits in F_2 population of rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding,* 13(3): 983-990.

Priya CHS, Suneetha Y, Babu DR and Rao VS. 2017. Inter-relationship and path analysis for yield and quality characters in rice (*Oryza sativa* L.). *International Journal of Science, Environment and Technology,* 6(1): 381-390.

Rachappanavar V. 2017. Morphological and molecular characterization of traditional and improved germplasm of paddy cultivated in Himachal Pradesh. M.Sc. Thesis, p 172. Department of Genetics and Plant Breeding, CSK Himachal Pradesh KrishiVishvavidyalaya, Palampur, India

Saha SR, Hassan L, Haque MA, Islam MM and Rasel M. 2019. Genetic variability, heritability, correlation and path analyses of yield components in traditional rice (*Oryza sativa* L.) landraces: Variability and traits association in rice. *Journal of the Bangladesh Agricultural University*, 17(1): 26-32.

Srivastava N, Babu GS, Singh ON, Verma R, Pathak SK, Behra M, Jena D and Chanda M. 2017. Genetic variation, heritability and diversity analysis of exotic upland rice (*Oryza sativa* L.) germplasms based on quantitative traits. *The Pharma Innovation Journal,* 6(12): 316-320.

Srujana G, Suresh BG, Lavanya GR, Ram BJ and Sumanth V. 2017. Studies on genetic variability, heritability and genetic advance for yield and quality components in rice (*Oryza sativa* L.). *Journal of Pharmacognosy and Phytochemistry,* 6(4): 564-566.

Surjaye N, Singh Y, Singh SK, Rahangdale S and Mehta AK. 2022. Genetic variability, correlation and path coefficient study for various yield and quality traits in NPT lines of rice (*Oryza sativa* L.). *Environment and Ecology,* 40(1): 115-122.

Tiwari DN, Tripathi SR, Tripathi MP, Khatri N and Bastola BR. 2019. Genetic variability and correlation coefficients of major traits in early maturing rice under rainfed lowland environments of Nepal. *Advances in Agriculture,* 2019 (1): 5975901. https://doi.org/10.1155/2019/5975901.

Tuwar AK, Singh SK, Sharma A and Bhati PK. 2013. Appraisal of genetic variability for yield and its component characters in rice (*Oryza sativa* L.). *Biolife,* 1(3): 84-89.

United States Department of Agriculture (USDA). 2023. Commodity Intelligence Report, United States Development Agriculture, Foreign Agriculture Service. http://www.fas.usda.gov.

RESEARCH ARTICLE https://doi.org/10.58297/DKDW1604

Influence of Zinc Source on Yield and Zn Uptake of Hybrid rice

Darpana Patel[1*], Gami MR[2], and Patel PB[3]

[1,2]Main Rice Research Centre, Soil and Water Management Research Unit,
[3] N. M. College of Agriculture, Navsari Agricultural University, Navsari-396450, Gujarat, India
*Corresponding author E-mail: darpana_srs@yahoo.com

Received: 3rd October, 2025, Accepted: 4th December, 2025

Abstract

A field experiment was carried out at the Main Rice Research Centre, Soil and Water Management Research Unit, Navsari Agricultural University, Navsari, Gujarat during *kharif* seasons of 2019-2021 to study the influence of zinc source on yield of hybrid rice and Zn uptake by rice plant in response to zinc sulphate ($ZnSO_4$) and zn-ethylene diamine tetra acetate (Zn-EDTA) as Zn source carried out in randomized block design with four replications. The experiment consists of eight treatments *viz.,* Z_1: control, Z_2: application of Zn as per soil test based through $ZnSO_4$, Z_3:100% soil application ($ZnSO_4$ @ 25 kg ha^{-1}), Z_4: spray 0.05% $ZnSO_4$ at tillering +panicle initiation (PI) stage, Z_5: spray 0.1% $ZnSO_4$ at tillering + PI stage, Z_6: spray 0.05% Zn -at tillering + PI stage, Z_7: spray 0.1 % Zn-EDTA at tillering stage + PI stage and Z_8: application of Zn as per soil test based through Zn-EDTA. The results revealed that yield attributes and yield of rice was significantly enhanced on addition of zinc sources over control. The maximum panicle length, panicle weight, grain and straw yield were recorded with the application of zinc as per soil test based application through Zn-EDTA and was on par with spraying of 0.05 and 0.1 % Zn-EDTA at tillering and panicle initiation stage. Application of zinc in the form of Zn-EDTA resulted in grater values for these parameters as compared to zinc sulphate source. Application of both zinc sources failed to produce any remarkable changes in zinc content in rice grain. However, zinc content in rice straw and zinc uptake by rice plant was recorded higher with the application of Zn-EDTA. Thus, Zn-EDTA proved to be efficient sources as foliar spray @ 0.05 % for rice production and Zn uptake by rice plant.

Keywords: Hybrid rice, zinc sulphate, Zn-EDTA, foliar spray, yield, uptake

Introduction

Rice is generally grown under submerged condition and consequently depletion and toxicity of the micronutrient is encountered in many parts of India. Rice is one of sensitive crops to zinc deficiency which may limits its growth and yield. Zinc is one of the most important micronutrients essential for plant growth especially for rice. It acts as an essential component of many enzymes and controls several biochemical processes in the plants required for growth (IRRI, 2000). Its deficiency in rice has been reported in lowland rice of India (Mandal *et al*., 2000). In India, among micro-nutrients, Zn deficiency is the most widespread under the area of high yielding crop varieties particularly in low land rice (Singh and Ram, 2010). In high rice consuming areas, zinc deficiency caused yield reduction and Zn malnutrition in humans (Tiong *et al*., 2014). Zinc deficiency continues to be one of the key factors in determining rice production in several parts of the country (Chaudhary *et al*., 2007). Zinc deficiency in plant is noticed when the supply of zinc to the rice plant is inadequate. Among the several factors which influence zinc supply to the plants include pH, concentration of zinc, iron, manganese and phosphorus in soil solution are very important. Zinc deficiency is usually corrected by application of zinc sulphate and response of rice to zinc under flooded condition has been reported by many workers (Mollah *et al*., and Fageria *et al*., 2011). Moreover, Zn chelates, such as Zinc ethylene diamine tetra acetic acid (Zn-EDTA), which supply significant amount of Zn to the plant without interacting with soil components may also found beneficial. High cost of Zn containing fertilizers, limit its use for checking its deficiency (Mustafa *et al*., 2011). Soil application of micronutrients can be costly. The macro and micronutrients added to the soil and their availability will be affected by the soil environmental factors. Amongst different methods, foliar spraying, as a particular practice to supply these nutrients could avoid these factors and results in rapid absorption. This method is generally more effective and less costly and may enhance crop productivity. Further, to meet the increasing global demand of rice, hybrids can out yield other varieties to close the yield gap evident in many areas. It also raises yield potential. Keeping in view the importance of zinc nutrition; its use efficiency in rice and to mitigate zinc deficiency, the study was taken to know the influence of zinc source applied through soil or foliar method on hybrid rice.

Materials and Methods

Field experiments were conducted at Main Rice Research Centre, Navsari Agricultural University, Navsari (Gujarat) during *kharif* 2019-2021. The soil of experimental field was clayey in texture, medium in organic carbon, low in nitrogen, medium in phosphorus, higher in potassium, medium in zinc and slightly alkaline in reaction. The different treatment of zinc sources and application methods involved Z_1: control, Z_2: application of Zn as per soil test based through $ZnSO_4$, Z_3:100% soil application ($ZnSO_4$ @ 25 kg ha^{-1}), Z_4: spray 0.05% $ZnSO_4$ at tillering +panicle initiation (PI) stage, Z_5: spray 0.1% $ZnSo_4$ at tillering + PI stage, Z_6: spray 0.05% Zn-EDTA at tillering + PI stage, Z_7: spray 0.1 % Zn-EDTA at tillering stage + PI stage and Z_8: application of Zn as per soil test based through Zn-EDTA. The experiment was laid out in randomized block design and replicated for four times. The hybrid rice variety GRH-2 was planted on a spacing 20 cm x 15 cm by transplanting using 25 kg ha^{-1} seed material in *kharif* season. Recommended dose of fertilizer for hybrid rice 120:37.5:00 NPK kg ha^{-1} was applied in two split *viz.,* 50% dose of nitrogen and 50% of nitrogen through urea at tillering and grain filling stage. Full dose of phosphorus through SSP were applied as basal dose. Zinc was applied as per treatments. The other cultural operation, irrigations and plant protection measures were given as common practices as per the recommendation for the rice. Yield attributes were measured from a sample of 5 panicles drawn at random from each plot at harvesting. The net plot was harvested and sun dried followed by weighing the biological yield. Threshing was done manually and weighing of grain was done at about 14 % moisture content. All the data recorded during the study period were statistically analysed by using standard methods as suggested by Panse and Sukhatme (1967).

Results and Discussion

The pooled results revealed that the effect of zinc was found to be significant on different growth and yield and its attributes **(Table 1)**. Significantly higher panicle length (29.08 cm), panicle/m^2 (192) and panicle weight (4.5 gm) were counted with application of Zn as per soil test based application through Zn-EDTA (Z_8) and at par with almost all the soil applied and foliar spray of zinc over control. Increase in productive tillers might be due to adequate supply of zinc which might increase the uptake and availability of other nutrients that improve plant metabolic processes and resulted in increased plant growth. Adequate supply of zinc produced more number of productive tillers per m^2 (Naik and Das, 2007). Zn-EDTA spray at maximum tillering and at booting stage increased number of panicle/m^2 (Saha *et al*., 2020). The overall increase in these parameters of rice could be attributed to overcoming the hidden deficiency of Zn nutrient through its application under low to marginal available Zn containing soil. Application of Zn to marginal soil, improved their availability which also substantiates the beneficial effects of their application on rice crop. Rana and Saifur (2014) also reported that application of $ZnSO_4$ and Zn-EDTA improved the growth and yield attributes of rice crop. Patel and Singh (2010) also found the beneficial effects of multi-micronutrients could be the balanced nutrition of the crops and thereby improved crop growth as well as yield. Grain and straw yield were significantly influenced due to different zinc application treatments. Significantly higher grain yield was recorded with soil test based applied Zn-EDTA (Z_8) and found at par with foliar spray of 0.05 % and 0.1 % Zn-EDTA at tillering and panicle initiation stage; straw yield was also noticed significantly higher with treatment Z_8 and on par with almost all the zinc applied methods except soil test based applied $ZnSO_4$ (Z_2) and control plot. The higher rice yield due to zinc is attributed to its involvement in many metallic enzymes system, regulatory function and auxin production (Hacisalihoglu, 2002), enhanced synthesis of carbohydrates and their transport to the site of grain production (Pedda Babu *et al*., 2007). Fageria *et al*., (2011) reported 97% increase in rice yield due to zinc fertilization. The favourable influence of applied Zn on yield may be due to its catalytic or stimulatory effect on most of the physiological and metabolic processes of plants (Mandal *et al*., 2009). Alvarez *et al*., (2001) reported that when Zn was added as Zn-EDTA, the amounts of the most labile fractions (water soluble plus exchangeable and organically complexed Zn) increased throughout the entire soil profile column, which enhanced the root-cell membrane function. Chhabra and kumar (2018) also reported that soil and foliar applications of zinc enhance the rice yield. Karak *et al*., (2006) revealed that the use of different sources of Zn (Zn-EDTA, and $ZnSO_4.7H_2O$) gave significantly increase in both rice grain (4.56 t ha^{-1}) and straw (6.88 t ha-^{1}) yield during 2-year experiment where 1.0 kg Zn applied as Zn-EDTA. Naik and Das (2008) examined the relative performance of chelated Zn-EDTA and $ZnSO_4$. Initial incorporation of chelated Zn showed pronounced effect on growth over single basal application of $ZnSO_4$. The highest rice grain and straw yield were recorded due to application of 1 kg Zn ha^{-1} as Zn-EDTA as basal with highest mean filled grain percentage, thousands grain weight, and number of panicle/m^2.

Table 1: Yield and its attributes influenced by different zinc treatments (pooled)

Treatments	Panicle length (cm)	Number of panicle / m^2	Panicle weight (gm)	Grain yield (kg/ha)	Straw yield (kg/ha)
Z_1	26.34	128	3.88	5093	6147
Z_2	26.37	141	4.18	5492	6490
Z_3	26.96	136	4.22	5421	6558
Z_4	26.80	138	4.29	5587	6574
Z_5	26.59	151	4.42	5554	6695
Z_6	26.58	156	4.48	5914	6778
Z_7	26.98	177	4.22	5983	6876
Z_8	29.08	192	4.5	6286	7300
S.Em.±	0.90	7.03	0.16	219	282
C.D. 5%	2.55	19.87	0.44	618	797

Application of soil test based applied Zn-EDTA (Z_8) was increased Zn content in grain however it was found non-significant **(Table 2)**. The zinc content in rice straw was recorded maximum with spraying of 0.1 % Zn-EDTA at tillering stage + PI stage (Z_7) and found at par with the treatment spraying of 0.1% $ZnSO_4$ (Z_5) and 0.05% Zn-EDTA (Z_6) at tillering + PI stage and with soil test based applied Zn-EDTA (Z_8).

Yogi *et al*., (2023) also reported that application of Zn fertilizer (either as a foliar spray or into soil) increased Zn concentration than control treatment. Zn content in straw was significantly increased with the 0.5% Zn-EDTA treatment (Wang *et al*., 2020). Zn content in both grain and straw was significantly higher with the application of different levels and modes of Zn-EDTA as compared to $ZnSO_4$ application (Karak *et al*., 2005). It may be due to the foliar application of Zn which was effective in rice as Zn was directly absorbed by rice plant leaves and finally accumulated in grain. Zn uptake by rice plant was recorded significantly higher with the treatment Z_8 and found at par with treatment foliar spray of Zn application at both the sources and doses however Zn uptake in straw was remained at par with 100 % soil application (Z_3). Kulhare *et al*., (2017) reported that the Zn uptake by grain was significantly increased with Zn-EDTA found superior to $ZnCl_2$. Karak *et al*., (2005) also found almost similar results. It may be due to higher efficiency of Zn-EDTA for the absorption of Zn by rice grain and straw as higher content of Zn in plant due to Zn-EDTA. Further, foliar application of zinc efficiently promotes zinc uptake by plant root, which increased zinc absorption.

Table 2: Zn content in rice and uptake in grain and straw influenced by different zinc treatments (pooled)

Treatments	Zn content in grain (ppm)	Zn content in straw (ppm)	Zn uptake by rice grain (g/ha)	Zn uptake (g/ha) by rice straw
Z_1	14.68	21.72	74.98	139.36
Z_2	15.00	20.79	82.69	137.40
Z_3	15.69	22.38	85.37	150.93
Z_4	16.21	21.61	91.06	144.12
Z_5	16.27	22.50	91.16	153.84
Z_6	15.79	22.32	93.44	154.33
Z_7	15.62	24.52	93.52	173.40
Z_8	16.28	23.76	102.44	176.22
S.Em.±	0.61	0.79	4.92	9.01
C.D. 5%	NS	2.24	13.91	25.47

The present investigation concluded that application of Zn as per soil test based through Zn-EDTA recorded significantly higher grain yield. Further, foliar spraying of 0.05 % and 0.1 % Zn-EDTA at tillering and panicle initiation stage was also found equally effective as soil test based Zn-EDTA application. Thus, it is recommended that Zn-EDTA applied in rice will prove to be an efficient sources as foliar spray @ 0.05 % at tillering and panicle initiation stage for rice production and Zn uptake by rice.

References

Alvarez JM, Rio MI and Obrador A. 2001. Lixiviation and extraction of zinc in a calcareous soil treated with zinc chelated fertilizes. *Journal of Agricultural and Food Chemistry*, 44(10): 3383-3387.

Chaudhary SK, Thakur SK and Pandey AK. 2007. Response of wetland rice to nitrogen and zinc. *Oryza,* 44(1): 31-34.

Chhabra V and Kumar R. 2018. Role of zinc application on rice growth and yield. *Plant Archives*, 18(2): 1382-1384.

Fageria NK, Dos Santos AB and Cobucci T. 2011. Zinc nutrition of lowland rice. *Communication in Soil Science Plant Analysis,* 42(14): 1719-1727.

Hacisalihoglu G. 2002. Physiological and biochemical mechanism underlying zinc efficiency in monocot and dicot crop plants. Ph.D. Thesis, Cornell University, Ithaca, New York, USA.

IRRI. 2000. Nutritional disorders and nutrient management in rice. International Rice Research Institute, Manila, Philippines. Pages : 1-203.

Karak T, Das DK and Maiti D. 2006. Yield and Zn uptake in rice (*Oryza sativa* L.) As influenced by sources and times of Zn application. *The Indian Journal of Agricultural Science,* 76(6): 346–348.

Karak T, Singh U, Das S, Das D and Kuzyakov Y. 2005. Comparative efficacy of ZnSO4 and Zn-EDTA application for fertilization of rice **(***Oryza sativa* L.**).** *Archives of Agronomy and Soil Science***,** 51(3):253-264.

Kulhare PS, Tagore FS and Sharma GD. 2017. Effect of foliar spray and sources of zinc on yield, zinc content and uptake by rice grown in a vertisol of central India. *International Journal of Chemical Studies***,** 5(2):35-38.

Mandal B, Hazra GC and Mandal LN 2000. Soil management influences on zinc desorption for rice and maize nutrition. *Soil Science Society of America Journal***,** 64(5): 1699-1705.

Mandal L, Maiti D and Bandyopathyay P. 2009. Response of zinc in transplanted rice under integrated nutrient management in new alluvival zone of West Bengal. *Oryza* 2: 46.

Mollah MZI, Talukder NM, Islam MN and Ferdous Z. 2009. Effect of nutrients content in rice as influenced by zinc fertilization. *World Applied Sciences Journal,* 6(8): 1082-2009.

Mustafa G, Ehsanullah Akbar N, Qaisrani SA, Iqbal A, Khan HZ, Jabran K, Chattha AA, Trethowan R, Chattha T and Atta BM. 2011. Effect of zinc application on growth and yield of rice (*Oryza sativa* L.). *International Journal of Agro Veterinary and Medical Sciences*, 5 (6): 530- 535.

Naik SK and Das DK. 2007. Effect of split application of zinc on yield of rice (*Oryza sativa* L.) in an inceptisol. *Achieves of Agronomy and Soil Science*, 53(3):305-313.

Naik SK, Das DK. 2008. Relative performance of chelated zinc and zinc sulphate for lowland rice (*Oryza sativa* L.). *Nutrient Cycling in Agroecosystems,* 81(3), 219–227.

Panse VG and Sukhatme PV. 1967. In: Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research, New Delhi.

Patel KP and Singh MV. 2010. Management of micronutrients deficiencies for enhancing yield of crops. World congress of soil science, Soil solutions for changing world, Australia.

Peda BP, Shanti M, Rajendra PB and Minhas PS. 2007. Effect of zinc on rice in rice –black gram cropping system in saline soils. *The Andhra Agricultural Journal*, 54 (1&2): 47-50.

Rana WK and Saifur RK. 2014. Effect of different zinc sources and methods of application on rice yield and nutrients concentration in rice grain and straw. *Journal of Environment and Agricultural Sciences,* 1:9(1-5).

Saha S, Bandoyopadhyay S, Mitra B, Patra PS and Paul T. 2020. Response of wet direct-seeded rice to method of zinc application*. Journal of Rice Research*, 13(1): 59-65.

Singh V and Ram N. 2005. Effect of 25 years of continuous fertilizer use on response to applied nutrients and uptake of micronutrients by rice-wheat-cowpea system. *Cereal Research Communications,* 33(2-3): 589-594.

Tiong J, McDonald GK, Yusuf G, Pedas P, Hayes JE, Toubia J, Langridge P. and Haung CY. 2014. HvZIP7 mediates zinc accumulation in barley (*Hordeum vulgare*) at moderately high zinc supply. *New Phytologist*, 201(1):131– 143.

Wang Z, Wang H, Xu C, Lv G, Luo Z, Zhu H, Wang S, Zhu Q, Huang D and Li B. 2020. Foliar application of Zn-EDTA at Early filling stage to increase grain Zn and Fe, and reduce grain Cd, Pb and grain yield in rice (*Oryza sativa* L.). *Bulletin of Environmental Contamination and Toxicology*, 105:428-432.

Yogi AK, Bana RS, Bamboriya SD, Choudhary RL, Laing AM, Singh D, Godara S, Babu S and Chaudhary A. 2023. Foliar zinc fertilization improves yield, biofortification and nutrient-use efficiency of upland rice. *Nutrient Cycling in Agroecosystems*, 125 (3):453-469.

RESEARCH ARTICLE https://doi.org/10.58297/RIRG2057

Sustaining Rice Production in Wet Direct Seeding Under Delayed Sowing Through Drought Tolerant Rice Varieties

Soumya Saha[1,2*], Mangal Deep Tuti[1], Mahender Kumar R[1] and Vidhan Singh T[1]

[1]ICAR-Indian Institute of Rice Research, Hyderabad-500030, India

[2]ICAR-NRRI-Central Rainfed Upland Rice Research Station, Hazaribag-825301, India

*Corresponding author Email: saha.soumya5@gmail.com

Received : 8[h] July, 2025, Accepted : 31[st] August, 2025

Abstract

Rice is a major crop of India, with significant contributions to the nation's economy and food security. Due to increasing concerns over water scarcity and labour shortages, there is a growing shift towards practices such as wet direct seeding. Many farmers in irrigated and rainfed regions face delayed rice sowing due to socio-climatic and physical constraints. Evaluating short-duration, drought-tolerant varieties is crucial, as they perform better under direct-seeded conditions. This study aimed to assess such varieties under wet direct seeding in areas with partial irrigation or puddled soils, focusing on delayed sowing windows, which are often caused by late arrival of monsoon. The study was conducted during the *kharif* seasons of 2020 and 2021 at the ICAR-Indian Institute of Rice Research, Hyderabad, where two delayed sowing dates and four drought-tolerant rice varieties were tested. Identifying rice varieties suited to wet direct seeding under delayed sowing can help farmers secure better return from rice than leaving land fallow or facing losses and support sustainable rice production. The results indicated that delayed sowing in 3-4th week of July led to better growth, yield and economic outcome than sowing further delayed in 1st week of August. Among the varieties, DRR Dhan 46 consistently performed better, showing higher grain yield (7.8% higher than average), better economic returns (12% higher than average), and a higher Benefit-Cost ratio. The study showed that DRR Dhan 46 is the most promising variety for wet direct seeding under delayed sowing conditions.

Key words: Drought tolerant, rice varieties, wet direct seeding, sustainable, rice production

Introduction

Rice, being a major food crop, plays a vital role in the life and livelihood of Indians. The crop has diverse contribution in India's economy, ranging from subsistence farming, which meets farmers' own needs, to export-oriented production of Basmati and other specialty rice varieties (Pathak *et al*., 2018). Traditionally, rice cultivation in India has predominantly been through transplanting, a method that is both labour-intensive and water-demanding (Hossen *et al*., 2018). However, the growing concern over water scarcity and labour shortages has necessitated a shift towards more sustainable practices, such as wet direct seeding (Kumar and Ladha, 2011). Wet direct seeding involves sowing pre-germinated seeds directly into puddled fields, significantly reducing labour requirements compared with puddled transplanting - studies reported labour savings in the range of ~11–29% due to elimination of nursery and transplanting operation (Isvilanonda 2002; Rashid *et al*., 2009). Despite its advantages, wet direct seeding poses challenges, especially with long duration varieties under delayed sowing conditions.

The recommended sowing time of rice in Telangana and surrounding region is June to early July and transplanting is typically carried out in July to August, once the monsoon rains have begun. Delayed sowing often occurs due to late onset of monsoon, delayed release of water from the canal, and management issues, impacting crop establishment and yield (Lavanya and Reddy, 2019). Delayed sowing typically leads to poor seed emergence and a reduced number of panicles and spikelets per panicle, ultimately lowering yields (Zhang *et al*., 2023). However, direct seeding combined with suitable rice varieties can mitigate these challenges (Farooq *et al*., 2011). Direct seeding provides several benefits, including quicker and easier planting, reduced labour requirements, earlier crop maturity (by 7-10 days), improved water-use efficiency, increased tolerance to water shortages, lower methane emissions, and the potential for higher profitability in regions with a reliable water supply (Chakraborty *et al*., 2017; Chaudhary *et al*., 2022).

Many farmers in irrigated and monsoon-dependent regions of India are often forced to delay the sowing of rice due to several socio-climatic (e.g. labour unavailability) and physical constraints, thereby face yield reduction and sometimes negative net return. To mitigate the adverse effects of these delays and improve rice yield, it is essential to select rice varieties that are less sensitive to photoperiod changes and can perform well in late-sown conditions for sustainable rice production in Telangana and India at large. Short- to medium-duration rice varieties are particularly suitable for late sowing as they experience high or low-temperature stress for a shorter period during their reproductive phase compared to long-duration varieties (Murthy and Rao, 2010). Moreover, drought-tolerant varieties are particularly recommended for areas where there may be a possibility of water stress at any stage of crop growth (Rahman *et al*., 2022). Therefore, evaluating short-duration drought-tolerant varieties is immensely important, as these varieties possess inherent characteristics that enable them to perform better under direct-seeded conditions (Singh *et al*., 2017).

Our aim was to further evaluate these varieties in wet-direct seeding for areas with assured irrigation during some parts of the crop growing stage or where farmers are bound to prepare the soil by puddling due to soil factors with a focus on delayed sowing windows. Furthermore, being of short duration, these varieties would facilitate timely sowing of subsequent *rabi* crops (Das *et al*., 2012). Telangana, a key rice-growing state in India, frequently experiences water shortages, making it an ideal region for evaluating drought-tolerant rice varieties. Identifying and promoting rice varieties that can thrive under wet direct seeding and delayed sowing conditions will not only ensure productivity but also enable economic sustainability in rice cultivation. By examining these varieties' growth, yield, and profitability in delayed sown conditions, the study seeks to provide farmers with reliable options to mitigate the risks associated with delayed sowing and improve the resilience and productivity of rice farming in the face of climate variability and resource constraints.

Materials and Methods

Experimental site, climate, and soil

The present experiment was taken up during the *kharif* seasons of (July to November) of 2020 and 2021 at the research farm of ICAR-Indian Institute of Rice Research, Hyderabad (17°19′34″ N, 78°23′01″ E). Total rainfall during the crop growth period were 1139 mm and 727.2 mm in 2020 and 2021, respectively (**Table 1**). Maximum and minimum temperatures ranged between 22-35°C and 10.5-23.5°C in 2020, and 24-36°C and 13-25°C in 2021. The soil in the experimental site had a clayey texture, was slightly alkaline in pH, low in available nitrogen and organic carbon, medium in available phosphorus, and rich in available potassium. Prior to the establishment of the experiment, the site had been under a rice-rice cropping system for several years.

Table 1: **Summary of weather condition during the study in 2020 and 2021**

	2020					2021				
	Temperature (oC)		Rainfall (mm)	Bright Sunshine (hrs.)	Evaporation (mm)	Temperature (oC)		Rainfall (mm)	Bright Sunshine (hrs.)	Evaporation (mm)
	Max.	Min.				Max.	Min.			
July	33.0	20.5	266.8	4.6	125.2	36.0	21.5	305.8	3.7	125.6
Aug	32.0	20.5	234.2	3.6	129.0	34.0	22.0	106.2	4.9	121.7
Sep	35.0	20.0	384.8	4.8	116.7	32.0	21.5	255.2	3.9	100.5
Oct	32.5	14.5	344.6	5.2	88.4	33.0	16.0	100.8	7.3	104.2
Nov	32.0	10.5	15.2	7.3	93.5	31.5	13.0	18.2	4.3	85.9

Note: *Rainfall and Evaporation are monthly totals, whereas Bright Sunshine hours is daily average of the month.*

Treatment details

The experiment was laid out in split plot design with two different dates of sowing with a gap of two weeks (2020: 25 July and 8 Aug; 2021: 17 July and 3 Aug) in main plots and four promising drought tolerant rice varieties (see **Table 2**) in sub-plots with three replications.

Table 2: Information on drought tolerant rice varieties used in the study

Name of Variety	Grain type	Duration (days)	Parentage	Special characteristics
DRR Dhan 42 (IR64 *Drt1*)	Long Slender	120	Aday Sel/*3 IR 64	Resistant to Blast, moderately resistant to bacterial blight and brown spot
DRR Dhan 43	Long bold	115	IR03L03/IRRI148	resistant to blast and moderate resistant to sheath rot and brown spot, neck blast, brown plant hopper
DRR Dhan 44	Long Slender	120	IR 71700-247-1-1-2/IR 03 L120	Resistant to blast, moderately resistant to bacterial leaf blight.
DRR Dhan 46	Long Slender	120	IR72022-46-2-3-3-2/ IR57514-TMI-5-B-1-2	Moderate Resistant to brown spot, BPH and WBPH

Field and crop management

In both seasons, land preparation in the experimental plots involved two passes with a power tiller, followed by two rounds of laddering before sowing or transplanting. Two to three sprouted seeds were dibbled in a puddled field, spaced 20 cm × 15 cm, with little to no standing water on the surface. Nutrient management for both the seasons was accomplished as recommended *i.e.,* 120 kg N, 60 kg P_2O_5 and 40 kg K_2O per hectare through urea, single super phosphate and muriate of potash. The full dose of phosphorus and half of the potassium were applied as a basal treatment, while nitrogen was applied in three equal splits at 10 days after sowing (DAS), at active tillering, and at the panicle initiation stage. The remaining half of the potassium was added at the panicle initiation stage. Water management followed an alternate wetting and drying method, with irrigation applied until the soil reached field capacity. Pests and diseases were controlled through chemical means as needed, though no severe infestations occurred during the experiment. Weed management involved a combination of herbicide use and hand-weeding when necessary. The crop was harvested when 95 per cent of panicles turned into golden colour.

Observation and Statistical analysis

Plants were separated into straw (including rachis) and spikelets by hand threshing. Straw and grain yield were recorded for each treatment in replication wise and reported in t ha^{-1}. The observed data was analysed using Statistix 8.1, analytical software, Tallahassee, Florida, USA and subjected to the analysis of variance under split-plot design. Treatment means were compared using the least significant difference (LSD) test at 5% probability level.

Results and Discussion

Effect on growth and yield parameters

The July sowing resulted in slightly taller plants (7.7% and 2.2% taller) compared to the August sowing in both years (**Table 3**). However, the differences were more pronounced in 2020 and were statistically significant. DRR Dhan 46 was found to be the tallest (10.6% and 10.4% taller than the shortest) variety in both years, with significant differences compared to the other varieties. The number of tillers was higher for the July sowing date (18.2% and 7.2% higher) compared to sowing in August in both years. This difference was significant in 2020 but not in 2021. In 2020, DRR Dhan 46 had the highest number of tillers (11.5%) followed by DRR Dhan 44 (8.2%), however, in 2021 higher tiller count was found with DRR Dhan 43 (20.3%) followed by DRR Dhan 44 (16.3%). The July sowing produced more panicles per square meter than the August sowing date in both years, with no significant differences. DRR Dhan 43 (15.9% and 21% higher) produced highest number of panicles per square meter in both years, followed by DRR Dhan 42 and DRR Dhan 44. There were more filled grains per panicle in the July sowing date compared to August in both years, with significant differences in 2020. DRR Dhan 46 had the highest number of filled grains per panicle (25.6% and 13%) in both years, followed by DRR Dhan 44 (10.4% and 4.3%). Sreedevi *et al*., (2022) reported higher percent of filled grains per panicle in DRR Dhan 44 and 46 contributed to the higher yield of the varieties in direct seeding. Test weight was relatively consistent across both sowing dates and years, with no significant differences. DRR Dhan 46 had the highest test weight in both years, with significant differences compared to other varieties.

Table 3: Growth and yield parameters of rice as influenced by delayed sowing and rice varieties

2020															
	Plant height (cm)			**No. of tillers m^{-2}**			**Panicles m^{-2}**			**Filled grains panicle^{-1}**			**Test weight(g)**		
	Delayed Sowing (S)			**Delayed Sowing (S)**			**Delayed Sowing (S)**			**Delayed Sowing (S)**			**Delayed Sowing (S)**		
Variety (V)	July	Aug	**Mean**	July	Aug	**Mean**	July	Aug	**Mean**	July	Aug	**Mean**	July	Aug	**Mean**
DRR Dhan 42	100.3	86.4	93.4^{b}	282	227	255^{ab}	210	196	203^{b}	91	84	88^{b}	21.2	21.1	21.2^{c}
DRR Dhan 43	95.8	93.7	94.8^{b}	250	234	242^{b}	229	221	225^{a}	87	76	82^{b}	22.7	22.8	22.7^{b}
DRR Dhan 44	102.1	91.9	97.0^{b}	294	230	262^{a}	208	193	200^{b}	97	86	91^{b}	21.9	22.6	22.2^{b}
DRR Dhan 46	104.7	101.9	103.3^{a}	288	252	270^{a}	199	188	194^{b}	105	100	103^{a}	24.0	23.9	23.9^{a}
Mean	100.7^{A}	93.5^{B}		279^{A}	236^{B}		211	199		95^{A}	87^{B}		22.4	22.6	
CD (0.05)	S=3.4, V=5.3			S=26, V=19			S=NS, V=21			S=3.8, V=9.7			S=NS, V=0.82		
2021															
Variety (V)	July	Aug	**Mean**	July	Aug	**Mean**	July	Aug	**Mean**	July	Aug	**Mean**	July	Aug	**Mean**
DRR Dhan 42	94.9	92.8	93.8^{b}	306	274	290^{b}	256	242	249^{b}	93	91	92^{b}	20.5	20.5	20.5^{b}
DRR Dhan 43	93.3	92.8	93.1^{b}	336	325	331^{a}	293	283	288^{a}	91	92	92^{b}	22.3	20.2	21.3^{b}
DRR Dhan 44	96.5	93.3	94.9^{b}	328	312	320^{ab}	283	274	279^{ab}	96	96	96^{ab}	21.4	20.6	21.0^{b}
DRR Dhan 46	104.0	101.5	102.8^{a}	287	263	275^{b}	248	228	238^{b}	109	99	104^{a}	26.2	23.6	24.9^{a}
Mean	97.2	95.1		314	293		270	257		97	95		22.6	21.2	
CD (0.05)	S=NS, V=5.1			S=NS, V=36			S=NS, V=33			S=NS, V=8.3			S=NS, V=1.71		

Effect on yield

Grain yield results from the interaction of several yield components, including the number of grains per panicle, the number of productive tillers, and the test weight (Huang, *et al*., 2013). Sowing in 3-4th week of July resulted in a little higher grain yield (5.9% and 2%) compared to sowing on August for both years (**Table 4**). The yield difference was statistically significant in 2020 but not in 2021. Among the varieties, DRR Dhan 46 consistently showed the highest grain yield in both years, followed by DRR Dhan 43. The differences in yield among the varieties were statistically significant. Higher grain yield varieties are mainly attributed either to a higher number of panicles per square meter or a higher number of filled grain in panicles. Although, DRR Dhan 46 had a bit lower number of panicles but number of filled grains per panicle was higher than other varieties in the study. Liu *et al*., (2024) also opined that, greater number of spikelet per panicle and total number of spikelets were the key factors to achieve high yield in rice. Straw yield followed a similar trend, with the July sowing date yielding more straw than the August sowing date. The difference was statistically significant in both years. DRR Dhan 43 and DRR Dhan 46 had significantly higher straw yields compared to other varieties in 2020 and 2021, respectively. The harvest index was slightly higher in second year of study than in the first year of study, with the August sowing date showing a marginally higher index than the July sowing date, but the difference was not statistically significant in the first year. DRR Dhan 46 had the highest harvest index, indicating it was the most efficient in converting biomass to grain.

Table 4: Yield of rice as influenced by delayed sowing and rice varieties

2020									
	Grain yield (t ha^{-1})			**Straw yield (t ha^{-1})**			**Harvest index (%)**		
	Delayed Sowing (S)			**Delayed Sowing (S)**			**Delayed Sowing (S)**		
Variety (V)	July	Aug	**Mean**	July	Aug	**Mean**	July	Aug	**Mean**
DRR Dhan 42	4.50	4.36	4.43^{b}	6.45	5.89	6.17^{ab}	41.1	42.5	41.8
DRR Dhan 43	4.74	4.52	4.63^{ab}	6.49	6.37	6.43^{a}	42.2	41.5	41.9
DRR Dhan 44	4.40	4.31	4.36^{b}	6.27	5.93	6.10^{ab}	41.4	42.1	41.7
DRR Dhan 46	5.01	4.40	4.71^{a}	6.16	5.62	5.89^{b}	44.9	44.0	44.4
Mean	4.66^{A}	4.40^{B}		6.34^{A}	5.95^{B}		42.4	42.5	
CD (0.05)	S=0.24, V=0.26			S=0.35, V=0.36			S=NS, V=NS		
2021									
Variety (V)	July	Aug	**Mean**	July	Aug	**Mean**	July	Aug	**Mean**
DRR Dhan 42	4.94	4.89	4.92^{c}	6.34	5.89	6.12^{c}	43.7	45.3	44.5
DRR Dhan 43	5.57	5.48	5.53^{b}	7.72	6.43	7.08^{ab}	41.9	46.0	44.0
DRR Dhan 44	5.45	5.39	5.42^{b}	6.96	6.40	6.68^{b}	43.9	45.7	44.8
DRR Dhan 46	6.20	5.98	6.09^{a}	7.56	7.04	7.30^{a}	45.1	45.9	45.5
Mean	5.54	5.43		7.14^{A}	6.44^{B}		43.7^{B}	45.7^{A}	
CD (0.05)	S=NS, V=0.32			S=0.31, V=0.41			S=1.6, V=NS		

All rice varieties experienced lower yield reductions in the second year compared to the first year, which could be attributed to improved environmental conditions, better management practices, or enhanced varietal performance (**Figure 1**). On an average 2.1 to 12% reduction in grain yield in different varieties was observed when sowing was done on August compared to July in 2020; while in 2021 the yield reduction ranged from 1.1 to 4.6%. This suggests that these varieties have the potential to perform well under late sowing conditions, and puddled direct sowing could provide farmers with a new opportunity in such scenarios. Notably, DRR Dhan 46, which showed the highest initial yield reduction in 2020, demonstrated a remarkable recovery in 2021, highlighting its potential resilience under late sown wet-DSR.

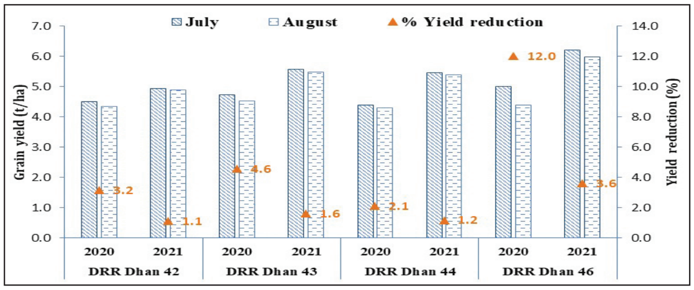


Figure 1: Grain yield and yield reduction of rice varieties due to August late sowing

Effect on economic returns

Gross and net returns were higher for the sowing in 3-4th week of July in both years. However, the difference in respect to net returns were 12.6% and 5.6% in first and second year, respectively (**Table 5**). The Benefit-Cost (B:C) ratio, which indicates profitability, was also higher for sowing in 3-4th week of July, with significant differences between the two delayed sowing dates in both years. DRR Dhan 43 and DRR Dhan 46 had the higher gross (₹1,05,772 and ₹1,40,050) and net returns (₹ 54,197 and ₹90,789), and the higher B:C (1.05 and 1.84), in the first and second year, respectively. The sowing in 3-4th week of July resulted in higher grain and straw yields, as well as better economic returns, compared to the August sowing. The yield advantage of early sowing even by two weeks can be explained by the prolonged growing period and better utilization of the available water and nutrients, which are crucial under the direct-seeded rice system (Ding *et al*., 2017; Bodner *et al*., 2015). DRR Dhan 46 followed by DRR Dhan 43 emerged as the most promising variety, demonstrating superior performance across multiple growth parameters, including plant height, number of tillers, and panicle formation. The ability of DRR Dhan 46 to maintain high productivity under both sowing windows suggests its resilience to varying climatic stresses, a trait that is increasingly valued in the context of climate change.

Table 5: Profitability of rice as influenced by delayed sowing and rice varieties

Variety (V)	2020								
	Gross return (₹ ha^{-1})			Net return (₹ ha^{-1})			B:C		
	Delayed Sowing (S)			Delayed Sowing (S)			Delayed Sowing (S)		
	July	Aug	**Mean**	July	Aug	**Mean**	July	Aug	**Mean**
DRR Dhan 42	103407	99053	101230^{b}	51832	47478	49655^{b}	1.00	0.92	0.96^{ab}
DRR Dhan 43	107980	103565	105772^{a}	56405	51990	54197^{a}	1.09	1.01	1.05^{a}
DRR Dhan 44	101074	98320	99697^{b}	49499	46745	48122^{b}	0.96	0.91	0.93^{b}
DRR Dhan 46	111997	99126	105562^{ab}	60422	47551	53987^{ab}	1.17	0.92	1.05^{a}
Mean	106115^{A}	100016^{B}		54540^{A}	48441^{B}		1.06^{A}	0.94^{B}	
CD (0.05)	S=4937, V=4534			S=4937, V=4534			S=0.10, V=0.09		
2021									
Variety (V)	July	Aug	**Mean**	July	Aug	**Mean**	July	Aug	**Mean**
DRR Dhan 42	114916	112510	113713^{c}	65655	63249	64452^{c}	1.33	1.28	1.31^{c}
DRR Dhan 43	131313	125699	128506^{b}	82052	76438	79245^{b}	1.67	1.55	1.61^{b}
DRR Dhan 44	126683	123749	125216^{b}	77422	74488	75955^{b}	1.57	1.51	1.54^{b}
DRR Dhan 46	143012	137088	140050^{a}	93751	87827	90789^{a}	1.90	1.78	1.84^{a}
Mean	128981^{A}	124762^{B}		79720^{A}	75501^{B}		1.62^{A}	1.53^{B}	
CD (0.05)	S=3125, V=6910			S=3125, V=6910			S=0.06, V=0.14		

Conclusion

In late sown wet direct seeding short duration, drought tolerant rice varieties are suitable option to cope up with the late onset of monsoon or other related situation which forces the farmers for delayed sowing or transplanting. The findings suggest that optimum rice yields in direct-seeded rice can be obtained by selection of suitable variety even in late sown condition. DRR Dhan 46 could be a promising variety for wet direct seeding under delayed sowing conditions in Telangana. Additionally, it may also be suggested that, earlier sowing led to higher yields, economic returns, and a better B:C ratio, with DRR Dhan 46 being the most profitable option.

References

Bodner G, Nakhforoosh A and Kaul HP. (2015). Management of crop water under drought: a review. *Agronomy for Sustainable Development*, 35(2): 401-442.

Chakraborty D, Ladha JK, Rana DS, Jat ML, Gathala MK, Yadav S, Rao AN, Ramesha MS and Raman A. (2017). A global analysis of alternative tillage and crop establishment practices for economically and environmentally efficient rice production. *Scientific Reports*, *7*(1): 9342, DOI:10.1038/s41598-017-09742-9

Chaudhary A, Venkatramanan V, Mishra AK and Sharma S. (2022). Agronomic and environmental determinants of direct seeded rice in South Asia. *Circular Economy and Sustainability*, 3(1): 253–290.

Das A, Patel DP, Ramkrushna GI, Munda GC, Ngachan SV, Choudhury BU, Mohapatra KP, Rajkhowa DJ, Rajesh Kumar and Panwar AS. (2012). Improved Rice Production Technology - for resource conservation and climate resilience (Farmers' Guide). Extension Bulletin No 78. ICAR Research Complex for NEH Region, Umiam - 793 103, Meghalaya.

Ding Y, Wang W, Song R, Shao Q, Jiao X and Xing W. (2017). Modeling spatial and temporal variability of the impact of climate change on rice irrigation water requirements in the middle and lower reaches of the Yangtze River, China. *Agricultural Water Management*, 193(12): 89-101.

Farooq M, Siddique KH, Rehman H, Aziz T, Lee D and Wahid A. (2011). Rice direct seeding: Experiences, challenges and opportunities. *Soil and Tillage Research*, 111(2): 87–98.

Hossen M, Hossain M, Haque M and Bell R. (2018). Transplanting into non-puddled soils with a small-scale mechanical transplanter reduced fuel, labour and irrigation water requirements for rice (*Oryza sativa* L.) establishment and increased yield. *Field Crops Research*, 225: 141–151.

Huang R, Jiang L, Zheng J, Wang T, Wang H, Huang Y and Hong Z. (2013). Genetic bases of rice grain shape: so many genes, so little known. *Trends in plant science*, 18(4): 218-226.

Isvilanonda S. (2002). Development trends and farmers' benefits in the adoption of wet seeded rice in Thailand. In: Pandey S, Mortimer M, Wade L, Tuong TP, Lopez K, Hardy B (ed) Direct seeding: research strategies and opportunities proceedings of the International Workshop on Direct Seeding in Asian Rice Systems: Strategic Research Issues and Opportunities 25–28 January 2000, Bangkok, Thailand. International Rice Research Institute, Los Baños, Philippines, pp 115–124.

Kumar V and Ladha JK. (2011). Direct seeding of rice: Recent developments and future research needs. *Advances in Agronomy*, 111: 297-413. https://doi.org/10.1016/B978-0-12-387689-8.00001-1

Lavanya N and Reddy MM. (2019). Yield attributes and quality parameters of rice under different establishment methods and varieties with nitrogen levels under late sown conditions in Telangana state. *Journal of Pharmacognosy Phytochemistry* 8(3):4185-4192.

Liu K, Zhang K, Zhang Y, Cui J, Li Z, Huang J, Li S, Zhang J, Deng S, Zhang Y, Huang J, Ren L, Chu Y, Zhao H and Chen H. (2024). Optimizing the total spikelets increased grain yield in rice. *Agronomy*, 14(1): 152 (1-14).

Murthy DKM and Rao UA. (2010). Influence of low temperatures stress on growth and yield of rice. *International Journal of Agricultural Sciences* 6(2):415-417.

Pathak H, Nayak A, Jena M, Singh O, Samal P and Sharma S. (2018). Rice research for enhancing productivity, profitability and climate resilience. ICAR-National Rice Research Institute, Cuttack, Odisha, India, pp 542.

Rahman MS, Sujan MHK, Acharjee DC, Rasha RK and Rahman M. (2022). Intensity of adoption and welfare impacts of drought-tolerant rice varieties cultivation in Bangladesh. *Heliyon*, 8(5), e09490.

Rashid MH, Alam MM, Khan MAH and Ladha JK. (2009). Productivity and resource use of direct-(drum)-seeded and transplanted rice in puddled soils in rice–rice and rice–wheat ecosystems. *Field Crops Research*, 113(3): 274-281.

Singh B, Reddy KR, Redoña ED and Walker T (2017). Screening of rice cultivars for morpho-physiological responses to early-season soil moisture stress. *Rice Science*, 24(6): 322-335.

Sreedevi B, Singh A, Ram T, Singh S, Srivastava AK, Singh US and Kumar RM. (2022). Assessing the Performance of Drought-Tolerant Rice Varieties under Varied Nitrogen Doses. *Current Journal of Applied Science and Technology*, 41(6): 21-35.

Zhang RP, Zhou NN, Ashen RG, Zhou L, Feng TY, Zhang KY, Liao XH, Aer LS, Shu JC, He XW, Gao F and Ma P. (2023). Effect of Sowing Date on the Growth Characteristics and Yield of Growth-Constrained Direct-Seeding Rice. *Plants*, 12(9): 1899 (1-16).

RESEARCH ARTICLE https://doi.org/10.58297/SDTR3063

Bio-efficacy of Botanicals and Biopesticides against Rice Caseworm, *Parapoynx stagnalis* (Zeller)

Muhammed Arshad V[1*], Karthikeyan K[2], Haseena Bhaskar[1], Mani Chellappan[1] and Sajitha Vijayan M[1]

[1]Department of Agricultural Entomology, College of Agriculture, Vellanikkara, Kerala Agricultural University, KAU P.O., Thrissur, Kerala, India 680656

[2]Department of Agricultural Entomology, Regional Agricultural Research Station, Pattambi, Kerala Agricultural University, P.O., Mele Pattambi, Palakkad, India 679306

*Corresponding author Email: arshadmuhammed345@gmail.com ORCID ID: 0009-0006-2238-2814

Received : 3rd July, 2025, Accepted : 30th September, 2025

Abstract

The experiment was conducted in order to find the efficacy of eco-friendly insecticides against rice caseworm, *Parapoynx stagnalis*. The efficacy of three de-oiled botanical cakes *viz*., neem cake (2 and 3 %), mahua cake (2 and 3 %), and castor cake (2 and 3 %), as well as two biopesticides *viz*., *Bacillus thuringiensis* (1 ml L^{-1}) and *Beauveria bassiana* (20 ml L^{-1}) were evaluated under net house condition at Regional Agricultural Research Station, Pattambi during September 2023. The mortality and feeding were recorded at 1, 3, 5 and 7 days after treatment. The results showed that 100 per cent larval mortality was recorded on the 3rd day with mahua cake (3 %) treatment recorded followed by mahua cake (2 %) and *B. thuringiensis*. The treatments could also significantly reduce the feeding damage by 3rd day @ 7.73,13.67 and 13.27 % respectively. Neem cake showed significant larval mortality (90 %) of caseworm on the 7th day after treatment at a higher concentration (3%).

Keywords: *Parapoynx stagnalis*, *Bacillus thuringiensis*, mahua cake, castor cake, neem cake, botanicals, biopesticides, feeding deterrent

Introduction

India is the largest producer of rice after China, with an average production of 120 million tonnes. The productivity levels of paddy are significantly influenced by a myriad of biotic and abiotic factors, among which the contribution of insect pests accounts for approximately 25 per cent of total losses (Dhaliwal *et al*., 2010). The rice caseworm, *Parapoynx stagnalis* (Zeller) (Lepidoptera: Crambidae) in contrast to other lepidopteran pests that affect rice, possesses a larval stage that is aquatic in nature, that relies on dissolved oxygen present in the water contained within the case constructed out of paddy leaves (Nilamudeen *et al*., 2024). The rice crop during its seedling phase is vulnerable to pest infestation, which is notably prevalent in agricultural fields characterized by persistent standing water. The pest gets translocated from one field to another through drainage channels, and in the course of infestation, the affected plants will be reduced to mere stumps. Pandit *et al*., (2023) documented the damage level of 26 to 50 per cent due to the pest in susceptible varieties. The injury inflicted by larvae through foliar scraping results in white discoloration, leading to a diminution in yield of approximately 10 per cent in Philippines (Heinrichs and Vijante, 1987), and as much as 52 per cent reduction in Argentina (Trujillo, 1991).

Farmers rely on higher concentrations of insecticides than the recommended doses to manage the pest problem in rice fields. This practice heightens the potential for pesticide contamination of aquatic ecosystems, resurgence and adverse effects on natural enemies. The unique attributes of botanical and bio-insecticides, particularly their environmental safety and minimal impact on non-target organisms, render them formidable candidates for integration into pest management strategies. These botanical agents are highly biodegradable, and the likelihood of insects developing resistance to these compounds is minimal due to their diverse mode of action (Pedigo, 1999). Nevertheless, the pesticidal properties of botanicals and bio-insecticides against rice caseworms remain unexplored. Field experiments at multi-locations under the All India Coordinated Rice Improvement Programme (DRR, 1995-97) revealed that neem formulations *viz*., Achook, Nimbecidine, Neemax, Neemgold and Econeem at recommended concentrations (2% in oil based formulation) were moderately effective against stem borer (6.5 to 7.1% dead hearts-DH and 10.2 to 11.6% white ears-WE) and leaf folder (17.0 to 26.0 average damaged leaves - ADL per 10 hills) compared to standard insecticide check (5.4% DH, 8.0% WE and 19.2% ADL), but were significantly superior to control (11.3% DH, 14.8% WE and 42.4% ADL) (Katti, 2013).

Prior to the advent of synthetic insecticides, farmers relied on botanicals for pest management (Thacker, 2002). The application of oil cakes such as neem and karanj has been recognized as a potent strategy for mitigating pest prevalence, that reduced the incidence of *Scirpophaga incertulas* (Prasad, 2020). The study conducted by David (1986) concluded that the utilization of neem-coated urea led to a reduced incidence of whorl maggot and leaf folder. Employment of biopesticides that induce disease in insects plays an important role in mitigating the pest population. According to Nilamudeen and Sudharma (2020), the talc formulations of *Beauveria bassiana* significantly reduced the leaf folder damage. Aghaee and Godfrey (2015) documented that *Bacillus thuringiensis* could effectively manage rice water weevil and the results were comparable to the synthetic insecticide, λ cyhalothrin.

Considering the potential of botanicals and biopesticides in managing various pests, the present study evaluated the oil cakes and bio-pesticides against rice caseworm caterpillars under net house conditions.

Materials and Methods

The study was conducted in the net house of the Regional Agricultural Research Station (RARS), Pattambi, Kerala Agricultural University during September, 2023 with the weather conditions of maximum temperature: (32.1°C ± 1.40°C), minimum temperature: (23.1°C ± 0.69°C), and relative humidity: (84.33 ± 2.11%). The early instar larvae of *Parapoynx stagnalis* were collected from the rice fields of RARS Pattambi and mass multiplied under the net house.

Mass multiplication of rice caseworm

Mass multiplication of the caseworm was carried out under net house conditions in the rice seedlings (variety: Jyothi) grown in plastic trays kept in rearing cages. Larvae of *Parapoynx stagnalis* collected from the rice fields of RARS Pattambi were released on the surface of water in the plastic trays with three weeks old rice seedlings and allowed to pupate. The pupae were collected and placed in plastic cups at a rate of 10 pupae per cup in adult rearing cages. The newly emerged moths were collected using a glass tube and a pair (male and female) were released on potted rice plants maintained in a net house under a cage and were allowed to mate. The female moths were allowed to lay eggs on rice plants. The larvae emerged from the eggs were allowed to development into fourth instar larvae.

Evaluation of botanical cakes and biopesticides against rice caseworm

The experiment was laid out in a Completely Randomised Design (CRD) with nine treatments including untreated control and three replications. The treatments were selected based on the published literature on the efficacy of different oil cakes and bio-agents against leaf-feeding insects in rice. Each treatment had three replications. The botanicals evaluated includes neem cake (2 and 3 %), mahua cake (2 and 3 %) and castor cake (2 and 3 %). Among the bio-pesticides, granular formulations of *Bacillus thuringiensis* (1 g L^{-1}) and talc formulation of *Beauveria bassiana* (20 g L^{-1}). The oil cakes were weighed using an electronic weighing balance and quantified based on the requirement as per the volume of water in the pot. The test insects of ten numbers per pot of third/ fourth larval instars were released on the potted rice plants (20 cm diameter) (Jyothi) with three seedlings of 21 days old with a water level of 3-5 cm was maintained in the experimental pots. The weighed oil cakes were tied in a muslin cloth and immersed into the water filled in pots, while the microbial agents were given as a spray treatment along with jaggery to enhance feeding (0.5 g L^{-1}), and sticker solution (1 ml L^{-1}) using one litre plastic capacity sprayer. The mortality of the larvae was recorded at intervals of 1, 3, 5, and 7 days after treatment along with an assessment of foliar damage. The per cent mortality of larvae as well as the per cent leaf damage were assessed. Then data on mortality and leaf damage were then subjected to arcsine transformation after corrected mortality. The results obtained were statistically analyzed using the software GRAPES version 1.1.0. The mean values were compared using Duncan's Multiple Range Test (DMRT) to determine significant variation at $P<0.05$.

Results and Discussion

The findings derived from the current study of eco-friendly insecticides against rice caseworm larvae are delineated in **Tables 1 and 2**. Notably, a substantial variation was detected among the treatments on mortality rate and feeding. The efficacy of all administered treatments exhibited a notable enhancement from one day to seven days. The treatment with mahua cake at a concentration of 3 % was found to be most effective, followed by *B. thuringiensis* and mahua cake at 2%, with respect to feeding and mortality. On the 1st day after treatment with mahua cake (3%), 46.66 per cent mortality of the larvae was observed, whereas the leaf damage was 13.16 % (**Figures 1 and 2**). By 3rd day, the treatment recorded 100 per cent mortality of larva with leaf damage only 7.73 per cent. On 5th day of treatment, mahua cake (2%) and *B. thuringiensis* recorded 100 per cent mortality of larva with 14.27 and 15. 23 per cent leaf damage, respectively. Neem cake @ 2 and 3% was found to be effective with 79.26 and 76.66 per cent mortality respectively on the 5th day of treatment. During the 7th day of treatment neem cake at both the concentrations could cause significant mortality of larva (90 per cent). Castor cake was poor in efficacy with 69.26 and 86.30 per cent mortality of larva with the larval leaf damage of 23.37 and 23.83 % at the concentration of 3% at 5th and 7th day of treatment. The fungus, *B. bassiana* did not cause any significant effect on both the mortality of larvae and reduction in feeding damage, which was on par with untreated control.

Table 1: Efficacy of botanicals and bio-pesticides on mortality of *Parapoynx stagnalis*

Microbial agent/oil cake	concentration	Mortality of larvae (%)*			
		1 DAT	3 DAT	5 DAT	7 DAT
T1-Neem cake	2g / 100ml	10.00 (15.18)^{bc}	51.85 (46.06)^{cd}	76.66 (66.15)^{b}	90 (75.00)^{ab}
T2-Neem cake	3g / 100ml	23.33 (28.78)^{ab}	72.59 (58.69)^{bcd}	79.26 (63.41)^{b}	90 (75.00)^{ab}
T3-Castor cake	2g / 100ml	10.00 (15.18)^{bc}	57.78 (49.82)^{bcd}	61.11 (52.53)^{b}	75.19 (64.99)^{b}
T4-Castor cake	3g / 100ml	10.00 (15.18)^{bc}	45.18 (42.22)^{d}	69.26 (56.77)^{b}	86.30 (68.51)^{b}
T5-Mahua cake	2g / 100ml	26.66 (30.78)^{ab}	79.26 (62.91)^{bc}	100 (90.00)^{a}	100 (90.00)^{a}
T6-Mahua cake	3g / 100ml	46.66 (43.07)^{a}	100 (90.00)^{a}	100 (90.00)^{a}	100 (90.00)^{a}
T7-*Beauveria bassiana*	20g / litre	0 (0.551)^{c}	10.37 (15.52)^{e}	10.37 (15.35)^{c}	37.78 (37.82)^{c}
T8-*Bacillus thuringiensis*	1g / litre	13.33 (17.89)^{b}	78.52 (67.21)^{b}	100 (90.00)^{a}	100 (90.00)^{a}
T9-control	-	0 (0.55)^{c}	0 (0.55)^{e}	0 (0.55)^{c}	0 (0.55)^{d}
CD value (p=0.05)		17.188	17.527	19.685	17.319
CV		19.67	18.42	16.81	15.35

Figures in parenthesis are arcsine transformed values

*Corrected mortality, DAT – Days after treatment, CV – Coefficient of variation, Means followed by the same letter are not significantly different

Table 2: Impact of botanicals and bio-pesticides on the feeding of *Parapoynx stagnalis*

Microbial agent/oil cake	concentration	Percent leaf damaged			
		1 DAT	3 DAT	5 DAT	7 DAT
T1-Neem cake	2g / 100ml	12.47 (20.60)[d]	22.41 (28.23)[bc]	25.28 (30.17)[bc]	27.45 (31.59)[cd]
T2-Neem cake	3g / 100ml	10.49 (18.87)[d]	13.70 (21.71)[d]	14.37 (22.26)[d]	14.73 (22.55)[e]
T3-Castor cake	2g / 100ml	23.31 (28.86)[b]	26.77 (31.14)[b]	29.80 (33.05)[b]	32.20 (34.54)[c]
T4-Castor cake	3g / 100ml	17.48 (24.69)[c]	21.83 (27.85)[c]	23.37 (28.90)[c]	23.83 (29.22)[d]
T5-Mahua cake	2g / 100ml	11.80 (20.04)[d]	13.67 (21.65)[d]	14.27 (22.17)[d]	14.27 (22.17)[e]
T6-Mahua cake	3g / 100ml	5.19 (13.16)[e]	7.73 (15.99)[e]	7.73 (15.99)[e]	7.73 (15.99)[f]
T7-*Beauveria bassiana*	20g / litre	28.03 (31.96)[a]	42.19 (40.51)[a]	49.12 (44.49)[a]	54.28 (47.46)[b]
T8-*Bacillus thuringiensis*	1g / litre	10.01 (18.44)[d]	13.21 (21.23)[d]	15.23 (22.93)[d]	15.23 (22.93)[e]
T9-control	-	31.61 (34.21)[a]	42.18 (40.50)[a]	52.60 (46.49)[a]	68.69 (55.99)[a]
CD value (p=0.05)		2.546	3.127	3.307	3.553
CV		6.32	6.59	6.54	6.6

Figures in parenthesis are arcsine transformed values

DAT – Days after treatment, CV – Coefficient of variation, Means followed by the same letter are not significantly different

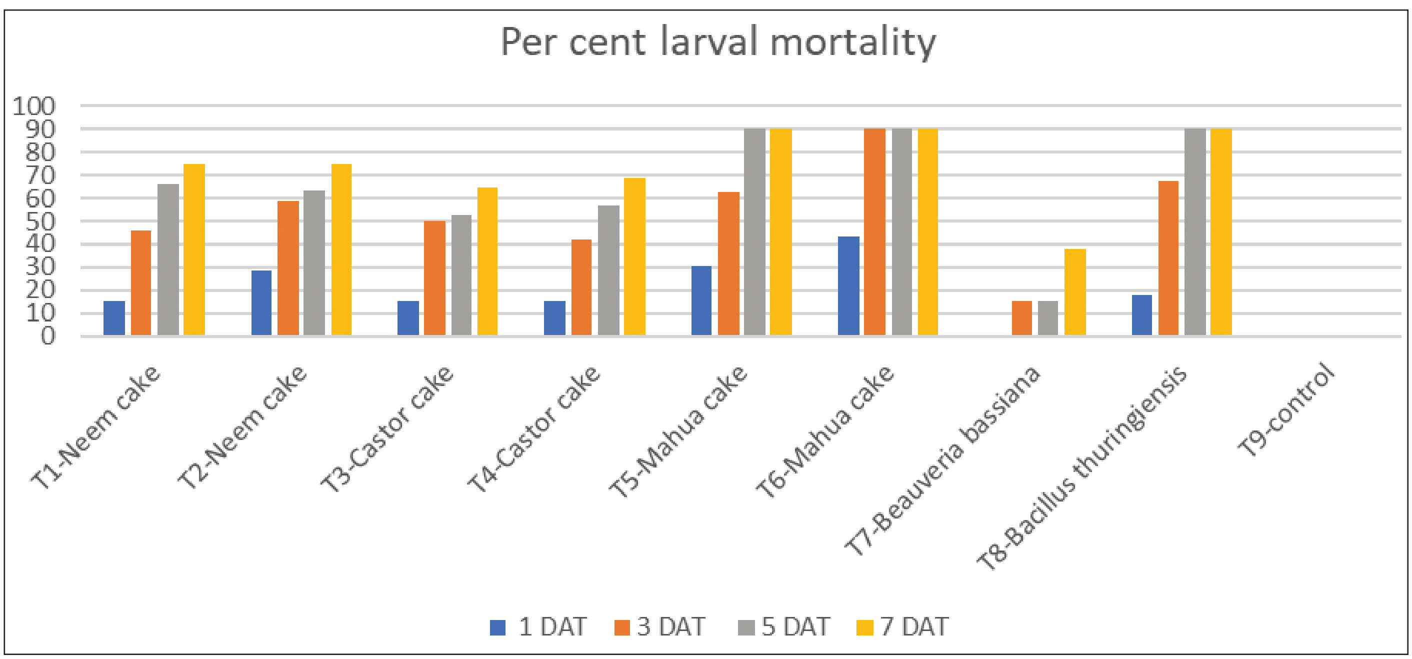


Figure 1: Efficacy of different treatments on the mortality of caseworm larvae

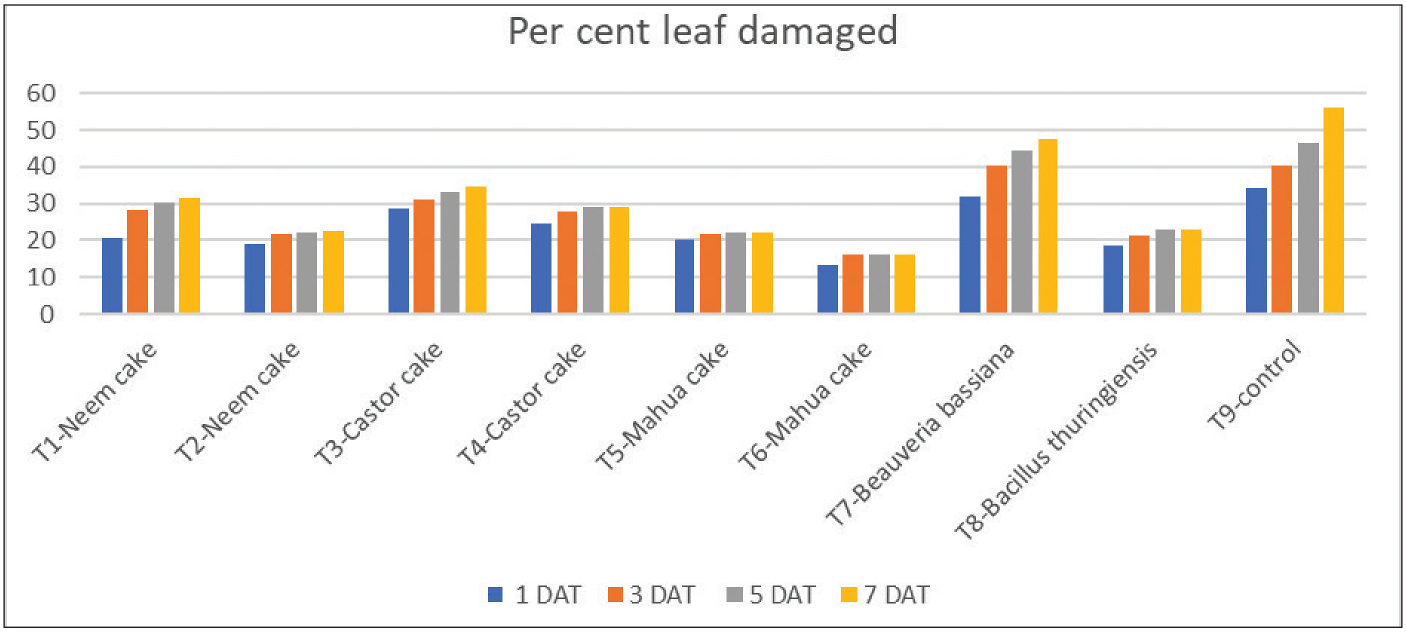


Figure 2: Effect of different treatments on leaf damage by caseworm larvae

Among the botanical cakes, mahua cake showed significant larval mortality and reduced leaf damage followed by neem cake, and castor cake, while in case of biopesticides, only *B.t* was found to be effective against larval mortality and leaf damage. In rice fields, application of mahua oil was reported to have reduced the damage caused by rice leaf folder, *Cnaphalocrocis medinalis* (Rajasekaran *et al*., 1987) and green leaf hopper, *Nephotettix virescens* (Mariappan *et al*., 1988). The saponin content present in *Madhuca indica* (mahua) was found responsible for the antifeedant principle, larval and adult growth inhibition of *Helicoverpa armigera* (Loganathan *et al*., 2006). Mordue and Blackwell (1993) documented the effects of azadirachtin on growth, molting and reproduction along with antifeedant action, even though antifeedant action varies with species of Lepidoptera. Similar results were obtained in this study, where reduced feeding damage by caseworm was found in neem cake applied treatment. Manendra (2016) recorded the least damage (0.80 %) on potato leaves when treated with neem cake, followed by mahua cake (1.2 %) against cutworms. The active compound azadirachtin extracted from neem cake has insecticidal, antibacterial, and antifungal properties (Harikrishnan *et al*., 2003).

Sanahuja *et al*. (2011) highlighted the potential value of *B. thuringiensis* toxin that kills the lepidopteran pest. Commercial formulations of *B. thuringiensis* and *Beauveria bassiana* have been shown to effectively manage *Helicoverpa armigera* populations (Kumar and Kaur, 2017). In the present study, *B. thuringiensis* produced comparable results, significantly increasing larval mortality and reducing feeding activity. In contrast, *B. bassiana* proved ineffective, possibly due to the protective casing of the larvae, which may have reduced fungal contact, or to the semiaquatic habit of the caseworm larvae, which could have washed away fungal spores. The primary mode of action of *B. thuringiensis* involves Cry proteins, which act on the alkaline midgut of lepidopteran insects to form pores (Aronson and Shai, 2001). According to Gould *et al*. (1991), feeding on *B. thuringiensis* - treated leaves by neonate larvae can lead to feeding cessation and gut paralysis. In the present study, although castor cake treatment caused noticeable feeding damage to rice plants, it also resulted in significant caseworm mortality from five days after application. Sousa *et al*., (2017) attributed the toxic effects of castor cake to the presence of ricinine. The insecticidal and insectistatic activities of castor seed extracts have been demonstrated against *Spodoptera litura* caterpillars

(Ramos-López *et al*., 2010), with castor oil and ricinine identified as the principal active compounds. Similarly, seed kernel extracts and oil emulsions of castor have been shown to cause significant mortality of *Plutella xylostella* under laboratory conditions (Kodjo *et al*., 2011). The results from the study showed a significant reduction in caseworm population and leaf damage to rice when treated with de-oiled cakes and bio-pesticides. This study also demonstrates the potential of de-oiled cakes and bio-pesticides as effective and environment-friendly alternatives for managing caseworm infestation in rice. These eco-friendly alternatives can lead to reduced reliance on chemical pesticides, and contribute to a healthier environment.

Acknowledgments

The authors thank the Department of Agricultural Entomology, College of Agriculture Vellanikkara and Regional Agricultural Research Station, Pattambi, Kerala Agricultural University, Thrissur, Kerala, India for providing facilities.

Financial Support

The authors thank the financial support provided by Kerala Agricultural University for carrying out the study.

Author Contribution Statement

Conceptualization, K.K.; methodology, K.K.; formal analysis, M.A.V., K.K., and H.B, investigation, M.A.V.; data curation, M.A.V., K.K. and H.B.; writing – original draft preparation, M.A.V. and K.K.; writing-review and editing, H.B. M.C. and S.V.M. All the authors have read and agreed to the published version of the manuscript.

Conflict of Interest

No conflict of interest

References

Aghaee MA and Godfrey L D. 2015. The efficacy of *Bacillus thuringiensis* spp. *galleriae* against Rice Water Weevil (Coleoptera: Curculionidae) for integrated pest management in California rice. *Journal of Economic Entomology,* 108(1): 45–52.

Aronson AI and Shai Y. 2001. Why *Bacillus thuringiensis* insecticidal toxins are so effective: unique features of their mode of action. *FEMS Microbiology Letters,* 195(1): 1–8.

David PMM. 1986. Effect of slow-release nitrogen fertilizer and foliar application of neem products. *Madras Agricultural Journal,* 73(5): 274-277.

Dhaliwal GS, Jindal V and Dhawan AK. 2010. Insect pest problems and crop losses: Changing trends. *Indian Journal of Ecology,* 37(1): 1–7.

Gould F, Anderson A, Landism D and Van Mellert H. 1991. Feeding behaviour and growth of *Heliothis virescens* larvae on diets containing *Bacillus thuringiensis* formulations or endotoxins. *Entomologia Experimentalis et Applicata,* 58(199): 199-210.

Harikrishnan R, Rani MN and Balasundaram C. 2003. Hematological and biochemical parameters in common carp, *Cyprinus carpio*, following treatment for *Aeromonas hydrophila* infection, *Aquaculture,* 221(1-4): 41–50.

Heinrichs EA and Viajante VD. 1987. Yield loss in rice caused by the caseworm *Nymphula depunctalis* (Guenee) (Lepidoptera: Pyralidae). *Journal of Plant Protection in the Tropics*, 4(1): 15-26.

Katti G. 2013. Biopesticides for Insect Pest Management in Rice – Present Status and Future Scope *Journal of Rice Research,* 6(1): 1-14

Kodjo TA, Gbénonchi M, Sadate A, Komi A, Yaovi G, Dieudonné M and Komla S. 2011. Bio-insecticidal effects of plant extracts and oil emulsions of *Ricinus communis* L. (Malpighiales: Euphorbiaceae) on the diamondback, *Plutella xylostella* L. (Lepidoptera: Plutellidae) under laboratory and semi-field conditions. *Journal of Applied Bioscience*, 43: 2899-2914.

Kumar S and Kaur J. 2017. Efficacy of *Beauveria bassiana* and *Bacillus thuringiensis* as ecosafe alternatives to chemical insecticides against sunflower capitulum borer, *Helicoverpa armigera* (Hübner). *Journal of Entomology and Zoology Studies*, 5(2):185-188.

Loganathan J, Dhingra S, Walia S and Ganesh KS. 2006. Effect of *Madhuca indica* seed extracts on survival, feeding and development of *Helicoverpa armigera* (Hubner). *Journal of Entomological Research,* 30(3): 225-229.

Manendra K. 2016. Efficacy of different oil cakes against potato cutworm, *Agrotis ipsilon* (Hufn) in Bihar (India). *World Journal of Pharmaceutical Research,* 5(6): 1258-1262.

Mariappan V, Jayaraj S and Saxena RC. 1988. Effect of nonedible seed oils on survival of *Nephotettix virescens* (Homoptera: Cicadellidae) and on transmission of rice tungro virus. *Journal of Economic Entomology,* 81(5): 1369-1372.

Mordue AJ and Blackwell A. 1993. Azadirachtin: an update. *Journal of Insect Physiology,* 39(2): 903-924.

Nilamudeen M, Karthikeyan K, Raji P and Arshad MV. 2024. Evaluation of Botanicals against Rice Case Worm *Parapoynx stagnalis* Zeller. (Lepidoptera: Pyralidae). *Journal of Agriculture and Ecology Research International*, 25(3): 1-4.

Nilamudeen M and Sudharma K. 2020. Entomopathogenic fungi for managing the Rice leaf roller, *Cnaphalocrocis medinalis* Guen. *Journal of Entomology and Zoology Studies,* 8(4): 2331-2336

Pandit, Vijaykumar L, Thippaiah M, Shivanna B and Reddy CL, Krishanamurthy R. 2023. Resistance response of local landraces and advanced rice genotypes to paddy caseworm, *Nymphula depunctalis* (Guenee) under field condition. *Mysore Journal of Agricultural Sciences,* 57(1): 220-228.

Pedigo LP. 1999. Entomology and pest management. Prentice Hall, 2: 1-691.

Prasad R. 2020. Management of major insect pests of rice through organic manures with special emphasis on use of neem and karanj cakes. *Journal of Eco-friendly Agriculture,* 15(1): 63-66.

Rajasekaran B, Rajendran R, Velusamy R and Badu PCS. 1987. Effect of vegetable oil on rice leaf folder feeding behavior. *International Rice Research Newsletter,* 12(2): 34.

Ramos-López MA, Pérez S, Rodríguez-Hernández GC, Guevara-Fefer P and Zavala-Sanchez MA. 2010. Activity of *Ricinus communis* (Euphorbiaceae) against *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *African Journal of Biotechnology*, 9(9): 1359-1361.

Sanahuja G, Banakar R, Twyman R, Capell T and Christou P. 2011. *Bacillus thuringiensis*: a century of research, development and commercial applications. *Plant Biotechnology Journal,* 9(3): 283–300.

Sousa NL, Cabral G B, Vieira PM, Baldoni AB and Aragão FJ. 2017. Bio-detoxification of ricin in castor bean (*Ricinus communis* L.) seeds. *Scientific Reports*, 7: 15385.

Thacker JRM. 2002. An Introduction to Arthropod Pest Control. Cambridge University Press. pp. 1-27.

Trujillo R. 1991. Case worm: first report in Latin America. *Arroz en las America*, 12(2): 6-7.

RESEARCH ARTICLE https://doi.org/10.58297/DDUQ8496

Screening of Rice Genotypes for Resistance against Leaffolder

Karthikeyan K[1]*, Faseela KV[1], Biji KR[1] and Padmavathi Ch[2]

[1]Regional Agricultural Research Station, Pattambi-679306

[2]ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad-500030

*Corresponding author E-mail: karthikeyan.k@kau.in

Received: 25th October, 2025, Accepted: 23rd December, 2025

Abstract

Initial field screening in station trials (2021-2024) followed by evaluation under All India Coordinated Research Programme on Rice (AICRPR) (2022 to 2023) revealed ten Pattambi entries *viz*., RP5564 PTB 2-4-1-5, 0614-13-15-7-1-2, RP5564 PTB 2-4-2-1-2, RP5564 PTB 1-4-2, 0614-13-15-7-1-1, RP5564 PTB 1-4-1. RP5564 PTB 1-3. 0614-1-6-21-1-2, 0614-1-6-21-1-4 and RP5564 PTB 2-4-2-1-1 were found resistant to rice leaf folder in station trials and multilocational trials were promising in fifteen locations across India during the test period. Six entries *viz*., RP 5564 PTB 2-4-2-1-2, RP 5564 PTB 1-4-2, RP 5564 PTB 2-4-2-1-1, 0614-1-6-21-1-2, RP 5564 PTB-1-3 and RP 0614-13-15-7-1-2 were found promising against both stem borer and leaffolder.

Keywords: Stem borer, leaffolder, station trials, screening trial, AICRPR

Introduction

Rice (*Oryza sativa* L.) is a monocotyledonous crop, belongs to the family Poaceae and genus Oryza with 22 wild species. Being the staple crop for half of the world population, it is one of the most important cereal crops (Pandit *et al*., 2020). It comprises 80% carbohydrates, 8% protein, 3% fat, and 3% fiber (Chaudhari *et al*., 2018). The rice plant is subjected to attack by more than 100 species of insects, of which 20 species are of economic importance, resulting in yield losses of 20-30% every year (Chatterjee *et al*., 2017). Yellow stem borer, *Scirpophaga incertulas* (Walker) and Leaffolder (*Cnaphalocrocis medinalis* Guenée) of rice are considered as prime devastators responsible for major economic loss (Chatterjee and Mondal, 2014; Chatterjee *et al*., 2017). Host plant resistance is a relationship between the plant-feeding insects and their host plants (Painter, 1951). Insect-resistant plant varieties or genotypes not only decrease insect pest populations but also complement other eco-friendly pest management strategies (Rani *et al*., 2020). Plant traits that facilitate direct defenses have been demonstrated to reduce insect growth rates by diminishing the digestibility and nutritional quality of plant tissues (Belete, 2018). Cultures JS1, 3, 5, and 7 showed tolerance to both the Stem borer and Leaffolder, while Cult M9 exhibited field tolerance to multiple pests, including the Stem borer, a mixed population of planthoppers, and the Leaffolder (Karthikeyan *et al.*, 2024). This study was undertaken to evaluate more promising Pattambi cultures against two major pests like rice stem borer and leaffolder.

Materials and Methods

Sixteen Pattambi cultures were screened with TN 1 as susceptible check during the six seasons, *viz., Kharif* 2021, 2022 and 2023 in the first crop season and *Rabi* 2021-22, *Rabi* 2022-2023 and *Rabi* 2023-2024 in the second crop season against rice stem borer and rice leaffolder in fields of the Regional Agricultural Research Station, Kerala. The entries were planted with one row of 20/21 hills at a spacing of 20 x 15 cm and observations were taken on per cent damaged leaves for the leaffolder at 45 and 60 DAT. The ten promising Pattambi entries were evaluated for two seasons during the period from 2022 to 2023 at 18 locations across India in the Leaffolder screening trial under All India Coordinated Research Project on Rice (Entomology). At all the locations, data was considered when the field incidence was very high and at ICAR-IIRR, the stem borer damage was supplemented with the release of larvae. The observation were made on tiller damage for stem borer by counting ten randomly selected hills per entry for dead heart at vegetative stage and white ears at reproductive stage similarly for leaffolder observation made on ten randomly selected hills per entry on counting damaged leaves. The data were analyzed statistically by Randomized Block design (RBD) and means were compared at CD at 0.05% level.

Results and Discussion

Station trials at Pattambi

Leaffolder

The pooled analysis of the first crop seasons (*Kharif* 2020, 2021 and 2022) under station trials among sixteen entries tested, six /ten Pattambi entries *viz*., RP5564 PTB 2-4-1-5, 0614-13-15-7-1-2, RP5564 PTB 2-4-2-1-2, RP5564 PTB 1-4-2, 0614-13-15-7-1-1, RP5564 PTB 1-4-1. Four entries, namely, RP5564 PTB 1-3, 0614-1-6-21-1-2, 0614-1-6-21-1-4 and RP 5564 PTB 2-4-2-1-1 showed low leaf folder damage ranging from 1.84 (0614-1-6-21-1-2) to 4.01 per cent (RP 5564 PTB 2-4-2-1-1) and 3.48 (0614-13-15-7-1-2) to 5.00 per cent (RP 5564 PTB 2-4-2-1-1) while other entries *viz*.,RP 5490 PTB 1-1-2, 0615 PTB 01-23-21, 0627 PTB 2-14-1, 0614 PTB 7-8-24, 0615 PTB 01-23-21, 0615-11-20-8-2 and RP 5517 PTB 1-1-1-1-1 showed higher leaf damage ranging from 4.81 (0615 PTB 01-23-21) to 7.92 per cent (RP 5517 PTB 1-1-1-1-1) and 3.68 (RP 5490 PTB 1-1-2) to 7.59 % (RP 5517 PTB 1-1-1-1-1)damaged leaves at 45 and 60 DAT, respectively. Thecheck entry TN 1 showed leaf damage of14.80 and 17.37 per cent at 45 and 60 DAT, respectively **(Table 1).**

Table 1: Incidence of leaf folder in different entries at Station trial in Pattambi (Pooled Analysis of *Kharif* 2020, 2021 and 2022)

Designation	Parentage	Leaf folder damaged leaves (%)	
		%DL	%DL
		45DAT	60DAT
RP5564 PTB 2-4-1-5	RP Bio 226 X IRGC 71598 X MTU1010	3.86 (0.20)	4.62 (0.21)
0614-13-15-7-1-2	Pranava X Vellari	2.00 (0.14)[a]	3.48 (0.19)
RP5564 PTB 2-4-2-1-2	RP Bio 226 X IRGC 71598 X MTU1010	3.00 (0.16)[a]	3.50 (0.19)
RP5564 PTB 1-4-2	RP Bio 226 X IRGC 71598 X MTU1010	2.23 (0.15)[a]	3.78 (0.19)
0614-13-15-7-1-1	Pranava X Vellari	3.68 (0.19)	4.51 (0.21)
RP5564 PTB 1-4-1	RP Bio 226 X IRGC 71598 X MTU1010	3.09 (0.18)	3.61 (0.19)
RP5564 PTB 1-3	RP Bio 226 X IRGC 71598 X MTU1010	3.51 (0.19)	5.31 (0.23)
0614-1-6-21-1-2	Pranava X Vellari	1.84 (0.14)	3.95 (0.20)
0614-1-6-21-1-4	Pranava X Vellari	2.70 (0.17)	3.70 (0.19)
RP 5564 PTB 2-4-2-1-1	RP Bio 226 X IRGC 71598 X MTU1010	4.01 (0.20)	5.00 (0.23)
RP5490 PTB 1-1-2	Sampada/IRGC 11010 x Sampada	5.95 (0.25)	3.68 (0.19)
0627PTB-2-14-1	Swetha x Kuruka	5.84 (0.24)	8.40 (0.19)
0614PTB-7-8-24	Pranava x Vellari	7.10 (0.27)	6.30 (0.26)
0615-PTB01-23-21	Pranava x Chettadi	4.81 (0.22)	6.94 (0.27)
0615-11-20-8-2	Pranava x Chettadi	5.62 (0.24)	6.04 (0.25)
RP 5517 PTB 1-1-1-1-1	Sampada/IRGC30938/Triguna	7.92 (0.29)	7.59 (0.28)
TN1		14.80 (0.39)	17.37 (0.43)
	C. D (0.05)	0.05	0.05

DAT- Days after transplanting, DL- Damaged leaves, Values in brackets are arcsine transformed values

During the second crop season of *Rabi* 2020-21, 2021-22 and 2022-23, similar results were obtained with pooled analysis of all three crop seasons with ten entries,*viz*., RP5564 PTB 2-4-1-5, 0614-13-15-7-1-2, RP5564 PTB 2-4-2-1-2, RP5564 PTB 1-4-2, 0614-13-15-7-1-1, RP5564 PTB 1-4-1. RP5564 PTB 1-3, 0614-1-6-21-1-2, 0614-1-6-21-1-4 andRP 5564 PTB 2-4-2-1-1 showing low incidence of leaffolder ranging from 2.80 (0614-13-15-7-1-2) to 4.53 per cent (RP5564 PTB 1-4-1 and RP5564 PTB 1-3) at 45 DAT and 2.38(0614-1-6-21-1-2) to 4.20 per cent (RP5564 PTB 2-4-1-5) damaged leaves at 60 DAT while other tested entries showed higher leaf damage ranging from 4.81/4.36 (0614- PTB 7-8-24/0627 PTB 2-14-1) to 7.84 per cent (0615-11-20-8-2) at 45 DAT and 7.80 /3.35(0627 PTB 2-14-1) to 9.07 per cent (0614 PTB 7-8-24) at 60 DAT while check entry (TN 1) suffered highest per cent leaf damage of 20.53 and 18.03 per cent at 45 and 60 DAT,respectively **(Table 2).**

Table 2: Incidence of leaf folder in different entries at Station trial in Pattambi (Pooled Analysis of *Rabi* 2020-21, 2021-22 and *Rabi* 2022-23)

Designation	Parentage	Leaffolder damage	
		%DL	%DL
		45DAT	60DAT
RP5564 PTB 2-4-1-5	RP Bio 226 X IRGC 71598 X MTU1010	4.18 (0.20)	4.20 (0.21)
0614-13-15-7-1-2	Pranava X Vellari	2.80 (0.17)	3.41 (0.18)
RP5564 PTB 2-4-2-1-2	RP Bio 226 X IRGC 71598 X MTU1010	4.19 (0.21)	3.71 (0.19)
RP5564 PTB 1-4-2	RP Bio 226 X IRGC 71598 X MTU1010	4.11 (0.20)	3.25 (0.18)
0614-13-15-7-1-1	Pranava X Vellari	3.80 (0.10)	3.79 (0.20)
RP5564 PTB 1-4-1	RP Bio 226 X IRGC 71598 X MTU1010	4.53 (0.21)	4.13 (0.20)
RP5564 PTB 1-3	RP Bio 226 X IRGC 71598 X MTU1010	4.53 (0.21)	2.47 (0.16)
0614-1-6-21-1-2	Pranava X Vellari	3.41 (0.18)	2.38 (0.15)
0614-1-6-21-1-4	Pranava X Vellari	4.25 (0.21)	3.50 (0.19)
RP 5564 PTB 2-4-2-1-1	RP Bio 226 X IRGC 71598 X MTU1010	4.35 (0.21)	4.17 (0.21)
RP5490 PTB 1-1-2	Sampada/IRGC 11010 x Sampada	4.36 (0.20)	3.35 (0.19)
0627-PTB-2-14-1	Swetha x Kuruka	7.83 (0.28)	7.80 (0.28)
0614-PTB-7-8-24	Pranava x Vellari	4.81 (0.21)	9.07 (0.30)
0615-PTB-01-23-21	Pranava x Chettadi	5.23 (0.23)	8.37 (0.29)
0615-11-20-8-2	Pranava x Chettadi	7.84 (0.28)	8.10 (0.29)
RP 5517 PTB 1-1-1-1-1	Sampada/IRGC30938/Triguna	6.75 (0.26)	7.67 (0.28)
TN1		20.53 (0.47)	18.03 (0.43)
	CD (0.05)	0.05	0.05

DAT- Days after transplanting, DL- Damaged leaves, Values in brackets are arcsine transformed values

AICRPR Trial

Field evaluation of 25 entries at 14 locations, replicated thrice in Leaf Folder Screening Trial (LFST) during *Kharif* 2022 under AICRPR revealed that 22 entries were promising in 2-6 tests out of 14 valid field tests. In the first year of testing, RP5564 PTB 1-4-2 was found promising in 6 of the 14 valid tests while three/four entries, *viz.,* BPT 3182, 0614-13-15-7-1-2, RP5564 PTB 2-4-1-5, and 0614-13-15-7-1-1 were promising in 5 out of 14 valid field tests. BPT 3068, RP5564 PTB 1-4-1 and BPT 3085 was/were found promising in 4 valid field tests out of 14 while four/seven entries, *viz*., RP5564 PTB 1-3, 0614-1-6-21-1-2, RP5564 PTB 2-4-2-1-1 and 0614-1-6-21-1-4 were promising in 3 valid field tests and one entry, RP5564 PTB 2-4-2-1-2 found promising the rest of the entries in 2 out of 14 valid field tests **(Table 3).**

Table3: Reaction of Pattambientries against leaf folderunder Leaf folder screening trial during *kharif*, 2022 at different locations in India (AICRPR Progress Report 2022)

Designation	Parentage	Leaf folder damaged leaves (%)														
		ADT	BPT	CHT	CHN	CTC	KKL	KUL	LDN	MLN	NVS	NWG	PTB	RNR	NLR	NPT
		80DAT	80DAT	47DAT	84DAT	60DAT	80DAT	60DAT	60DAT	98DAT	60DAT	60DAT	60DAT	87DAT	50DAT	14DAT
RP5564 PTB1-4-2	**RP Bio226 X IRGC 71598 X MTU1010**	**11.2**	**12.8**	**21.1**	**12.9**	**24.2**	**19.8**	**28.2**	**37.7**	**18.3**	**5.6**	**18.6**	**18.2**	**10.9**	**22.6**	**6**
BPT 3182	BPT 2231/MTU 1075	25.8	14.1	21.7	9.2	17.2	29.8	27	44.2	18.1	0.0	17.9	23.9	16.6	9.6	5
0614-13-15-7-1-2	**Pranava X Vellari**	**19.6**	**5.2**	**20.2**	**11.8**	**11.0**	**17.9**	**31.7**	**34.2**	**17.5**	**5.7**	**29.5**	**20.2**	**17.6**	**12.8**	**5**
RP5564 PTB 2-4-1-5	**RP Bio 226 X IRGC 71598 X MTU1010**	**15.8**	**5.7**	**21.7**	**13.8**	**9.7**	**25.3**	**26.1**	**32.8**	**16.6**	**0.0**	**34.3**	**23.5**	**8.0**	**15.9**	**5**
0614-13-15-7-1-1	**Pranava X Vellari**	**10.9**	**6.9**	**21.5**	**12.8**	**14.5**	**28.6**	**22.4**	**36.7**	**17.1**	**6.6**	**29.2**	**29.1**	**12.8**	**13.4**	**5**
BPT 3068	MLR 34449 / Ramappa	21.7	10.8	19.8	10.8	11.3	29.5	18.8	37.5	20.1	6.4	28.2	31.6	22.9	8.5	4
RP5564 PTB 1-4-1	**RP Bio 226 X IRGC 71598 X MTU1010**	**6.8**	**8.9**	**21.7**	**12.3**	**14.4**	**26.6**	**26.9**	**35.5**	**20.7**	**15.1**	**28.2**	**21.3**	**15.2**	**9.9**	**4**
BPT 3085	BPT5204/MTU 1075	29.2	17.0	22.7	15.2	8.7	20.9	19.7	32.9	16.5	26.3	17.7	25.5	31.7	26.3	4
RP5564 PTB 1-3	**RP Bio 226 X IRGC 71598 X MTU1010**	**10.8**	**10.6**	**21.6**	**11.8**	**22.2**	**31.4**	**25.2**	**31.5**	**17.4**	**9.6**	**23.2**	**24.3**	**24.2**	**18.2**	**3**
BPT 3077	BPT5204/MTU 1075	27.3	15.7	19.6	14.5	17.3	30.1	26.3	37.7	17.2	6.0	19.0	20.9	23.2	12.6	3
0614-1-6-21-1-2	**Pranava X Vellari**	**33.6**	**7.5**	**20.3**	**13.8**	**21.4**	**26.7**	**28.0**	**32.7**	**15.5**	**5.8**	**28.2**	**23.0**	**15.1**	**13.9**	**3**
RP5564 PTB 2-4-2-1-1	**RP Bio 226 X IRGC 71598 X MTU1010**	**20.1**	**4.4**	**21.9**	**15.1**	**7.2**	**20.3**	**27.2**	**35.6**	**21.8**	**5.3**	**20.2**	**21.4**	**11.1**	**30.3**	**3**
BPT 3130	BPT5204/MTU 1075	41.6	19.9	21.9	11.4	18.5	30.4	17.1	41.9	20.7	5.6	37.4	25.7	27.5	8.3	3
0614-1-6-21-1-4	**Pranava X Vellari**	**44.1**	**16.9**	**21.5**	**13.9**	**24.1**	**36.8**	**17.5**	**34.7**	**17.9**	**10.3**	**30.4**	**23.2**	**22.7**	**10.3**	**3**
NPK 46	Swarna / O nivara BIL	32.2	28.4	19.1	15.7	21.7	32.1	29.0	36.4	17.5	0.1	37.8	25.4	24.4	7.6	3
BPT 3135	BPT 5204 / MTU 1001	27.6	18.0	20.6	14.6	27.5	26.8	24.3	40.7	19.8	6.7	30.6	24.5	26.1	17.6	2
BPT 3148	RP Bio 226/IRGC 23385/Nidhi/ MTU 1081	26.8	20.6	22.9	10.9	19.9	18.3	24.4	33.5	17.6	19.3	30.1	20.8	26.7	10.9	2
NWGR 16032	Gurjari /NWGR 3015	45.9	39.7	22.5	11.4	24.7	20.1	30.7	35.9	18.2	4.1	24.9	25.1	20.6	13.8	2
RP5564 PTB 2-4-2-1-2	**RP Bio 226 X IRGC 71598 X MTU1010**	**21.1**	**4.7**	**20.9**	**11.8**	**20.1**	**28.4**	**32.1**	**35.6**	**14.0**	**18.1**	**25.9**	**24.8**	**15.3**	**12.7**	**2**
NPK 24	Swarna / O nivara BIL	8.3	18.2	21.7	10.2	17.7	29.9	18.9	38.0	20.0	15.3	40.0	20.8	14.0	12.8	2
BPT 3113	BPT 2270 / NLR 145	33.3	11.3	19.9	11.6	26.2	28.9	26.2	39.6	19.9	14.6	34.4	26.2	22.1	14.5	2
BPT 3192	BPT5204/MTU 1075	32.9	12.0	22.0	15.6	30.6	25.9	24.3	34.8	17.9	13.8	25.5	26.1	25.8	11.1	2
BPT 3239	BPT5204/MTU 1075	26.8	11.8	19.4	12.5	37.6	35.6	23.5	36.9	25.6	7.3	29.7	21.7	21.9	11.5	1
W 1263	Resistant Check	7.9	9.5	10.3	10.3	11.8	18.2	17.8	29.2	15.0	0.1	14.7	21.7	13.5	9.3	10
TN1	Susceptible Check	40.3	33.5	20.5	15.5	22.2	27.6	27.8	46.8	17.1	31.3	42.6	22.8	30.8	15.7	
Minimum Damage		6.8	4.4	10.3	9.2	7.2	17.9	17.1	29.2	14.0	0.0	14.7	18.2	8.0	7.6	
Maximum Damage		45.9	39.7	22.9	15.7	37.6	36.8	32.1	44.2	25.6	26.3	40.0	31.6	31.7	30.3	
Average damage in Trial		24.3	13.8	20.7	12.7	19.1	26.6	24.7	36.1	18.4	8.7	27.3	23.7	19.6	13.9	
Promising Level		15	10	15	10	15	20	20	20	20	15	20	20	10	10	
Number Promising		6	8	1	1	8	4	6	0	18	19	5	1	1	6	

ADT-duthurai, BPT-Bapatla, CHT-Chatha, CHN-Chinsurah,CTC- Cuttack, KKL-Karaikal, KUL-Kaul, LDN-Ludhiana, MLN-Malan, NVS-Navsari, NWG Nawagam, PTB-Pattambi, RNR-Rajendranagar, NLR-Nellore, NPT: Number of promising test entries

In the second year of testing under AICRPR (*Kharif* 2023), the maximum damage in the test entries varied between 15.1 and 54.5% whereas the average damage in the trial ranged from 7.6 to 39.5%. Data analysis revealed that 23 entries as promising in 4-9 tests of 15 valid field tests. Nominations from Pattambi were promising at many locations whose parentage includes RP Bio226/IRGC 71598/MTU 1010. RP5564 PTB 2-4-2-1-1 was found promising in 9 out of 15 valid field tests. Three entries, *viz*., RP5564 PTB 1-4-1, RP5564 PTB 2-4-1-5 and 0614-1-6-21-1-2 were promising in 8 out of 15 valid field tests. Entries, 0614-13-15-7-1-1, 0614-13-15-7-1-2 and RP5564 PTB 1-4-2 were found promising in 7 tests out of 15 valid tests. RP5564 PTB 2-4-2-1-2 and 0614-1-6-21-1-4 were promising in 6 out of 15 valid field tests. Entry, RP5564 PTB 1-3 was/were promising in 5 out of 15 field tests. The resistant check, W 1263 was promising in 11 out of 15 valid field tests **(Table 4).**

Table 4: Reaction of different entries against leaf folder under Leaf folder screening trial at different locations (AICRPR Progress Report 2023)

Designation	Parentage	BPT	ADT	CHT	CHN	CTC	KJT	KUL	LDN	MLN	MSD	NLR	NVS	NWG	PTB	RNR	NPT
		60	60	48	70	80	80	38	80	97	90	30	80	60	75	95	(15)
W 1263	Resistant Check	13.4	15.5	18.2	4.7	14.3	11.7	19.9	17.4	19.1	8.3	12.2	0.0	18.8	20.2	2.3	11
RP5564 PTB 2-4-2-1-1	**RP Bio 226 X IRGC 71598 X MTU1010**	**11.5**	**1.9**	**16.2**	**8.3**	**13.9**	**11.6**	**20.6**	**34.4**	**24.3**	**8.3**	**22.3**	**4.4**	**19.7**	**30.8**	**6.5**	**9**
RP5564 PTB 1-4-1	**RP Bio 226 X IRGC 71598 X MTU1010**	**14.3**	**4.5**	**17.9**	**9.2**	**22.6**	**13.5**	**21.3**	**25.3**	**20.5**	**7.6**	**9.2**	**8.7**	**19.8**	**34.7**	**8.0**	**8**
RP5564 PTB 2-4-1-5	**RP Bio 226 X IRGC 71598 X MTU1010**	**8.4**	**2.7**	**16.1**	**10.5**	**23.7**	**14.6**	**19.8**	**24.7**	**17.0**	**9.4**	**8.5**	**11.0**	**19.7**	**25.5**	**9.8**	**8**
0614-1-6-21-1-2	**Pranava X Vellari**	**14.3**	**9.6**	**18.6**	**9.5**	**34.9**	**10.6**	**18.7**	**33.3**	**16.3**	**9.3**	**11.0**	**2.0**	**33.7**	**40.4**	**7.4**	**8**
BPT 3077	BPT5204/MTU 1075	9.6	8.1	21.4	9.3	25.8	12.1	19.9	37.0	18.9	8.4	17.2	5.7	30.6	45.5	7.3	7
BPT 3148	RP Bio 226/IRGC 23385/ Nidhi/ MTU 1081	13.2	6.7	20.3	7.0	16.1	10.5	24.3	35.7	17.8	9.4	9.8	20.8	30.8	36.7	9.5	7
0614-13-15-7-1-1	**Pranava X Vellari**	**10.5**	**6.1**	**18.1**	**8.2**	**18.0**	**10.5**	**20.8**	**19.7**	**17.5**	**17.7**	**11.0**	**22.6**	**32.6**	**32.4**	**4.8**	**7**
0614-13-15-7-1-2	**Pranava X Vellari**	**8.4**	**6.9**	**15.8**	**34.2**	**20.7**	**12.8**	**20.0**	**18.7**	**19.0**	**12.7**	**9.3**	**0.0**	**39.4**	**31.5**	**9.1**	**7**
RP5564 PTB 1-4-2	**RP Bio 226 X IRGC 71598 X MTU1010**	**10.0**	**4.3**	**17.8**	**9.7**	**34.2**	**12.5**	**22.4**	**19.4**	**19.2**	**8.5**	**17.6**	**24.7**	**33.4**	**26.5**	**8.5**	**7**
NPK 24	Swarna / O nivara BIL	17.3	15.7	16.2	9.0	15.6	10.9	18.3	27.2	19.9	8.5	16.3	14.9	40.5	35.9	8.4	7
BPT 3113	BPT 2270 / NLR 145	11.6	8.9	21.0	12.2	15.0	10.5	19.0	41.3	20.7	9.8	14.9	9.6	35.1	38.5	14.8	6
BPT 3130	BPT5204/MTU 1075	15.2	4.9	19.1	8.7	15.0	12.7	20.6	25.1	20.9	9.8	12.5	13.8	33.2	42.2	8.7	6
RP5564 PTB 2-4-2-1-2	**RP Bio 226 X IRGC 71598 X MTU1010**	**12.5**	**6.0**	**15.7**	**10.3**	**33.3**	**13.3**	**20.6**	**37.6**	**13.9**	**7.3**	**16.0**	**16.3**	**19.5**	**31.4**	**8.0**	**6**
0614-1-6-21-1-4	**Pranava X Vellari**	**14.7**	**10.3**	**16.8**	**7.6**	**34.2**	**11.1**	**18.7**	**25.3**	**21.8**	**10.0**	**8.6**	**8.1**	**45.6**	**44.7**	**12.7**	**6**
NPK 46	Swarna / O nivara BIL	21.9	8.9	18.8	8.8	27.1	10.6	19.8	31.9	17.8	7.9	14.5	13.7	38.3	54.5	15.8	6
BPT 3135	BPT 5204 / MTU 1001	14.1	6.1	22.7	9.2	35.1	11.3	23.7	36.7	21.3	9.6	18.8	10.7	31.8	46.3	8.5	5
BPT 3182	BPT 2231 / MTU 1075	12.3	5.3	21.5	9.2	25.1	12.3	22.7	19.9	19.1	9.6	10.3	16.5	33.5	41.4	8.2	5
BPT 3085	BPT 5204 /MTU 1075	18.6	7.7	17.8	9.7	37.2	15.1	20.7	20.2	16.2	9.2	13.7	11.1	19.4	46.7	10.4	5
NWGR 16032	Gurjari /NWGR 3015	12.1	15.3	20.0	9.3	33.8	12.2	21.5	33.6	18.7	8.0	26.7	8.6	35.8	44.0	9.3	5
RP5564 PTB 1-3	**RP Bio 226 X IRGC 71598 X MTU1010**	**11.0**	**6.5**	**20.7**	**8.9**	**26.0**	**12.5**	**19.5**	**24.7**	**18.4**	**8.2**	**13.2**	**26.0**	**29.1**	**31.7**	**9.9**	**5**
BPT 3239	BPT5204/MTU 1075	16.2	3.0	23.0	6.8	26.4	13.0	25.5	40.2	28.3	9.2	12.5	12.4	33.8	45.9	10.0	4
BPT 3068	NLR 34449 / Ramappa	19.4	7.5	22.8	9.4	25.5	12.0	23.2	20.5	20.4	11.2	12.7	0.0	19.7	49.8	10.7	4
BPT 3192	BPT5204/MTU 1075	15.4	11.9	22.3	9.6	16.0	12.5	21.2	38.9	17.7	8.7	16.1	12.4	36.5	43.8	8.4	4
GR-11													38.4	42.6			
TN1	Susceptible Check	29.2	14.3	20.0	7.0	37.4	16.1	21.4	40.4	30.7	7.8	18.0	37.9	43.3	52.4	14.4	
Minimum Damage		8.4	2.7	15.7	6.8	15.0	10.5	18.3	18.7	13.9	7.3	8.5	0.0	19.4	25.5	4.8	
Maximum Damage		21.9	15.7	23.0	34.2	37.2	15.1	25.5	41.3	28.3	17.7	26.7	38.4	45.6	54.5	15.8	
Average damage in Trial		13.7	7.6	19.3	10.3	25.5	12.2	21.0	29.0	19.2	9.5	13.6	13.4	31.9	39.5	9.5	
Promising Level		10	10	20	10	20	12	20	20	15	10	10	10	20	25	10	
Number Promising		4	19	16	21	8	10	9	5	1	21	5	10	7	1	19	
Total Entries Tested		25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	

*BPT-Bapatla, ADT-duthurai CHT-Chatha, CTC-Cuttack, CHN-Chinsurah, KJT-Kajrat, KUL-Kaul, LDN-Ludhiana, MLN-Malan, MSD-Masoda ,NLR-Nellore. NVS-Navsari, NWG-Nawagam, PTB-Pattambi, RNR-Rajendranagar, During *kharif* 2024, the field evaluation of 35 entries, including susceptible and resistant checks replicated twice at 22 locations in the Leaf Folder Screening Trial (LFST) in AICRPR testing revealed that 14 entries were promising in 4-6 tests out of 15 valid field tests. In the first year of testing, RP5490 PTB 1-1-2 was promising in 6 out of 15 valid tests and at par with the resistant check, W1263. Eight entries were promising in 4 out of 15 tests (Table 5). Similar studies recorded the lowest leaf folder infestation in RP 5588 (0.57%) followed by DRRH 2 (0.76%), CR 2274-2-33-1 (0.88%) and RP 5588-B-B-B-B-116 (0.93%) (Chatterjee *et al*., 2016). Rice culture NLR 3542 recorded resistant reaction against leaf folder by recording 8.68 and 4.80% leaf damage during *Kharif* 2017 and 2018, respectively, with a grade 1. Devaraj *et al*., (2024) identified the genotypes ADT 45, ADT 46, ADT 54, Salem Senna, Karuppu Kavuni, Mottakar, Anna (R) 4, TRY 1, TRY 3 and Kalsaras resistant to leaf folder.

Conclusion

Field screening for three seasons identified ten Pattambi entries *viz*., RP5564 PTB 2-4-1-5, 0614-13-15-7-1-2, RP5564 PTB 2-4-2-1-2, RP5564 PTB 1-4-2, 0614-13-15-7-1-1, RP5564 PTB 1-4-1. RP5564 PTB 1-3. 0614-1-6-21-1-2, 0614-1-6-21-1-4 and RP5564 PTB 2-4-2-1-1 as resistant to rice leaf folder in both station trials and multi-locational trials across India under AICRPR-Entomology programme. were promising in fifteen locations across India.

Authors contribution

KK, screened the cultures at Pattambi against stem borer and leaffolder. FKV and BKR were involved in the development of the material. CHPV designed the LFST trial for multilocation testing in AICRPR and analysed the data. KKand CHPV wrote the manuscript. All authors read and approved the manuscript.

References

Belete T. 2018. Defense mechanisms of plants to insect pests: From morphological to biochemical approach. *Trends in Technical and ScientificResearch,*2(2):30-38.

Chatterjee S and Mondal P. 2014. Management of rice yellow stem borer, *Scirpophaga incertulas* Walker using some bio rational insecticides. *Journal of Biopesticides*, 7 (suppl):143-147.

Chatterjee S, Mousumi G and Gangopadhyay C. 2016. Field screening of different rice entries against different insect-pests of rice during *kharif* season. *International Journal of Agriculture, Environment and Biotechnology,* 9 (4) :667-669.

Chatterjee S, Mondal P, Dana I, Gangopadhyay C and Nayak U. 2017. Screening of rice genotypes for their resistance against yellow stem borer and leaffolder. *SATSA Mukhaptra Annual Technical Issue*, 21:200-206.

Chaudhari PR, Tamrakar N, Singh S, Tandon A, Sharma D. 2018. Rice nutritional and medicinal properties: A review article. *Journal of Pharmacognosy and Phytochemistry,* 7(2):150-156.

Devaraj R, Vadivel K, Nivetha KR and Sabbithi P. 2024. Screening against stem borer [*Scirpophaga incertulas* (walker)], leaffolder [*Cnaphalocrocis medinalis (*guenee)] and leaf spot [*Helminthosporium oryzae* breda de haan) resistance in rice (*Oryza sativa* L.) genotype *Biochemical and Cellular Achieves,* 24(1):1003-1007.

ICAR-IIRR (2022). Entomology Technical Programme *Kharif* 2022 and *Rabi*, 2021-2022. All India Coordinated Research Project on Rice, Indian Institute of Rice Research, Rajendranagar, Hyderabad, Telanagana State, India.

ICAR-IIRR (2023). Entomology Technical Programme, *Kharif* 2023 and *Rabi*, 2022-2023. All India Coordinated Research Project on Rice, Indian Institute of Rice Research, Rajendranagar, Hyderabad, Telanagana State, India.

ICAR-IIRR (2024). Entomology Technical Programme, *Kharif* 2023 and *Rabi*, 2022-2023. All India Coordinated Research Project on Rice, Indian Institute of Rice Research, Rajendranagar, Hyderabad, Telanagana State, India.

Karthikeyan K, Faseela KV, Biji KR, Padmavathi Ch and Padmakumari AP.2024. Field Screening of Rice Genotypes for Resistance to Major Rice Pests. *Journal of Rice Research,*17(1): 96-106.

Pandit TK, Mookherjee S, Karforma J. 2020. Performance of direct seeded rice under integrated nutrient management practices in Old Alluvial Soils of West Bengal. *International Research Journal of Pure and Applied Chemistry,*21(5):19-24.

Painter R. 1951. Insect resistance in crop plants. MacMillan, New-York, p. 168.

Rani DS, Chiranjeevi C, Madhumathi T, Raju S K and Umar SN. 2020. Biochemical Analysis for Rice Germplasm Lines for Combat against Yellow Stem Borer, *Scirpophagaincertulas*: Implication for Varietal Selection of Rice in India. *International Research Journal of Pure and Applied Chemistry,*21(7):41-51.

RESEARCH ARTICLE https://doi.org/10.58297/UWSM8455

Evaluation of Resistance in Rice Genotypes against Root-Knot Nematode *Meloidogyne graminicola*

Nethi Somasekhar, Satish N Chavan*, Shiva Krishna K, Shravan Kumar K, Sai Prasad SV, Senguttuvel P and Sundaram RM

ICAR-Indian Institute of Rice Research, Hyderabad 500030
*Corresponding author Email: satishagrico@gmail.com

Received : 10th July, 2025; Accepted : 8th September, 2025

Abstract

Rice (*Oryza sativa* L.) is a major cereal crop and staple food for over half of the global population. The rice root-knot nematode (*Meloidogyne graminicola* Golden and Birchfeild, 1965) poses a significant threat to rice production across major rice-growing regions, particularly under changing cultivation systems such as aerobic and direct-seeded rice. Effective management of this nematode is challenging due to its short life cycle, broad host range, and the lack of effective nematicides. In the present study, twenty rice genotypes were evaluated under glasshouse conditions to identify sources of resistance against *M. graminicola*. The resistance reaction was assessed using the Relative Root Gall Index (RRGI) and Relative Reproduction Index (RRI), with TN1 serving as the susceptible check. Results revealed that only one genotype, K 2419 (Land race KARI, Accession No. K:2419), exhibited a resistant response, showing significant reductions in both root galling (RRGI: 0.72) and nematode multiplication (RRI: 0.96), compared to the susceptible check TN1. Two genotypes were categorized as moderately resistant, while the remaining genotypes were either susceptible or highly susceptible. The resistant genotype K 2419 was found to be consistently resistant across all four seasons of *Kharif* and *Rabi* in 2023 and 2024 in glasshouse. This resistant genotype may serve as a valuable donor in breeding programs aimed at developing nematode-resistant rice cultivars.

Keywords: Rice, root-knot nematode, *Meloidogyne graminicola*, resistance.

Introduction

Rice (*Oryza sativa* L.), is a predominant staple cereal crop in the tropics and subtropics, particularly in Asia. In India, it covers an area of 47.8 million hectares with an annual production of around 138 million metric tons (INDIASTAT, 2024). However, rice production is susceptible to various biotic and abiotic stresses, among which the rice root-knot nematode, *Meloidogyne graminicola*, stands out as one of the most economically important pests affecting rice cultivation in India and other major rice-growing regions worldwide. This obligate endo parasite inflicts characteristic hook-shaped galls on rice roots, resulting in stunted growth, chlorosis, poor tillering, and significant yield losses ranging from 10-17%, with severe infestations causing up to 87% loss under favorable conditions (Prasad *et al*., 2010, Walia *et al.,* 2020, Kumar *et al.,* 2020, Chavan *et al.,* 2023, Somasekhar and Prasad, 2024). The increasing prevalence of the nematode has been mainly due to changes in cultivation practices, particularly the adoption of aerobic and direct-seeded rice (DSR) systems, which provides favorable conditions for its development and reproduction (Kaur and Singh, 2017, Bhagawati *et al.,* 2023).

Managing *M. graminicola* in rice fields through methods such as crop rotation, field flooding, and application of nematicides remains challenging. The limited use of nematicides, coupled with the poor efficacy of traditional control practices, has hindered effective management of this nematode in rice. Hence, the deployment of resistant cultivars is recognized as the most economical and environmentally sustainable strategy for managing *M. graminicola* in rice (Pokharel *et al*., 2011). However, the availability of robust resistance sources, especially in *indica* rice, remains a key limitation. Several studies conducted across India have primarily reported high levels of susceptibility in the majority of screened cultivars, with only a few exhibiting moderate resistance or tolerance (Chavan *et al*., 2019, Srivastava *et al*., 2011, Kumar *et al*., 2022). Recently, a major gene conferring resistance to *M. graminicola* was identified in a japonica cultivar in China, underscoring the potential for genetic resistance breeding (Wang *et al*., 2023). In this context, the present study was undertaken to evaluate the resistance status of selected rice genotypes against *M. graminicola* under controlled screening conditions. The study was to identify potential resistant sources that can be utilized in breeding programmes aimed at developing nematode-resistant rice cultivars.

Materials and Methods

The present investigation was undertaken at Nematology Unit, ICAR-IIRR, Rajendranagar, Hyderabad, Telangana. A total of twenty rice genotypes were screened for resistance to the rice root-knot nematode, *Meloidogyne graminicola*, under glasshouse conditions.

Nematode Culture

A pure culture of *M. graminicola* (isolate Drr-Mg1; GenBank accession no. JF949754.1), maintained on the susceptible rice variety TN1 at the Nematology Unit, ICAR-Indian Institute of Rice Research (ICAR-IIRR), Hyderabad, served as the inoculum source for the present study. Second-stage juveniles (J2s) were extracted from infested rice roots using a modified Baermann funnel method, as described by Hooper (1986). Freshly emerged J2s were collected in a glass beaker. The concentration of J2s in the suspension was estimated by counting three 100 µL aliquots under a stereoscopic binocular microscope.

Rice Genotypes

The seeds of rice genotypes used in this study were obtained from the Plant Breeding Section of ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad, India. The rice cultivar TN1 was used as susceptible check (Chavan *et al*., 2019) while the LD 24 was used as resistant check (Dimkpa *et al*., 2016; Wang *et al*., 2023).

Screening for resistance to *Meloidogyne graminicola*

Seeds were first germinated on moist filter paper for three days at 27 °C. The sprouted seeds were then transferred into polyvinyl chloride (PVC) tubes (3 cm in diameter and 18 cm in length), with one seed per tube, filled with a standardized SAP (Sand mixed with an Absorbent Polymer) substrate (Reversat *et al*., 1999). Each rice cultivar was tested with five replications. After one week of growth, each plant was inoculated near the root zone with 1 mL of nematode suspension containing 100 freshly hatched J2s. The plants were kept in a glasshouse (25-30 °C) and were irrigated three times per week using 10 mL of Hoagland's nutrient solution.

Plants were uprooted 21 days post-inoculation (DPI). Roots were gently washed to remove adhering sand, and the number of galls induced by *M. graminicola* was counted using a binocular stereomicroscope. To estimate the total nematode population, the galled roots were thoroughly cleaned and dissected with fine needles under a stereo-zoom microscope. The dissected galls were placed on double-layered tissue paper supported by a wire mesh over a Petri plate in a modified Baermann funnel apparatus, following the method of Hooper (1986). After 72 h, J2 hatched into water were collected in a glass beaker and the total number of J2s in suspension were estimated by counting under stereo zoom microscope. The experiment was repeated twice, during the *Rabi* and *Kharif* seasons of 2023, to validate the findings and enhance the reliability of the results. The resistance level of each rice genotype was assessed based on the Relative Root-Gall Index (RRGI) and Relative

Reproduction Index (RRI), using the formulas outlined by Jena and Rao (1977) and Chavan *et al*., (2019) as follows:

$$\text{Relative root-gall index (RRGI)} = \frac{\text{Number of galls in test entry x 4}}{\text{Number of galls in susceptible check}}$$

$$\text{Relative reproduction index (RRI)} = \frac{\text{Total nematode population in test entry x 4}}{\text{Total nematode population in susceptible check}}$$

The reaction of rice cultivars against rice root-knot nematode *M. graminicola* was scored based on the RRGI and RRI using the scale mentioned below:

Relative Root-Gall Index (RRGI) / Relative Reproduction Index (RRI)	Reaction of Cultivar
0	Highly resistant
0.1-1.0	Resistant
1.1-2.0	Moderately Resistant
2.1-3.0	Susceptible
>3.0	Highly Susceptible

Reconfirming the resistance in rice genotype K 2419

The selected rice genotype K 2419 was further evaluated in a sap tube assembly, as explained above, for two consecutive seasons i.e. *Rabi* 2024 and *Kharif* 2024, to assess the consistency of resistant response of the genotype. One week old plants were inoculated with J2s of *M. graminicola* at a rate of 100 J2s per plant. Eight replications were maintained for each genotype. Observations on root galls were recorded 21 days post nematode inoculation. The scoring of genotypes was done based on the Relative Root-Gall Index (RRGI) as described above.

Further to confirm the reaction of rice plants after subjecting to the multiple generations of *M. graminicola* infection in rice plants, an experiment was conducted in big size plastic pots (3 kg capacity) where plants were maintained up to 90 days post nematode inoculation. This experiment gives an opportunity for the nematode to complete about 3-4 generations on host plants. The selected rice genotype K 2419 along with the susceptible check TN1 were evaluated. Pots were filled with a sterilized mixture of soil and sand in a 3:1 ratio. Pre-germinated seeds were sown at the rate of one seed per pot. Six such pots were maintained for each genotype, resulting in six replications per genotype. Two-week-old plants were inoculated with J2s of *M. graminicola* at a rate of 2 J2s per gram of soil (*i.e.* 6,000 J2s per pot). Observations on root galls were recorded 90 days after nematode inoculation. The scoring of genotypes was done based on the Relative Root-Gall Index (RRGI) as described above.

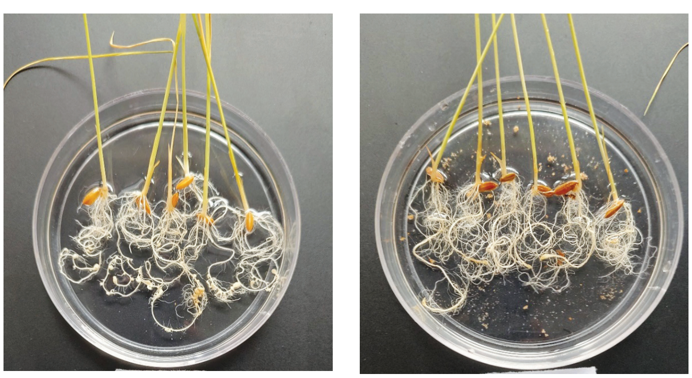
Results and Discussion

A large variation in root gall formation and total nematode population per plant was observed among the rice genotypes screened against *M. graminicola*. The reactions of the test entries were evaluated based on the Relative Root Gall Index (RRGI) and Relative Reproduction Index (RRI). Among the 20 genotypes tested, only one genotype, K 2419 (Land race KARI, Accession No. K:2419), was classified as resistant, exhibiting the lowest number of root galls (RRGI: 0.72) and nematode population (RRI: 0.96) during *Kharif* 2023, compared to the susceptible check TN1 **(Table 1 and Figure 1)**. Two genotypes showed a moderately resistant reaction, while all remaining genotypes were categorized as either susceptible or highly susceptible based on RRGI and RRI index values. Similar results were observed during *Rabi* 2023, with K 2419 again showing the lowest root galls (RRGI: 0.87) and nematode population (RRI: 0.63). One genotype was resistant, two were moderately resistant, and the remaining genotypes were classified as susceptible to highly susceptible **(Table 2)**. The response of K 2419 to *M. graminicola* was similar to that of the resistant check LD24.

Table 1: Reaction of rice genotypes to rice root-knot nematode *Meloidogyne graminicola* (*Rabi* 2023)

Sl. No.	Genotypes	RRGI*	Reaction$	RRI#	Reaction$
1	WGL 1719	3.25	HS	2.70	S
2	JKRH 1004	2.91	S	2.82	S
3	KSRH 01	2.45	S	2.19	S
4	MEPH 174	4.23	HS	3.43	HS
5	WGL 1720	2.23	S	2.32	S
6	KNM 12509	1.62	MR	1.75	MR
7	RNR 35105	2.34	S	2.52	S
8	JGL 28639	3.55	HS	3.23	HS
9	KAVERI 7374	3.36	HS	2.28	S
10	RRX 3276	4.38	HS	2.97	S
11	JKRH 1179	2.94	S	2.60	S
12	NWGR 17075	4.04	HS	3.63	HS
13	HRI 217	3.89	HS	2.75	S
14	RNR 38966	3.17	HS	2.89	S
15	RRX 3341	1.89	MR	1.65	MR
16	TMRH 5786	2.23	S	3.22	HS
17	BS 330	2.72	S	2.17	S
18	K 2419	0.72	**R**	0.96	**R**
19	LD 24 (Resistant Check)	0.57	**R**	0.17	**R**
20	TN1 (Susceptible Check)	4.00	HS	4.00	HS

*RRGI: Relative Root Gall Index, #RRI: Relative Reproduction Index; $Reaction of rice cultivars scored based on RRGI/RPI values: 0 = Highly Resistant (HR); 0.1-1.0 = Resistant (R); 1.1-2.0 = Moderately Resistant (MR); 2.1-3.0 = Susceptible (S); >3.0= Highly Susceptible (HS)



TN1 **K 2419**

Figure 1: Rice root-knot nematode *Meloidogyne graminicola* infection in susceptible (TN1) and resistant (K 2419) rice genotypes

Table 2: Reaction of rice genotypes to rice root-knot nematode *Meloidogyne graminicola* (*Kharif* 2023)

Sl. No.	Genotypes	RRGI*	Reaction$	RRI#	Reaction$
1	WGL 1719	3.81	HS	3.23	HS
2	JKRH 1004	2.79	S	2.89	S
3	KSRH 01	2.72	S	2.59	S
4	MEPH 174	2.87	S	2.93	S
5	WGL 1720	2.45	s	2.74	s
6	KNM 12509	1.58	MR	1.71	MR
7	RNR 35105	2.68	S	2.99	S
8	JGL 28639	3.43	HS	3.38	HS
9	KAVERI 7374	3.32	HS	3.78	HS
10	RRX 3276	3.92	HS	2.39	S
11	JKRH 1179	2.87	S	2.98	S
12	NWGR 17075	3.70	HS	4.53	HS
13	HRI 217	2.83	S	2.90	S
14	RNR 38966	3.36	HS	3.80	HS
15	RRX 3341	1.70	MR	1.77	MR
16	TMRH 5786	2.34	S	2.81	S
17	BS 330	2.98	S	2.20	S
18	K 2419	0.87	**R**	0.63	**R**
19	LD 24 (Resistant Check)	0.68	**R**	0.23	**R**
20	TN1 (Susceptible Check)	4.00	HS	4.00	HS

*RRGI: Relative Root Gall Index, #RRI: Relative Reproduction Index; $Reaction of rice cultivars scored based on RRGI/RPI values: 0 = Highly Resistant (HR); 0.1-1.0 = Resistant (R); 1.1-2.0 = Moderately Resistant (MR); 2.1-3.0 = Susceptible (S); >3.0= Highly Susceptible (HS)

The rice genotype K 2419 was found to be consistently resistant to the root-knot nematode *M. graminicola* during the next two consecutive seasons, *Kharif* 2024 (RRGI 0.95) and *Rabi* 2024 (RRGI score 0.88) **(Table 3).** The reduction in the number of root galls in the resistant genotype K 2419 compared to the susceptible check TN1 were observed to be 76.14% and 78.04% during *Rabi* 2024 and *Kharif* 2024, respectively.

Table 3: Comparative evaluation of the resistant (K 2419) and the susceptible (TN1) rice genotype against the rice root-knot nematode (*Meloidogyne graminicola*) during *Rabi* 2024 and *Kharif* 2024

Genotypes	Galls / plant	% Reduction$	RRGI#	Reaction@
***Rabi* 2024**				
TN1	16.00 ± 1.05		4.00	HS
K 2419	3.82 ± 0.44	76.14	0.95	**R**
***Kharif* 2024**				
TN1	17.80 ± 1.0		4.00	HS
K 2419	3.91 ± 0.34	78.04	0.88	**R**

*The data represents Mean ± Standard error from eight replications; $% reduction over susceptible check; #RRGI: Relative Root Gall Index; @ Reaction of rice cultivars scored based on RRGI values: 0 = Highly Resistant (HR); 0.1-1.0 = Resistant (R); 1.1-2.0 = Moderately Resistant (MR); 2.1-3.0 = Susceptible (S); >3.0= Highly Susceptible (HS)

Results of the long duration study conducted to assess the reaction of rice genotypes upon infection by multiple generations of *M. graminicola* revealed that the rice genotype K 2419 continued to show resistant reaction (RRGI score of 0.35) even after the nematode completed 3-4 generations on the host, while the susceptible check TN1 showed a highly susceptible reaction (RRGI score 4). These findings further confirm that the rice genotype K 2419 is resistant to the rice root-knot nematode *M. graminicola*.

These findings are in line with earlier studies that reported significant differences in resistance response among rice genotypes screened for *M. graminicola* under controlled conditions (Srivastava *et al*., 2011, Mhatre *et al*., 2015, Devaraja *et al*., 2018; Chavan *et al*., 2019). The susceptibility of TN1 was also reported by Berliner *et al*., (2014) and Subudhi *et al*., (2017). Identifying true resistance in cultivated rice varieties is uncommon. In our study, only one genotype exhibited resistance among all those evaluated. Similarly, Berliner *et al.,* (2014), who assessed 414 rice cultivars using a root gall index with TN1 as the susceptible check, reported just two resistant lines showing less than 10% galling. Comparable findings were also reported by Subudhi *et al.,* (2017), Devaraja *et al*., (2018) and Berliner *et al.,* (2022), further highlighting the rarity of resistance in the screened rice genotypes. While the majority of the genotypes tested in this study showed varying degrees of susceptibility, the consistent performance of K 2419 across both galling and reproduction indices highlights its potential as a promising resistant donor for incorporation of nematode resistance into rice breeding programmes. Consistent resistance has been reported in the rice genotypes LD 24 (indica cultivar from Sri Lanka) and Khao Pahk Maw (an aus cultivar from Thailand) as well (Dimkpa *et al*., 2016; Lahari *et al*., 2019; Wang *et al*., 2023; Somasekhar *et al*., 2023).

Conclusion

Out of the twenty rice genotypes screened for resistance to *Meloidogyne graminicola*, only one genotype, K 2419, was found to be resistant based on both root galling and reproduction indices. Two genotypes exhibited a moderately resistant response, whereas the remaining all genotypes were either susceptible or highly susceptible. The resistant genotype K 2419 showed significantly lower root galling and nematode multiplication compared to the susceptible check TN1, highlighting its potential as a valuable genetic source for nematode resistance. These findings reinforce the need for routine resistance screening and suggest that K 2419 may serve as a useful donor in breeding programs aimed at developing nematode-resistant rice cultivars for sustainable nematode management in rice ecosystems.

Acknowledgments

The authors are grateful to the Director, ICAR-Indian Institute of Rice Research (ICAR-IIRR), Rajendranagar, Hyderabad for providing the necessary facilities and support during the course of this investigation. The constant encouragement and technical guidance extended by the scientific and technical staff of ICAR-IIRR are sincerely acknowledged.

References

Berliner J, Pokhare SS, Meena KS, Manimaran B, Munda S, Adak T, Bose LK and Patra BC. 2022. Reaction of different *Oryza* species against rice root-knot nematode, *Meloidogyne graminicola*. *Oryza,* 59 (3): 387-391.

Berliner J, Pokhare SS, Mishra C, Jena M and Singh ON. 2014. Screening of rice germplasm lines against rice root-knot nematode *Meloidogyne graminicola*. *ORYZA-An International Journal on Rice*, 51(2): 177-178.

Bhagawati B, Khan MR, Neog PP and Kurulkar U. 2023. Major Nematode Problems in Direct Seeded Rice and Their Management. In *Novel Biological and Biotechnological Applications in Plant Nematode Management*. (Khan MR. Ed.). Springer Nature Singapore. pp. 515-537.

Chavan SN, Somasekhar N and Subbarao LV. 2019. Reaction of rice cultivars to rice root knot nematode (*Meloidogyne graminicola*). *Journal of Rice Research*, 12(2): 69.

Chavan SN. and Kyndt T. 2023. *Meloidogyne graminicola* - Parasite of the Month. *Trends in Parasitology*, 39(12): 1114-1115. https://doi.org/10.1016/j.pt.2023.08.010.

Devaraja KP, Sirohi A, Singh AK and Ellur RK. 2018. Expression analysis of defence related genes and histopathological changes in direct seeded rice genotypes (*Oryza sativa L.*) against root-knot nematode (*Meloidogyne graminicola*). *Indian Journal of Genetics and Plant Breeding*, 78(01): 147-150.

Dimkpa SO, Lahari Z, Shrestha R, Douglas A, Gheysen G and Price AH. 2016. A genome-wide association study of a global rice panel reveals resistance in *Oryza sativa* to root-knot nematodes. *Journal of experimental botany*, 67 (4): 1191-1200.

Hooper DJ. 1986. Extraction of free-living stages from soil. In 'Laboratory methods for work with plant and soil nematodes'. 6th edition:3-30.

IndiaStat. 2024. Selected State/Season-wise Area, Production and Productivity of Rice in India (2023-2024).

Jena RN and Seshagiri Rao Y. 1977. Nature of resistance in rice (*Oryza sativa* L) to the root-knot nematode (*Meloidogyne graminicola* Golden and Birchfield). II. Mechanisms of resistance. *In Proceedings of the Indian Academy of Sciences-Section B*, 86: 87-91.

Kaur J and Singh A. 2017. Direct seeded rice: Prospects, problems/constraints and researchable issues in India. *Current agriculture research Journal*, *5*(1): 13.

Kumar A, Khilari K, Yadav GK, Kumar A and Yadav P. 2022. Evaluation of different basmati varieties of rice against root-knot nematode (*Meloidogyne graminicola*). *Journal of Entomological Research,* 46(3): 541-545.

Kumar V, Khan MR and Walia RK. 2020. Crop loss estimations due to plant-parasitic nematodes in major crops in India. *National Academy Science Letters*, 43(5), pp. 409-412.

Lahari Z, Ribeiro A, Talukdar P, Martin B, Heidari Z, Gheysen G, Price AH and Shrestha R. (2019). QTL-seq reveals a major root-knot nematode resistance locus on chromosome 11 in rice (*Oryza sativa* L.). *Euphytica*, *215*: 1-13.

Mhatre PH, Malik SK, Kaur S, Singh AK, Mohan S and Sirohi A. 2015. Histopathological changes and evaluation of resistance in Asian rice (*Oryza sativa* L.) against rice root-knot nematode, *Meloidogyne graminicola* Golden and Birch. *Indian Journal of Genetics and Plant Breeding,* 75(01): 41-48.

Pokharel RR, Abawi GS and Duxbury JM. 2011. Greenhouse evaluation of rice and wheat germplasm for resistance to *Meloidogyne graminicola* with comments on evaluation indices and proposal of a new one. *Nematologia Mediterranea*, 39(2): 157-168.

Prasad JS, Somasekhar N and Varaprasad KS. 2010. Nematode infestation in Paddy. In: *Nematode infestations Part-I: Food crops*. (Khan MR and Jairajpuri MS. eds.). *National Academy of Science, India*. pp. 17-71.

Reversat G, Boyer J, Sannier C and Pando-Bahuon A. 1999. Use of a mixture of sand and water-absorbent synthetic polymer as substrate for the xenic culturing of plant-parasitic nematodes in the laboratory. *Nematology*, 1(2): 209-212.

Somasekhar N, Shiva Krishna K, Senguttuvel P and Chavan SN. 2023. Host Response and genetics of resistance to rice root-knot nematode *Meloidogyne graminicola* in Asian Rice (*Oryza sativa* L) cultivar Khao Pahk Maw. Abstract book of the 'International Conference on Plant Health Management ICPHM 2023: Innovation and Sustainability held at Hyderabad, from 15-18 November, 2023, pp. 239-240.

Somasekhar N and Prasad JS. 2024. Rice Root-Knot Nematode: From Mandya and Beyond. In: *Nematode Problems in Crops and their Management in South Asia*. (RK Walia and MR Khan. Eds.). Cambridge Scholars Publishing Company, UK. 2024. Pp. 118-130.

Srivastava A, Rana V, Rana S, Singh D and Singh V. 2011. Screening of rice and wheat cultivars for resistance against root-knot nematode, *Meloidogyne graminicola* (Golden and Birchfield) in rice-wheat cropping system. *Journal of Rice Research*, 4(1): 2.

Wang X, Cheng R, Xu D, Huang R, Li H, Jin L, Wu Y, Tang J, Sun C, Peng D and Chu C. 2023. MG1 interacts with a protease inhibitor and confers resistance to rice root-knot nematode. *Nature Communications*, 14(1): 3354.

RESEARCH ARTICLE https://doi.org/10.58297/QYBF5265

Generation Mean Analysis for Blast Resistance and Yield Traits in Rice (*Oryza sativa* L.)

Namrata[1]*, Singh RP[1], Ramlakhan Verma[2], Prashant Bisen[1], Prakash Singh[3], Arsode Pandurang[1], Madhu Choudhry[1], Padma Thakur[1], Bapsila Loitongbam[1] and Ramesh[4]

[1]Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221005, India

[2]Crop Improvement Division, ICAR-NRRI, Cuttack-753006, India

[3]Department of Plant Breeding and Genetics, VKSCA, Bihar Agricultural University, Sabour, Dumraon, Buxar- 802136, India

[4]Department of Genetics and Plant Breeding, College of Agriculture, Barmer Agricultural University, Baytu, Jodhpur- 344034, India

*Corresponding author's email: namratamotasara@gmail.com

Received: 12th July, 2025; Accepted: 9th September, 2025

Abstract

An investigation was performed to study the gene interactions for blast resistance and yield attributes in rice using six generations (P_1, P_2, F_1, F_2, B_1 and B_2) of cross HUR 3022 × Tetep. Results of scaling test, joint scaling test and digenic nonallelic interaction model with six parameters namely *m, d, h, i, j* and *l* indicated that the epistatic interaction model was appropriate to explain the gene action in all the fourteen traits under study. Mean and additive components were found highly significant for number of filled grains per plant, number of unfilled grains per plant, spikelet fertility percentage, grain yield per plant, area under disease progress curve and disease severity per cent. The dominance (*h*) gene effects were found highly significant for all the characters under study. All three types of gene effects (additive, dominance and epistasis) were found highly significant for blast resistance traits studied, except for additive effect in lesion number.

Key words: Blast resistance, gene interaction, duplicate epistasis

Introduction

Rice provides food for nearly half of the world's population which enables it to play a crucial role in the world food security (Billa *et al.,* 2024). Asian countries represent highest production as well as consumption of rice in the world (Khush 2005, Khush 2013, Yin *et al.,* 2021, Kumari *et al.,* 2024, Liu *et al.,* 2022, Boss *et al.,* 2024). Rice is grown globally in an area of 165.25 million hectares with a production of 787.29 million tonnes with an average productivity of 4.76 tonnes per hectare (FAOSTAT, 2021). India being the second largest producer of rice produces 130.29 million tonnes of rice on an area of 46.38 million hectares with productivity of 28.09 q/ha. In Uttar Pradesh it is grown in an area of 5.70 million hectares with production of 15.27 million tonnes and productivity of 26.79 q/ha (DES, 2021-22).

To feed increasing world population with the existing land resources, 26% more rice production is required in next 20 years (Khush, 2013). Rice production has widely increased after the green revolution, but the yield of superior varieties is still not increasing as farmer's expectations due to the influence of several biotic and abiotic factors (Divya *et al.,* 2014). Biotic factors globally cause approximately ~52% annual loss to rice production, among which major portion is due to the attack of diseases (Yarasi *et al.,* 2008, Ashkani *et al.,* 2015). Rice is reported to be attacked by more than 70 diseases caused by different fungi, bacteria, viruses and nematodes (Zhang *et al.,* 2009). Among these diseases, rice blast caused by fungus *Magnaporthe oryzae* belonging to the class Ascomycetes and the genus *Magnaporthe,* considered to be one of the most significant, potentially damaging and a costly constraint causing major food loss per year at global level. Rice blast has been responsible for up to 30% yield loss in rice globally (Qi *et al.,* 2023), but even if it is causing only 10% loss of the yield it accounts for grain loss equivalent to feed 60 million people for one whole year (Kato, 2001). The dynamic evolution nature of the blast fungus complicates breeding for the blast resistance. To breed for complex traits like yield and resistance to blast disease, a comprehensive idea about the gene interaction and genetics involved in governing these traits are required. Keeping this in view, the present study is formulated to study the gene action involved in governing the yield traits and resistance to blast in a cross of HUR 3022 × Tetep in rice.

Materials and Methods

The present experiment was conducted during two main crop seasons of *Kharif* 2016 and 2018 at Agriculture Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi and two off season crops were taken at Research Farm of ICAR-National Rice Research Institute (NRRI), Cuttack, Orissa during *Rabi* 2016-17 and 2017-18. Geographically, experimental site of Varanasi is situated at 25°18´ North latitude and 83°03´ East longitude and at altitude of 123.23 m from sea level while experimental site of Cuttack is situated between 85°55' E to 85°56' E longitudes and 20°26' to 20°27' N latitudes with altitude of 24 m from sea level. Parents used in the study includes an early maturing locally popular rice variety, HUR 3022 (Malviya Dhan 3022) as a recurrent parent and as a donor parent, well known rice blast resistant *Indica* rice cultivar Tetep.

Crossing plan

The season wise crossing programme is illustrated in **Figure 1**.

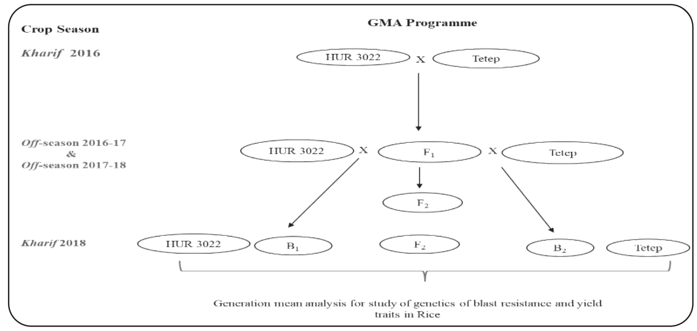


Figure 1: Season wise crossing programme for study of gene interaction.

During *Kharif* 2018, six generations of the cross HUR 3022 × Tetep (P_1, P_2, F_1, F_2, B_1 and B_2) along with the susceptible check Co-39 were planted in randomized block design in the open field condition. They were sprayed with 15 days old culture of *Magnaporthe oryzae* isolate *LB-TN-2,* obtained from Oat Meal Agar media at a concentration of 1 x 10^5 conidia/ml along with 0.2% Tween-20 at 24 days after sowing. Epiphytotic conditions were maintained by spraying water and covering the plants with polythene sheet to create humidity for the better establishment of the disease during night. Phenotypic traits were assessed on each individual entry in the segregating generations and observations were recorded for yield and blast resistance traits like Days to panicle emergence (DPE), Days to 50 per cent flowering (DF), Days to maturity (DM), Plant height (PH), Number of effective tillers per plant (NET), Panicle length (PL), Number of filled grains per panicle (NFG), Number of unfilled grains per panicle (NUG), Test weight (g) (TW), Grain yield per plant (GY), Lesion Number (LN) and calculated as per standard formula for the traits like- Spikelet fertility per cent (SFP), Disease severity (DS %) and Area under disease progressive curve (AUDPC) (Sabin *et al.,* 2016). Disease scoring for blast disease was performed using 0-9 scale as described in standard evaluation system (SES), IRRI (2013) and the host response was decided as described in Singh *et al.,* (2013).

Generation mean analysis

The generation mean analysis was performed to estimate the genetic components of variation, epistasis model and gene effects using two step procedure: (i) To perform scaling tests for determining the absence or presence of interallelic interactions, (ii) Determination of gene effects, variances and type of epistasis involved in yield and blast resistance traits. Six generations *viz.,* parental (P_1 and P_2), F_1, F_2, and two backcross generation (B_1 and B_2) were used to perform the tests. Average values were subjected to scaling test presented in **Table 2**. The significance of these scales (A, B, C and D) depicted the presence of non - allelic interaction. Presence of epistasis was detected by using Hayman and Mather (1955) approach. Further, the joint scaling test given by Cavalli (1952) was used which includes any combination of families at a time and tests the adequacy of additive-dominance model using a χ^2 test. For estimation of gene effects, Hayman's (1958) six parameter model was used to obtain the information about the inheritance of various traits.

Results and discussion

Generation means analyses reveals the relative importance of additive effects, dominance effects and epistatic effects (non-allelic interactions) in determining the genotypic values of the individuals and subsequently mean genotypic values of the generations. Generation means analysis is an effective technique for estimating gene effects for quantitative traits; its greatest merit lying in the ability to estimate all the three types of epistatic gene effects *viz*., additive × additive (i), additive × dominance (j) and dominance × dominance (l) effects.

To elucidate the nature of gene action for yield traits and blast resistance, generation mean analysis was carried out using the data recorded from six generations of the cross HUR 3022 × Tetep. The mean performances for 14 traits studied in the six generation P_1 (HUR 3022), P_2 (Tetep), F_1, F_2, B_1 (F_1 × HUR 3022) and B_2 (F_1 × Tetep) were presented in **Table 1.** F_1 generation showed early panicle emergence, flowering and maturity duration as compared to parents while three segregating populations (F_2, B_1 and B_2) observed taking slightly longer time for above three traits as compared to non-segregating generations. These findings are found in partial agreement with the earlier reports of early flowering of F_1, F_2, B_1 and B_2 generations than recurrent parent in rice (Divya *et al.,* 2014). Plant height in F_1 and F_2 were slightly shorter than recurrent parent HUR 3022, while B_1 and B_2 generations had intermediate plant height in comparison with both the parents. It was observed that F_1 generation having highest number of effective tillers followed by B_2 generation among all six generations studied. In B_1 generation intermediate number of effective tillers per plant recorded while F_2 had lesser number of effective tillers per plant than both the parents. These findings are in good agreement with previous reports for panicles per plant or number of effective tillers per plant in rice (Hassan *et al.,* 2016). B_2 generation in present study showed slightly better panicle length than better parent HUR 3022 while B_1 generation showed intermediate panicle length. F_1 and F_2 generation had lesser panicle length as compared to both the parents. These findings are in partial agreement with earlier reports for panicle length in rice (Divya *et al.,* 2014, Jondhale *et al.,* 2018). Not a single generation showed better number of filled grains per panicle than blast resistant parent Tetep. Highest number of unfilled grains per panicle found in B_2 generation followed by B_1 generation while lowest unfilled grains per panicle observed in blast resistant parent Tetep. Highest spikelet fertility observed in blast resistant parent Tetep followed by HUR 3022 while F_1, F_2, B_1 and B_2 had lesser spikelet fertility compared to both parents. Better test weight observed in F_1, B_1 and B_2 as compared to both parents but F_2 generation showed intermediate test weight. These findings are in good agreement for earlier reports of test weight in rice in similar experiment (Kiani *et al.,* 2013) and in partial agreement with earlier reports for number of filled grains per panicle and spikelet fertility per cent (Divya *et al.,* 2014).

Highest grain yield was observed in blast resistant parent Tetep followed by B_2 and F_1 generations while B_1 and F_2 generations showed intermediate and lower grain yield, respectively. In Comparison with recurrent parent HUR 3022, all three generations *viz.,* F_1, B_1 and B_2 generations showed higher grain yield. These findings showed similarity with the earlier reports of economic yield in blast condition in rice (Divya *et al.,* 2014).

Table 1: Mean performance of six generations of the cross HUR 3022 × Tetep for various yield attributing and blast resistance traits

Traits	P_1±Sem	P_2±Sem	F_1±Sem	F_2±Sem	B_1±SEm	B_2±SEm
#DPE	76.00 ± 0.30	75.47 ± 0.88	71.13 ± 0.41	82.72 ± 0.80	84.45 ± 1.02	85.85 ± 0.88
DOF	78.46 ± 0.50	78.20 ± 0.78	73.33 ± 0.57	84.89 ± 0.78	86.85 ± 1.01	88.06 ± 0.92
DOM	108.73 ± 0.73	106.00 ± 0.93	103.93 ± 0.75	115.26 ± 0.79	117.08 ±0.97	118.60 ± 0.82
PH	93.93 ± 3.73	126.33 ± 2.85	93.40 ± 3.01	89.90 ± 0.96	98.82 ± 0.90	100.27 ± 1.22
NET	13.60 ± 1.28	11.27 ± 0.70	17.73 ± 0.76	9.90 ± 0.53	13.55 ± 0.72	14.52 ± 0.73
PL	26.43 ± 061	25.86 ± 0.53	24.27 ± 0.76	20.99 ± 0.24	26.22 ± 0.42	26.47 ± 0.31
NFG	149.27 ± 16.18	157.80 ± 11.60	94.67 ± 11.30	125.25 ± 4.57	106.43 ± 3.96	130.26 ±4.74
NUG	51.80 ± 6.76	31.07 ± 7.90	62.10 ± 7.90	63.10 ± 3.80	112.75 ±6.78	122.28 ± 6.90
SFP	73.71 ± 9.48	84.29 ± 8.99	59.59 ± 10.32	66.72 ± 1.72	49.23 ± 1.17	51.97 ± 4.90
TW	15.76 ± 0.11	17.23 ± 0.36	19.48 ± 0.05	15.95 ± 0.20	20.89 ± 0.15	21.83 ± 0.39
GY	19.82 ± 3.31	40.69 ± 1.81	24.83 ± 1.30	15.42 ± 1.16	20.50 ± 1.12	26.46 ± 2.04
LN	48.20 ± 4.33	6.60 ± 0.60	4.00 ± 0.63	17.30 ± 1.40	16.00 ± 0.71	15.15 ±0.53
AUDPC	605.62 ± 30.14	127.95 ± 11.95	224.7 ± 26.128	477.51± 21.71	464.75 ± 26.52	318.20 ± 19.38
DSP	43.66 ± 1.62	9.32 ± 0.74	17.54 ± 1.48	34.22 ± 1.28	32.86 ± 1.51	22.84 ± 1.08

#(DPE) Days to panicle emergence, (DOF) Days to 50 per cent flowering, (DOM) days to maturity, (PH) plant height, (NET) number of effective tillers per plant, (PL) panicle length, (NFG) number of filled grains per panicle, (NUG) number of unfilled grains per panicle, (SFP) spikelet fertility per cent, (TW) test weight, (GY) grain yield per plant, (LN) lesion number, (AUDPC)area under disease progress curve and (DSP) disease severity per cent

To understand the adequacy of simple additive-dominance model both scaling and joint scaling tests were performed **(Table 2)**. The scaling test showed all A, B, C and D scales were significant for twelve traits *viz.,* days to panicle emergence, days to 50 % flowering, days to maturity, plant height, numbers of filled grains per panicle, numbers of unfilled grains per panicle, spikelet fertility percentage, test weight, grain yield per plant, lesion numbers, area under disease progress curve and disease severity per cent. Only three scales were observed significant for two traits *viz.,* A, C and D scales for number of effective tillers per plant while B, C and D scales for panicle length, respectively. These results showed that for above studied twelve traits simple additive- dominance model was inadequate and epistatic interactions were present. Similar findings were previously reported in rice (Bano *et al.,* 2017). Results of chi square test performed under joint scaling test showed significance for all the traits related to yield as well as blast resistance studied in present investigation. The inadequacy of simple additive-dominance model revealed by results of scaling and joint scaling tests. The role of epistatic interactions was identified by lack of goodness of fit into three parameter models and the data was further subjected to six parameter models.

Table 2: Estimates from scaling and joint scaling tests for fourteen traits

Character	Scaling test				Joint scaling test			
	Scale A	Scale B	Scale C	Scale D	m	D	h	χ^2
#DPE	-21.77**± .21	-25.10** ± 1.16	-37.15** ± 1.96	-4.86** ± 1.20	79.04**	2.44*	-5.42**	974.75**
DOF	-21.90**±1.24	-24.60** ± 1.20	-36.21** ± 1.98	-5.14** ± 1.19	81.22**	1.19	-3.52**	849.07**
DOM	-21.50** ± 1.27	-27.27** ± 1.17	-38.46** ± 2.12	-5.15** ± 1.16	111.67**	0.34	-1.09	840.66**
PH	-10.30** ± 2.98	19.20** ± 2.81	47.50** ± 5.01	-19.30** ± 1.41	108.74**	4.65**	-23.55*	334.72**
NET	4.23** ± 1.20	-0.03 ± 1.04	-20.80** ± 1.74	-8.30** ± 0.85	10.34**	0.21	5.33**	162.04**
PL	-0.73 ± 0.74	-2.81** ± 0.65	16.88** ± 1.14	-10.71** ± 0.41	25.44**	0.54	-3.28**	741.41**
NFG	31.07** ± 12.28	-8.06** ± 10.84	-4.60** ± 20.34	13.80** ± 6.37	147.63**	19.14**	-54.59**	13.87**
NUG	-111.60** ± 9.10	-151.40** ± 9.51	-45.32**± 11.77	108.84** ± 7.10	63.02**	-3.76**	13.83**	392.27**
SFP	34.82** ± 3.35	39.93** ± 3.75	10.29** ± 6.66	32.23** ± 2.39	72.06**	7.70**	-29.59**	276.32**
TW	-6.55** ± 0.19	-6.95** ± 0.50	8.16** ± 0.51	-10.83** ± 0.33	16.63**	0.28	2.30**	1867.48**
GY	3.64** ± 2.43	12.60** ± 2.68	48.48** ± 3.77	-16.12** ± 1.9	25.03**	10.24*	-3.72**	205.76**
LN	20.20** ± 2.65	-19.70** ± 0.80	-6.40** ± 4.17	3.45** ± 1.70	18.96**	-8.38**	-11.05**	720.32**
AUDPC	-79.17**±38.32	-263.74**± 27.86	-687.08** ± 61.45	172.08**± 31.44	390.75**	-242.94**	-30.05**	173.04**
DSP	-4.53** ± 2.16	-18.82**± 1.57	-48.84** ± 3.56	12.75** ± 1.83	28.105**	-17.09**	-2.56**	267.50**

** and *: Significant at 1 and 5 per cent level, respectively

#(DPE) Days to panicle emergence, (DOF) Days to 50 per cent flowering, (DOM) days to maturity, (PH) plant height, (NET) number of effective tillers per plant, (PL) panicle length, (NFG) number of filled grains per panicle, (NUG) number of unfilled grains per panicle, (SFP) spikelet fertility per cent, (TW) test weight, (GY) grain yield per plant, (LN) lesion number, (AUDPC)area under disease progress curve and (DSP) disease severity per cent

Results of digenic nonallelic interaction model with six parameters namely *m, d, h, i, j* and *l* indicated that the epistatic interaction model was appropriate to explain the gene action in all the fourteen traits under study **(Table 3).** These results showed significant similarity with the earlier reports in rice (Bano *et al.,* 2017, Divya *et al.,* 2014, Makwana *et al.,* 2018). Mean and additive components were found highly significant for number of filled grains per plant, number of unfilled grains per plant, spikelet fertility percentage, grain yield per plant, area under disease progress curve and disease severity per cent. Similar results were reported previously for the number of filled spikelets (Bano *et al.,* 2017), grain yield per plant (Bano *et al.,* 2017, Kumar *et al.,* 2017, Makwana *et al.,* 2018, Kour *et al.,* 2019). The dominance (*h*) gene effects were found highly significant for all the characters under study. All three types of gene effects (additive, dominance and epistasis) were found highly significant for blast resistance traits studied, except for additive effect in lesion number. These results are in contradiction with the previous report of dominance and dominance × dominance (l) mainly governing the blast resistance related traits (Divya *et al.,* 2014). The dominance (*h*) and dominance × dominance (*l*) gene effects displayed opposite signs for all the traits studied indicating presence of duplicate epistasis **(Table 3)**. Presence of duplicate epistasis was previously reported for days to 50 % flowering, days to maturity, plant height, panicle length (Bano *et al.,* 2017), numbers of filled grains per panicle, number of effective tillers per plant (Bano *et al.,* 2017), spikelet fertility percentage (Divya *et al.,* 2014), test weight (Divya *et al.,* 2014, Bano *et al.,* 2017), grain yield per plant (Bano *et al.,* 2017, Kumar *et al.,* 2017, Makwana *et al.,* 2018, Kour *et al.,* 2019) and for blast related traits *viz.,* lesion numbers and disease severity per cent only complementary epistasis was reported earlier (Divya *et al.,* 2014).

Table 3: Estimation of gene effects based on six parameter model for fourteen traits

Traits	M	D	H	I	J	l
DPE	82.72** ± 0.46	-1.40 ± 0.78	5.12** ± 2.43	9.72** ± 2.40	-3.33** ± 1.65	-56.59** ± 3.68
DOF	84.88** ± 0.45	-1.22 ± 0.79	5.29** ± 2.42	10.28** ± 2.39	-2.70** ± 1.67	-56.78** ± 3.73
DOM	115.27** ± 0.45	-1.52 ± 0.74	6.87** ± 2.39	10.30** ± 2.33	-5.77** ± 1.62	-59.06** ± 3.62
PH	89.90** ± 0.56	-1.45 ± 0.87	21.86** ± 3.60	38.59** ± 2.82	29.50** ± 3.22	-29.70** ± 6.10
NET	9.90** ± 0.31	-0.97 ± 0.60	21.90** ± 1.82	16.56** ± 1.71	-4.27** ± 1.15	-12.36** ± 2.94
PL	20.99** ± 0.14	-0.25 ± 0.30	19.54** ± 0.96	21.42** ± 0.82	-1.07 ± 0.76	-25.96** ± 1.66
NFG	125.25** ± 2.64	-23.83** ± 3.57	-86.48** ± 15.43	-27.61** ± 12.74	-39.13** ± 13.53	50.63** ± 24.85
NUG	63.10** ± 2.20	-9.53** ± 5.58	238.34** ± 14.74	217.67** ± 14.21	-39.80** ± 12.67	-480.67** ± 25.24
SFP	66.72** ± 0.99	-2.73** ± 1.32	-83.88** ± 5.48	-64.47** ± 4.78	5.10** ± 3.98	139.22** ± 8.50
TW	15.95** ± 0.11	-0.94 ± 0.24	24.65** ± 0.67	21.66** ± 0.66	-0.40 ± 0.53	-35.17** ± 1.09
GY	15.42** ± 0.67	-5.96** ± 1.34	26.82** ± 4.02	32.24** ± 3.80	8.96** ± 3.45	-16.00** ± 6.5
LN	17.30** ± 0.81	0.85 ± 0.51	-30.30** ± 3.64	-6.90** ± -39.90	-39.90** ± 2.72	7.40** ± 4.65
AUDPC	477.51** ± 12.53	146.55** ± 18.97	-466.25** ± 65.34	-344.16** ± 62.89	-184.57** ± 42.30	1.23 ± 97.63
DSP	34.22** ± 0.73	10.02**± 1.07	-34.45** ± 3.79	-25.49** ± 3.66	-14.29** ± 2.38	2.15* ± 5.59

** and *: Significant at 1 and 5 per cent level, respectively

#(DPE) Days to panicle emergence, (DOF) Days to 50 per cent flowering, (DOM) days to maturity, (PH) plant height, (NET) number of effective tillers per plant, (PL) panicle length, (NFG) number of filled grains per panicle, (NUG) number of unfilled grains per panicle, (SFP) spikelet fertility per cent, (TW) test weight, (GY) grain yield per plant, (LN) lesion number, (AUDPC)area under disease progress curve and (DSP) disease severity per cent

Results of present experiment revealed that yield attributes and blast resistance traits in the cross HUR 3022 × Tetep of rice are governed by more than one gene showing duplicate epistatic interactions. Although, the additive gene effect was highly significant for all the blast resistance related traits in three parameter model and six parameter model, lesion number revealed that this was due to additive × additive type of epistasis. The grain yield depicted predominance of dominance gene action with higher additive × additive gene action and duplicate epistasis. The results show that for improvement of all the traits under study, biparental mating design and transgressive segregant selection in later generations will be helpful. The individual traits need to be improved simultaneously, to get all the positive alleles in one improved progeny.

Acknowledgments

The financial support in the form of a DST-INSPIRE Fellowship (INSPIRE Code: IF160896) to first author for full-time doctoral (Ph. D.) degree programme at Banaras Hindu University, Varanasi, Uttar Pradesh, India provided by Ministry of Science and Technology, Department of Science and Technology, New Delhi, Government of India as for this study is sincerely acknowledged.

References

Anonymous (2021) Food and Agricultural Organization statistic.www.faostat.org.

Anonymous (2021-22) Directorate of Economics and Statistics, Department of agriculture and farmers welfare, Ministry of agriculture and farmers welfare, GOI. https://eands.dacnet.nic.in/APY_96_To_06.htm.

Ashkani S, Rafii MY, Shabanimofrad M, Miah G, Sahebi M, Azizi P, Tanweer FA, Akhtar M S and Nasehi A. 2015. Molecular breeding strategy and challenges towards improvement of blast disease resistance in rice crop. *Frontiers in Plant Science*, 6(886): 1-14.

Bano DA, Singh SP and Waza SA. 2017. Generation mean analysis for yield and quality traits in aromatic genotypes of rice (*Oryza sativa* L.). *International Journal of Pure and Applied Bioscience*, 5(6): 870-878.

Billa SC, Haritha T, Krishnaveni B, Swapna M and Tushara M. 2024. Character association studies for yield, nutritional and cooking quality characters in coloured rice (*Oryza sativa* L.). *Journal of Rice Research*, 17(1): 65-71.

Boss CGS, Veni K, Rani Ch, Tushara M and Ramesh D 2024. Genetic parameters and association studies for yield and grain quality traits in rice genotypes derived from distant crosses. *Journal of Rice Research*, 17(1): 57-64.

Divya B, Robin S, *Rabi*ndran R, Senthil S, Raveendran M and Joel AJ. 2014. Marker assisted backcross breeding approach to improve blast resistance in indian rice (*Oryza sativa* L) variety ADT-43. *Euphytica*, 200(1): 61-77.

Hayman BI and Mather K. 1955. The description of genetic interaction in continuous variation. *Biometrics* 11**(**1**)**: 69-82.

IRRI (2013). Standardization evaluation system for rice. International Rice Research Institute, P.O. Box 933, 1099 Manila, Philippines, 5:18.

Jondhale AS, Bhave SG and Jogi SR. 2018. Genetic evaluation of quantitative traits of rice (*Oryza sativa* L.) by generation mean analysis. *Journal of Pharmacognosy and Phytochemistry*, 1: 2477-2480.

Kato H. 2001. Rice blast disease. Pesticide Outlook 12(1): 23-25.

Khush GS. 2005. What it will take to feed 5.0 billion rice consumers in 2030. *Plant Molecular Biology*, 59: 1-6.

Khush GS. 2013. Strategies for increasing the yield potential of cereals: case of rice as an example. *Plant Breeding,* 132(5): 433-436.

Kiani SH, Kazemitabar SK, Jelodar NAB and Ranjbar GA. 2013. Genetic evaluation of quantitative traits of rice (*Oryza sativa* L.) using generation mean analysis. *International Journal of Agriculture and Crop Sciences*, 5(19): 2329-2336.

Kour A, Kumar B, Singh B, Attri H and Bangarwa SK. 2019. Generation mean analysis for yield and grain quality traits in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding*, 10(1): 289-292.

Kumar PS, Saravanan K and Sabesan T. 2017. Generation mean analysis for yield and grain quality characters in rice (*Oryza sativa* L.). *Plant Archives*, 17(1): 557-560.

Kumari K, Dass A, Dhar S, Sudhishri, Singh RK, Das TK and Rani A. 2024. Performance of basmati rice (*Oryza sativa* L.) under variable irrigation and nitrogen management. *Indian Journal of Agricultural Sciences*, 94(5): 467–471.

Liu CT, Mao BG, Yuan DY, Chu CC and Duan MJ. 2022. Salt tolerance in rice: physiological responses and molecular mechanisms. *Crop Journal*, 10(1):13–25.

Makwana RR, Patel VP, Pandya MM and Chaudhari BA. 2018. Inferences on magnitude and nature of gene effects for morpho-physiological traits in rice (*Oryza sativa* L.). *International Journal of Pure and Applied Bioscience*, 6(2): 1488-1493.

Mather K. 1949. Biometrical Genetics, Dover Publication, Inc., New York.

Qi Z, Du Y, Yu J, Zhang R, Yu M, Cao H, Song T, Pan X, Liang D and Liu Y. 2023. Molecular detection and analysis of blast resistance genes in rice main varieties in jiangsu province, china. *Agronomy*, 13(1): 157.

Sabin K, Bijay S, Amrit B, Raman GD, Bhuwan S, Priyanka N, Man SS and Prasad GS. 2016. Screening of different rice genotypes against *Pyricularia grisea* Sacc. in natural epidemic condition at seedling stage in chitwan, nepal.

Advances in Crop Science and Technology, 4(4): 1-6.

Singh VK, Singh A, Singh SP, Ellur RK, Singh D, Krishnan SG, Bhowmick PK, Nagarajan M, Vinod KK, Singh UD, Mohapatra T, Prabhu KV and Singh AK. 2013. Marker assisted simultaneous but stepwise backcross breeding for pyramiding blast resistance genes *Piz5* and *Pi54* into an elite basmati rice restorer line 'PRR 78'. *Plant Breeding*, 132(5):486-495.

Yarasi B, Sadumpati V, Immanni CP, Vudem DR and Khareedu VR. 2008. Transgenic rice expressing allium sativum leaf agglutinin (ASAL) exhibits high level resistance against major sap-sucking pests. *BMC Plant Biology*, 8(102): 1-13.

Yin JJ, Zou LJ, Zhu XB, Cao YY, He M and Chen XW. 2021. Fighting the enemy: How rice survives the blast pathogen's attack. *Crop Journal,* 9(3):543–552.

Zhang H, Li G, Li W and Song F. 2009. Transgenic strategies for improving rice disease resistance. *African Journal of Biotechnology,* 8(9):1750-1757.

RESEARCH ARTICLE https://doi.org/10.58297/PBZA1175

Morphological and Pathogenic Variability among Isolates of *Xanthomonas oryzae* pv. *oryzae*, Causal Agent of Bacterial Leaf Blight of Rice from Godavari Zone of Andhra Pradesh

Shanmuki Shirisha P[1*], Ramabhadra Raju M[2], Madhusudhan P[3], Sandhya Rani C[4], Srinivas T[5], Bhuvaneswari V[6] and Deepthi Priya B[7]

[1]Department of Plant Pathology, Agricultural College, Bapatla (ANGRAU), Andhra Pradesh
[2,7]Department of Plant Pathology, ARS, Peddapuram (ANGRAU), Andhra Pradesh
[3]Department of Plant Pathology, ARS, Nellore
[4]Department of Entomology, Agriculture College, Bapatla
[5]Department of Genetics and Plant Breeding RARS, Maruteru
[6]Department of Plant Pathology RARS, Maruteru
Corresponding Author: sirishapasam038@gmail.com

Received: 25th August, 2025, Accepted: 15th October, 2025

Abstract

Bacterial leaf blight (BLB) of rice, caused by *Xanthomonas oryzae* pv. *oryzae* (*Xoo*), is a major biotic constraint in rice cultivation and is widespread across India. Present study was undertaken to assess morphological, biochemical and pathogenic variability among the twenty isolates of *Xanthomonas oryzae* pv. *oryzae* collected from major rice growing areas of Godavari zone of Andhra Pradesh. Variation in colony size, colour, margin, appearance, texture and pigmentation were observed among the isolates. However, all the isolates were gram negative and tested positive for KOH test, catalase test, and starch hydrolysis test while, tested negative for oxidase test. In the pot study, *Xoo* isolates varied in their pathogenic ability in terms on lesion development post artificial inoculation (leaf clip method) on the three rice cultivars *viz*., BPT-5204, TN-1, and MTU-7029 under study. *Xoo* isolates from Konaseema district were found more virulent followed by isolates from Kakinada, West Godavari, Eluru and East Godavari districts.

Key words: BLB, Morphology, biochemical, pathogenic variability, rice, *Xanthomonas oryzae* pv. *oryzae*.

Introduction

Rice (*Oryzae sativa* L) is the most extensively consumed staple food for nearly 2.7 billion people worldwide, cultivated in tropical, subtropical and temperate countries of the world. In India, paddy production and productivity is greatly hampered by various biotic and abiotic factors resulting in yield losses up to 20-30%. Among the diseases, bacterial leaf blight (BLB) caused by *Xanthomonas oryzae* pv. *oryzae* (*Xoo*) is a serious problem and threat to rice production in both tropical and temperate rice growing regions due to its high epidemic potential (Mew, 1987). The causal organism of bacterial leaf blight of rice (BLB), is a Gram-negative, rod shaped, non-spore forming bacteria having single polar flagellum. BLB pathogen is known to be dynamic and have high degree of variability within the pathogen population (Chen *et al*., 2019). Morphologically, *Xoo* populations were typically yellow, mucoid, Gram-negative rods with variation in response of *Xoo* to certain biochemical responses *viz*., catalase activity, KOH solubility, starch hydrolysis and gelatin liquefaction (Yugander *et al.,* 2022). The Yield loss due to bacterial blight can be as much as 70% when susceptible varieties are grown and up to 100% in severe conditions (Walters *et al.*, 2013). In Andhra Pradesh, rice is a major crop in Godavari zone of Andhra Pradesh accounting for 27.7% of the total rice cultivation area (ANGRAU Paddy Outlook Report, 2023–2024). Bacterial leaf blight is one of the major diseases of rice in this region with incidence ranging from 25-80% on different varieties, rice cvs. Prabhat (IET 3626), Samba Mahsuri (BPT 5204) and PL-1100, whereas cv. Swarna (MTU 7029) was found comparatively resistant (Srivastava, 1966; Laha *et al.*, 2017). High degree of race cultivar specificity was recorded among *Xoo* races infecting different rice cultivars in different parts of the world (Salzberg *et al.*, 2008; Quibod *et al*., 2016). Variation in virulence among *Xoo* isolates was observed among resistant and susceptible rice cultivars, with differences in virulence more apparent during advanced crop growth stages. Virulent strains were reported to exhibit faster multiplication rates and higher population densities, which highlights the epidemiological significance of virulent *Xoo* populations in dictating disease progression during the crop season (Noda and Kaku, 1999). Keeping in view the destructive potential of BLB of rice, there is a need to understand region specific characters (morphology and biochemical reactions) of *Xoo* isolates and race cultivar specificity for formulating future disease management and breeding strategies. This study aims at understanding morphological, biochemical and pathogenic variability among *Xoo* isolates of Godavari zone of Andhra Pradesh.

Materials and Methods

The study was undertaken during the 2024–2025 at RARS, Maruteru (16.63° North, 81.75° West) of Acharya N G Ranga Agricultural University. A total of twenty *Xanthomonas oryzae pv. oryzae* (*Xoo*) isolates were obtained from five districts *viz*., Kakinada, East Godavari, West Godavari, Dr. B. R. Ambedkar Konaseema and Eluru of Godavari zone of Andhra Pradesh. Bacterial leaf blight (BLB)-infected rice leaves were collected during the panicle initiation to heading stages of crop growth. BLB pathogen was isolated from the infected leaves of rice crop as per the procedure described by Shankara *et al.,* (2016). Actively growing bacterial culture (48-72 h old) was used for conducting laboratory assays.

Morphological characterization

The study of colony morphology of twenty *Xoo* isolates was done using the standard procedure described by Bradbury (1970) and Mew *et al.,* (1993) with special consideration on colour, size of colonies, and their outline (circular and entire or indented or wavy or rhizoid). Their elevation was recorded as convex, flat, plate-like, or nodular. The texture and appearance were described as smooth, shiny, slimy, and mucoid, with yellow pigmentation.

Biochemical characterization

Pure culture of the *Xoo* was assayed for their reaction to standard biochemical tests for confirming the identity and understanding variability among the isolates. All the isolates of *X. oryzae* pv. *oryzae* were characterized based on the reaction of isolates in biochemical assays. Five biochemical tests *viz*., Gram staining, KOH test, Catalase, Oxidase test and Starch hydrolysis were performed during the study. Tests were performed as per standard protocols described by Aneja (2003).

Pathogenic Variability

A pot study was conducted at green house facility of Plant Pathology department, RARS, Maruteru. Three rice cultivars *viz*., TN-1 (national susceptible check for BLB), BPT-5204 (local susceptible check) and MTU-7029 (local resistant check) with differential resistance levels were selected for study on pathogenic variability among BLB isolates. Bacterial suspension of each isolate (10^8-10^9cfu/ml) obtained from 3-day old culture was inoculated by leaf clip method of inoculation (Kauffman, 1973). Surface sterilized scissors were dipped in bacterial suspension and used for clipping the top 2-3 cm of healthy leaves during panicle initiation to heading stage of crop growth. Final observations on development of susceptible BLB lesions was recorded at 15 days of inoculation by measuring the diseased lesion length (cm) for confirming pathogenicity of the isolates (Ou, 1985).

Results and Discussion

Cultural characteristics of *Xanthomonas oryzae* pv. *oryzae* isolates were studied at 72 hours after incubation. The pathogenicity of *Xoo* isolates was confirmed by the appearance of typical BLB symptoms 15 days after inoculation. Observations on the reaction of *Xoo* isolates to biochemical tests were taken as per standard protocol.

Morphological characterization

Colony diameter of twenty *Xoo* isolates collected from Godavari zone of Andhra Pradesh ranged from 1.21 to 2.52 mm. Isolates, *Xoo*10, *Xoo*19, *Xoo*6, *Xoo*11, *Xoo*9, *Xoo*8, and *Xoo*5 produced colonies in the range of 2.04-2.52 mm, whereas, *Xoo*2, *Xoo*12, *Xoo*20, and *Xoo*13 had colonies in the range of 1.24–1.84 mm. Characteristic yellow to dark yellow colonies were observed in twelve *Xoo* isolates, while five isolates recorded light yellow and three isolates creamy yellow colour (**Table 1**). Colony margin was mostly circular, with a few being circular to irregular (*Xoo*3, *Xoo*8, *Xoo*19) or irregular (*Xoo*17). Colony elevation among *Xoo* isolates from Godavari zone was mostly convex, however slightly raised colonies were observed in six *Xoo* isolates and flattened forms were recorded in *Xoo*11 and *Xoo*13. All isolates had a smooth texture and yellow pigmentation (**Table 2**). In terms of colony appearance, all the isolates had slimy and mucoid nature, while ten isolates were observed to be shiny and slimy, and four isolates *Xoo*4, *Xoo*5, *Xoo*10, *Xoo*17 showed shiny and mucoid characteristics. Present findings on variation in *Xoo* colony morphology among the collected isolates were in agreement with Han *et al*., 2005 who summarized *Xoo* morphology as circular, convex, yellow to straw yellow coloured with smooth surface on the nutrient agar medium. Similar findings were also made by Shankara *et al*., (2016) who reported variation in colony size, shape and colour among *Xoo* isolates. Variation in phenotype among BLB isolates of Godavari zone of Andhra Pradesh could likely contribute to differential virulence patterns observed at field level.

Table 1: Isolate code and locations of leaf sample collected for isolation of *Xanthomonas oryzae* pv. *oryzae* isolates (*Xoo*) from Godavari zone of Andhra Pradesh

Sl. No.	Isolate Code	Village	Mandal	District
1	*Xoo* 1	Elakolanu	Rangampeta	East Godavari
2	*Xoo* 2	Gandepalli	Gandepalli	
3	*Xoo* 3	Murari	Gandepalli	
4	*Xoo* 4	Vadisaleru	Rangampeta	
5	*Xoo* 5	Rajupalem	Mummidivaram	Dr. B. R. Ambedkar Konaseema
6	*Xoo* 6	Krapa	Ainavilli	
7	*Xoo* 7	Mummidivaram	Mummidivaram	
8	*Xoo* 8	Magam	Ainavilli	
9	*Xoo* 9	Nadipudi	Penugonda	West Godavari district
10	*Xoo* 10	Chinnamvaripalem	Penugonda	
11	*Xoo* 11	Kodamanchili	Achanta	
12	*Xoo* 12	Pedamallam	Achanta	
13	*Xoo* 13	Gogulapadu	Pedapadu	Eluru district
14	*Xoo* 14	Bhogapuram	Pedavegi	
15	*Xoo* 15	Vatluru	Pedapadu	
16	*Xoo* 16	Koppaka	Pedavegi	
17	*Xoo* 17	Kapavaram	Samalkota	Kakinada district
18	*Xoo* 18	Tatiparthi	Gollaprollu	
19	*Xoo* 19	Gollaprollu	Gollaprollu	
20	*Xoo* 20	Boyanapudi	Samalkota	

Table 2: Morphological characterisation of *Xoo* isolates of Godavari zone of Andhra Pradesh

Sl. No	Isolate	Colony Characters						
		Mean colony diameter (mm)	Colour	Margin	Elevation	Appearance	Texture	Pigmentation
1.	*Xoo*1	1.42	Yellow	Circular	Convex	Mucoid	Smooth	Yellow
2.	*Xoo*2	1.84	Light Yellow	Circular	Slightly Raised	Shiny, Slimy	Smooth	Yellow
3.	*Xoo*3	2.12	Light Yellow	Circular to irregular	Convex	Shiny, Slimy	Smooth	Yellow
4.	*Xoo*4	1.21	Creamy Yellow	Circular	Convex	Shiny, Mucoid	Smooth	Yellow
5.	*Xoo*5	2.52	Dark Yellow	Circular	Convex	Shiny, Mucoid	Glistening	Yellow
6.	*Xoo*6	2.06	Yellow	Circular	Convex	Shiny, Slimy	Smooth	Yellow
7.	*Xoo*7	1.61	Yellow	Circular	Convex	Shiny, Slimy	Smooth	Yellow
8.	*Xoo*8	2.26	Dark Yellow	Circular to irregular	Convex	Slimy	Smooth	Yellow
9.	*Xoo*9	2.14	Dark Yellow	Circular	Convex	Slimy, Shiny	Smooth	Yellow
10.	*Xoo*10	2.04	Dark Yellow	Circular	Slightly Raised	Shiny, Mucoid	Smooth	Yellow
11.	*Xoo*11	2.13	Dark Yellow	Circular	Flattened	Slimy, Shiny	Smooth	Yellow
12.	*Xoo*12	1.24	Dark Yellow	Circular	Slightly Raised	Shiny, Slimy	Smooth	Yellow
13.	*Xoo*13	1.25	Light Yellow	Circular	Flattened	Slimy	Smooth	Yellow
14.	*Xoo*14	1.34	Light Yellow	Circular	Slightly Raised	Shiny, Slimy	Smooth	Yellow
15.	*Xoo*15	1.74	Yellow	Circular	Convex	Slimy	Smooth	Yellow
16.	*Xoo*16	1.64	Creamy Yellow	Circular	Convex	Slimy	Smooth	Yellow
17.	*Xoo*17	1.84	Dark Yellow	Irregular	Slightly, Raised	Shiny, mucoid	Glistening	Yellow
18.	*Xoo*18	1.52	Light Yellow	Circular	Slightly Raised	Lightly Mucoid	Smooth	Yellow
19.	*Xoo*19	2.06	Creamy Yellow	Circular to irregular	Convex	Shiny, Slimy	Smooth	Yellow
20	*Xoo*20	1.24	Yellow	Circular	Convex	Shiny, Slimy	Smooth	Yellow

Biochemical characterization

All the twenty *Xoo* isolates of Godavari zone of Andhra Pradesh uniformly exhibited a Gram-negative reaction and tested positive for KOH solubility indicating Gram -ve nature of *Xanthomonas oryzae* pv *oryzae* (**Table 3**). Further, all isolates were found aerobic as evidenced by bubble formation on exposure to H_2O_2 (catalase test). All *Xoo* isolates were found to have ability to hydrolyse starch (starch hydrolysis test) and the reaction for oxidase test was found negative for all the isolates as evidenced by lack of development of characteristic blue-purple colour when tested with Kovacs reagent. Although previous findings suggested variation among isolates to catalase, starch hydrolysis and oxidase tests, except being Gram negative and positive reaction to KOH solubility test, (Shankara *et al.*, 2016, Padmaja, 2017 and Sreeramulu and Nayudu, 1987, Jabeen *et al.,* 2012, Patil *et al.,* 2023). However, uniform reaction of *Xoo* isolates to catalase activity, gelatin liquefaction, KOH solubility and protein digestion, with variation mainly confined to starch hydrolysis was observed by Chatterjee (2023). This study observed uniform reaction of *Xoo* isolates to biochemical tests, *viz*., starch hydrolysis, oxidase and catalase tests.

Table 3. Biochemical characterisation of different *Xoo* isolates of Godavari zone of Andhra Pradesh

Sl. No	Isolate	Gram staining	KOH Test (3%)	Catalase Test	Oxidase Test	Starch Hydrolysis
1.	*Xoo*1	Negative	Positive	Positive	Negative	Positive
2.	*Xoo*2	Negative	Positive	Positive	Negative	Positive
3.	*Xoo*3	Negative	Positive	Positive	Negative	Positive
4.	*Xoo*4	Negative	Positive	Positive	Negative	Positive
5.	*Xoo*5	Negative	Positive	Positive	Negative	Positive
6.	*Xoo*6	Negative	Positive	Positive	Negative	Positive
7.	*Xoo*7	Negative	Positive	Positive	Negative	Positive
8.	*Xoo*8	Negative	Positive	Positive	Negative	Positive
9.	*Xoo*9	Negative	Positive	Positive	Negative	Positive
10.	*Xoo*10	Negative	Positive	Positive	Negative	Positive
11.	*Xoo*11	Negative	Positive	Positive	Negative	Positive
12.	*Xoo*12	Negative	Positive	Positive	Negative	Positive
13.	*Xoo*13	Negative	Positive	Positive	Negative	Positive
14.	*Xoo*14	Negative	Positive	Positive	Negative	Positive
15.	*Xoo*15	Negative	Positive	Positive	Negative	Positive
16.	*Xoo*16	Negative	Positive	Positive	Negative	Positive
17.	*Xoo*17	Negative	Positive	Positive	Negative	Positive
18.	*Xoo*18	Negative	Positive	Positive	Negative	Positive
19.	*Xoo*19	Negative	Positive	Positive	Negative	Positive
20.	*Xoo*20	Negative	Positive	Positive	Negative	Positive

Pathogenicity Variability

All the *Xoo* isolates under study collected from Godavari zone of Andhra Pradesh were individually inoculated on three cultivars by leaf clip method of inoculation. After 3 days of inoculation, small water-soaked lesions with pale yellow discoloration appeared at the cut ends, which gradually expanded into yellow lesions with wavy margins, progressing to leaf blighting towards the base. Bacteria from the infected leaf was reisolated and compared with the original culture to prove Koch's postulate. Differences in lesion development indicated relative virulence among BLB isolates in addition to confirming pathogenicity of the isolates. BLB isolates inducing more lesion length in susceptible checks were considered more virulent in comparison in less lesion length producing isolates (Liu *et al.,* 2022). Among the three varieties, local susceptible check, BPT-5204 was found more susceptible to all the *Xoo* isolates recording mean lesion length of 3.66 cm in comparison to 3.25 cm recorded TN1 (**Table 4**). Local resistant check, MTU-7029 recorded mean lesion length of 0.32 cm, confirming its stable resistance to bacterial leaf blight (BLB). These findings are consistent with earlier reports which indicated TN-1 and BPT-5204 as highly susceptible varieties, while MTU-7029 was recognized for its resistance to *Xoo* strains (Sundaram *et al.,* 2011).

Table 4: Variation in pathogenic ability (lesion length) of *Xoo* isolates on three standard check varieties of rice (Pot study)

Sl. No	BLB Isolate	Mean lesion length (cm) - 15 Days after inoculation			
		BPT-5204 Local Susceptible check	TN-1 National Susceptible check	MTU-7029 Local Resistant check	Mean
1.	*Xoo*1	3.04* (1.88)^{j**}	1.91 (1.55)^{p}	0.28 (0.88)^{vwx}	1.74 (1.43)^{j}
2.	*Xoo*2	3.44 (1.98)^{h}	1.83 (1.52)^{p}	0.27(0.87)^{vwxyz}	1.84 (1.46)^{ij}
3.	*Xoo*3	2.62 (1.76)^{klm}	1.52 (1.41)^{q}	0.47 (0.98)st	1.53 (1.38)^{k}
4.	*Xoo*4	2.01 (1.58)^{p}	4.25 (2.18)^{f}	0.41 (0.94)^{stu}	2.22 (1.57)^{h}
5.	*Xoo*5	4.58 (2.25)^{e}	2.60 (1.76)^{klm}	0.26(0.87)^{vwxyz}	2.48 (1.62)^{g}
6.	*Xoo*6	4.14 (2.15)^{fg}	3.47 (1.99)^{h}	0.33 (0.91)^{uv}	2.64 (1.68)^{f}
7.	*Xoo*7	5.51 (2.45)^{a}	5.35 (2.42)^{ab}	0.68 (1.08)^{r}	3.84 (1.98)^{a}
8.	*Xoo*8	5.28 (2.40)^{ab}	3.05 (1.88)^{j}	0.32 (0.90)^{uvw}	2.88 (1.73)^{e}
9.	*Xoo*9	5.12 (2.37)^{bc}	4.75 (2.29)^{de}	0.51 (0.99)^{s}	3.46 (1.86)^{b}
10.	*Xoo*10	3.59 (2.02)^{h}	3.17 (1.91)^{ij}	0.29 (0.89)^{uvwx}	2.35 (1.60)^{g}
11.	*Xoo*11	2.42 (1.71)^{mno}	2.29 (1.67)^{no}	0.36 (0.92)^{tuv}	1.69 (1.43)^{j}
12.	*Xoo*12	2.21 (1.64)^{o}	3.41 (1.97)^{hi}	0.21 (0.83)^{xyz}	1.94 (1.48)^{i}
13.	*Xoo*13	2.50 (1.73)^{lmn}	2.78 (1.81)^{k}	0.23 (0.85)^{wxyz}	1.83 (1.46)^{ij}
14.	*Xoo*14	5.21 (2.39)^{b}	3.46 (1.99)^{h}	0.34 (0.91)^{uv}	3.01 (1.76)^{de}
15.	*Xoo*15	4.86 (2.31)^{cde}	2.67 (1.78)^{kl}	0.33 (0.91)^{uvw}	2.62 (1.66)^{f}
16.	*Xoo*16	1.41 (1.38)^{q}	4.01 (2.12)^{fg}	0.17 (0.82)^{z}	1.86 (1.44)^{j}
17.	*Xoo*17	2.33 (1.68)^{no}	2.37 (1.69)^{no}	0.17 (0.82)^{yz}	1.62 (1.39)^{k}
18.	*Xoo*18	3.42 (1.98)^{h}	3.41 (1.97)^{hi}	0.27 (0.88)^{vwxy}	2.36 (1.61)^{g}
19.	*Xoo*19	4.71 (2.28)^{de}	3.95 (2.11)^{g}	0.34 (0.92)^{uv}	3.01 (1.77)^{d}
20.	*Xoo*20	4.91 (2.32)^{cd}	4.91 (2.32)^{cd}	0.26 (0.87)^{vwxyz}	3.36 (1.83)^{c}
Mean	3.66 (2.02)^{a}	3.25 (1.92)^{b}	0.32 (0.91)^{c}		
	Variety (A)	**Isolates (B)**	**Interaction: VxI (AxB)**		
SEm ±	0.005	0.013	0.022		
C.D. ($p \leq 0.05$)	0.014	0.036	0.063		
CV (%)	2.39				

**Figures in parentheses are square root transformed values; * Values are mean of three replications

Among the BLB isolates, *Xoo*7 from Konaseema was the most virulent, with a mean lesion length of 3.84 cm. Isolates *Xoo*7, *Xoo*9, *Xoo*14, *Xoo*19, and *Xoo*20 were virulent on both susceptible checks, while *Xoo*8 and *Xoo*14 were more virulent on BPT-5204, and *Xoo*4 and *Xoo*16 on TN-1. *Xoo*11 and *Xoo*3 showed moderate reactions on the susceptible checks but higher virulence on MTU-7029 summarised in **Table 3**. Mean lesion length recorded on susceptible cultivars (**Figure 1**) indicated that *Xoo* isolates from Konaseema district showed more virulence followed by Kakinada, West Godavari, Eluru and East Godavari districts.

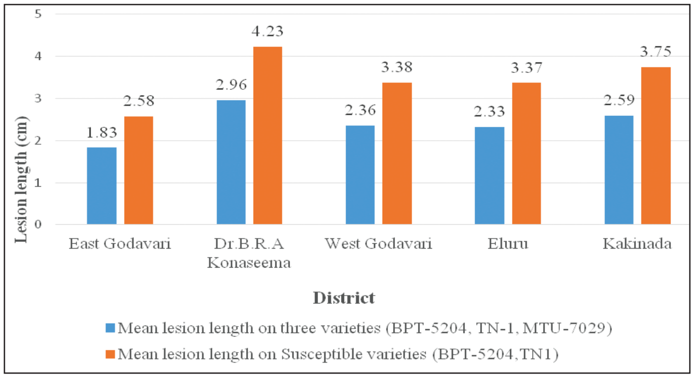


Figure 1: Variation in virulence (mean lesion length on identified check varieties) among *Xoo* isolates of Godavari zone of Andhra Pradesh (Pot study)

These results indicate variability in pathogenicity among *Xoo* isolates from the Godavari zone, consistent with findings by Adhikari *et al.,* (1995) and Hajira *et al*., (2016). Diversity among the *Xoo* genotypes and races could also be due to genomic variation and strain-specific adaptations (Nelson *et al*., 1994, Salzberg *et al.*, 2008). Similarly, Yugander *et al.,* (2022) reported extensive variability among *Xoo* isolates in Andhra Pradesh classifying based on virulence and pathotypes were grouped in three genetic clusters, with several highly aggressive types predominating in the region. Morphological and biochemical variations among the *Xoo* isolates could have induced changes in pathogenic ability among *Xoo* isolates. Further, pathogenic diversity could be attributed to selection pressure on *Xoo* pathogen by the rice cultivar in the location, crop management practices and weather conditions.

Acknowledgements

The authors are highly grateful to Acharya N G Ranga Agricultural University, Lam, Guntur for facilities and support for undertaking the study.

References

Acharya N. G. Ranga Agricultural University. 2023. Paddy Outlook Report - June–July 2023-24. Agriculture Market Intelligence Centre, ANGRAU, Lam, Guntur. pp 7.

Adhikari TB, Cruz C, Zhang Q, Nelson RJ, Skinner DZ, Mew TW and Leach JE. 1995. Genetic diversity of *Xanthomonas oryzae* pv. *oryzae* in Asia. *Applied and Environmental Microbiology*, 61(3): 966–971.

Aneja KR. 2003. Staining and Biochemical Techniques. In: Experiments in Microbiology, Plant Pathology and Biotechnology, 4th Edition, New Age International Ltd., New Delhi. Bradbury TF. 1970. Isolation and preliminary study of bacteria from plants. *Review of Plant Pathology*, 45(15): 213–218.

Chatterjee P. 2023. Biochemical Characterization of Xanthomonas campestris pv. oryzae Causing Leaf Blight Disease in Rice Plant. *Bulletin of Pure and Applied Sciences-Botany*, 42(1): 13-18

Chen X., Wei S and Yan Q. 2019. Virulence and DNA fingerprinting analysis of Xanthomonas oryzae pv. oryzae identify a new pathotype in Guangxi, South China. *Journal of Basic Microbiology*, 59(11): 1082–1091

Hajira SK, RM Sundaram, GS Laha, A Yugander, SM Balachandran, BC Viraktamath, K Sujatha, CH Balachiranjeevi, K Pranathi, M Anila and S Bhaskar. 2016. A single-tube, functional marker-based multiplex PCR assay for simultaneous detection of major bacterial blight resistance genes xa21, xa13, and xa5 in rice. *Rice Science*, 23(3): 144–151.

Han J, L Sun, X Dong, Z Cai, X Sun, H Yang and W Song. 2005. Characterization of a novel plant growth-promoting bacteria strain *Delftia tsuruhatensis* HR4 both as a diazotroph and a potential biocontrol agent against various plant pathogens. *Systematic and Applied Microbiology*, 28(1): 66–76.

Jabeen RT, Iftikhar and H Batool. 2012. Isolation, characterization, preservation and pathogenicity test of *Xanthomonas oryzae* pv. *oryzae* causing BLB disease in rice. *Pakistan Journal of Botany*, 44(1): 261–265.

Kauffman HE. 1973. An improved technique for evaluating resistance of rice varieties to *Xanthomonas oryzae*. *Plant Disease Reporter*, 57: 537–541.

Laha GS, Singh R, Ladhalakshmi D, Sunder S, Prasad MS, Dagar CS and Babu VR. 2017. Importance and Management of Rice Diseases: A Global Perspective. In: Chauhan B, Jabran K, Mahajan G. (eds) Rice Production Worldwide. Springer, Cham. pp 303-360

Liu M, Tian Y, Zaki HEM, Ahmed T, Yao R, Yan C, Leptihn S, Loh B, Shahid MS, Wang F, Chen J and Li B. 2022. Phage Resistance Reduced the Pathogenicity of Xanthomonas oryzae pv. oryzae on Rice. *Viruses*, 14(8): 1770.

Mew TW. 1987. Current status and future prospects of research on bacterial blight of rice. *Annual Review of Phytopathology*, 25: 359–382.

Mew TW, Alvarez AM, Leach JE and Swings J. 1993. Focus on bacterial blight of rice. *Plant Disease*, 77(1): 5-12.

Nelson RJ, MR Baraoidan, CMV Cruz, IV Yap and JE Leach. 1994. Relationship between phylogeny and pathotype for the bacterial blight pathogen of rice. *Applied Environmental Microbiology*, 60(9): 3275–3283

Noda T and Kaku H. 1999. Growth of *Xanthomonas oryzae* pv. *oryzae* in Planta and in Guttation Fluid of Rice, *Annals of Phytopathological Society of Japan*. 65: 9-14

Ou SH. 1985. *Rice Diseases*, 2nd edn. Commonwealth Mycological Institute, Kew, Surrey, England, pp. 61–96.

Padmaja G. 2017. Studies on bacterial blight of rice *(Oryza sativa* L.) [Doctoral dissertation]. Professor Jayashankar Telangana State Agricultural University, Hyderabad.

Patil SS, Prasannakumar MK, and Reddy NK. 2023. Morphological and Biochemical Characterization of Xanthomonas oryzae pv. oryzae Isolates from different Regions of India. *Mysore Journal of Agricultural Sciences*, *57*(3): 344-355.

Quibod IL, AP Quintero, NJ Booher, GS Dossa, G Grande, B Szurek, CV Cruz, AJ Bogdanove and R Oliva. 2016. Effector Diversification Contributes to *Xanthomonas oryzae* pv. *oryzae* Phenotypic Adaptation in a Semi-Isolated Environment. *Science Reports*, 6(34137): 134-137.

Salzberg SL, Sommer DD, Schatz MC, Phillippy AM, *Rabi*nowicz PD, Tsuge S, Furutani A, Ochiai H, Delcher AL, Kelley D, Madupu R, Puiu D, Radune D, Shumway M, Trapnell C, Aparna G, Jha G, Pandey A, Patil PB, Ishihara H, Meyer DF, Szurek B, Verdier V, Koebnik R, Dow JM, Ryan RP, Hirata H, Tsuyumu S, Won Lee S, Seo YS, Sriariyanum M, Ronald PC, Sonti RV, Van Sluys MA, Leach JE, White FF & Bogdanove AJ. 2008. Genome sequence and rapid evolution of the rice pathogen *Xanthomonas oryzae* pv. oryzae PXO99A. *BMC Genomics*, 9(204): 1-16.

Shankara K, MB Patil, D Pramesh and G Sunkad. 2016. Isolation and characterization of bacterial leaf blight of rice (*Xanthomonas oryzae* pv. *oryzae*) isolates from Southern India. *Advances in Life Sciences*, 5(14): 5625–5633.

Sreeramulu A and Nayudu MV. 1987. Biochemical characters and pathogenic variation of different isolates of paddy bacterial leaf blight pathogen. *Oryza*, 24(4): 363–367.

Srivastava DN. 1966. Epidemiology and control of bacterial blight of rice in India. In: Proceedings of a symposium of rice diseases and their control by growing resistant varieties and other measures; p. 11–18.

Sundaram RM, Laha GS, Viraktamath BC, Sujatha K, Natarajkumar P, Hari Y, Srinivasa Rao K, Reddy CS, Balachandran SM, Madhav MS and Hajira SK. 2011. Marker-assisted breeding for development of bacterial blight resistant rice. In: Genomics and Crop Improvement: Relevance and Reservations, Acharya N G Ranga Agricultural University, Hyderabad.

Walters DR, Ratsep J and Havis ND. 2013. Controlling crop diseases using induced resistance: challenges for the future. *Journal of Experimental Botany*, 64(5): 1263–1280.

Yugander A, Ershad M, Muthuraman PP, Prakasam V, Ladhalakshmi D, Sheshu Madhav M, Srinivas Prasad M, Sundaram RM and Laha GS.2022. Understanding the variability of rice bacterial blight pathogen, Xanthomonas oryzae pv. oryzae in Andhra Pradesh, India. *Journal of Basic Microbiology*, 62(2), 185–196.

RESEARCH ARTICLE https://doi.org/10.58297/HTZU4575

Need-Based Nitrogen Management Through Leaf Colour Chart in High Yielding Rice Variety

Kacha DJ*, Makawana NR, Parmar MB and Thorat SS

Main Rice Research Station, Anand Agricultural University, Nawagam-387 540 (Gujarat), India
Corresponding author Email: kacha_dharmesh@yahoo.com, rsrice_mrrs@yahoo.com

Received : 2nd August, 2025. Acepted: 30th September, 2025

Abstract

A field trial comprising two rice varieties (GAR 13 and Mahisagar) and 3 LCC scores (≤2, ≤3 and ≤4, Threshold level of LCC is 20 kg N/ha) with the recommended dose of N (80 kg and 120 kg N/ha, three split 40% basal, 40% at tillering and 20% at PI stages) was conducted in a factorial randomized block design with three replications to calibrate the LCC for nitrogen requirement of rice. In leaf color chart treatment LCC Score ≤ 4 recorded significantly higher yield attributing character *viz.,* panicle length, panicle weight, panicle/ m^2, grain and straw yield it followed by the 100% RDN (application of fertilizer as per recommendation) and LCC Score ≤ 3 during the both years and highest cost benefit ratio (2.43) was incurred under the treatment LCC Score ≤ 4 followed by treatment LCC Score ≤ 3 and 100% RDN).

Key words: Rice varieties, leaf colour chart, nitrogen management, high yielding varieties, RBD

Introduction

Rice is grown in over hundred countries and is the primary food for half of the people in the world. World population is expected to 8.5 billion by 2025 and to maintain self-sufficiency in rice, an increase of 2% - 3% per year in rice production has to be maintained within limited land (Vallino *et al*., 2009). The efficiency of fertilizer use for nitrogen is lower than 50% for phosphorus, lower than 10% and for potassium 40%. This low efficiency of fertilizer use is also associated with other losses by immobilization, volatilization, denitrification, leaching, and clay adsorption (Ruiz *et al*., 2012). Nutrient management is a major component of a soil and crop management system. Knowing the required nutrient for all stages of growth and understanding the soil's ability to supply the needed nutrient is critical to profitable crop production (Nedunchezhiyan and Laxminarayan, 2011). Higer dose of nitrogen gave significantly higher grain yield of rice (Kacha *et al.,* 2023). Increase in fertilizer nutrient input, especially N fertilizer, has contributed significantly to the improvement of crop yield in the world (Peng *et al*., 2010). Farmers generally apply fertilizer nitrogen in several spilt applications that results in high pest and disease incidence and serious lodging. The leaf color chart (LCC) is an easy-to-use and inexpensive diagnostic tool for monitoring the relative greenness of a rice leaf as an indicator of the plant N status. Leaf color chart have proved quick and reliable tool to decide the time when nitrogen fertilizer needs to be applied to the crop, farmers can apply N at the right time, thereby increasing the productivity and profitability of rice and reduction of used nitrogen fertilizer (Yosef tabar, 2013). The present research programme aims to identify the LCC threshold score and optimum dose of N through LCC for a different local rice variety.

Materials and Methods

A field experiment was conducted during the *Kharif* seasons 2016 to 2017 at Main Rice Research Station, Anand Agricultural University, Nawagam. A composite representative soil sample was collected from the experimentation and analysed for physico-chemical properties. The soils of experimental site was slightly clay loam and alkaline (*p*H value 8.20 with 1:2.5 soil and water ration). It consists 0.32% organic carbon, 31.20 kg/ha available P_2O_5 and 274.10 kg/ha available K_2O. The soil was low in organic matter and nitrogen content. The average rainfall 730 mm and average minimum and maximum temperature were recorded 20.35^{0} C and 33.27^{0} C respectively, in the year 2016 and 2017.

The experiment was laid out in factorial randomized block design (FRBD) with three replications. The treatment consisted of two varieties GAR 13 and Mahisagar that is originally Nawagam province four nutrient management treatments in which, three levels of LCC scores (≤2, ≤3 and ≤4, Threshold level of LCC is 20 kg N/ha), one levels of recommended dose of N (80 kg and 120 kg N/ha, three split 40% basal, 40% at tillering and 20% at PI stages) and 8 treatment combination in each replication.

Thirty days old seedlings of rice varieties transplanted on well puddled soil at 25th July, 2016 and 12th August 2017 at a spacing of 20 × 15 cm, 2-3 seedlings/hill. After the establishment of seedlings a constant water level of 5 ± 2 cm was maintained during the entire crop growth period till early dough stage. For the management of weeds two hand weeding were done at 35 and 55 days after transplanting (DAT). Irrigation, weeding and other agronomic practices were done as per recommendations. The crop was harvested manually at maturity at ground level on 22^{th} November, 2016 and 30th November, 2017 respectively.

Leaf Colour Chart

The five green shades ranging from yellowish green to dark green was used in the trial. LCC readings were taken at 7 days interval starting from 30 DAT till 50% flowering. Ten disease free hills were selected at random from the sampling area in each plot. From each hill topmost fully expanded leaf was selected and LCC readings were taken by placing the middle part of the leaf on the chart and the leaf colour was observed by keeping the sun blocked by body as sun light affects leaf colour reading. Whenever the green colour of more than 5 out of 10 leaves were observed equal to or below a set critical limit of LCC score, nitrogen was applied @ 20 kg/ha to all the three varieties. For both rice varieties GAR 13 and Mahisagar variety the final split application of N was completed by 65 days after transplanting coinciding with the heading stage (**Table 1**). In Mahisagar variety a total nitrogen was applied with LCC chart 40 kg, 60 kg, and 80 kg N/ha under the treatment LCC Score ≤2, ≤3 and ≤4 in the year of 2016 and 2017 respectively. Whereas, GAR 13 variety a total nitrogen was applied with LCC ≤2, ≤3 and ≤4 were 60 kg, 80 kg, and 100 kg N/ha during the year 2016 and 2017 respectively. However, under recommended dose of nitrogen it was 80 kg N/ha and 120 kg N/ha applied in 3 splits, 40% basal, 40% at tillering and 20% at PI stages for Mahisagar and GAR 13 varieties respectively.

Table 1: No of observation of LCC and application of total quantity of N kg/ha

Treatment	No. of splits		N applied kg/ha		Time of N application DAT									
	2016	2017	2016	2017	2016					2017				
Mahisagar														
T_1: LCC Score ≤ 2	2	2	40	40	30	37	-	-	-	30	37	-	-	-
T_2: LCC Score ≤ 3	3	3	60	60	30	37	41	-	-	30	37	41	-	-
T_3: LCC Score ≤ 4	4	4	80	80	30	37	41	55	-	30	37	41	55	-
T_4: 100 % RDN	3	3	80	80	0	30	55	-	-	0	30	55	-	-
GAR 13														
T_1: LCC Score ≤ 2	3	3	60	60	30	37	41	-	-	30	37	41	-	-
T_2: LCC Score ≤ 3	4	4	80	80	30	37	41	55	-	30	37	41	55	-
T_3: LCC Score ≤ 4	5	5	100	100	30	37	41	55	62	30	37	41	55	62
T_4: 100 % RDN	3	3	120	120	0	35	60	-	-	0	35	60	-	-

Results and Discussion

Growth and yield of rice variety was ascribed by plant height, panicles/m2, test weight, straw and grain yield was affected due to various levels of LCC score along with RDN. Data presented in **Table 2** showed that influence of rice varieties found non-significant, while LCC scores (≤2, ≤3 and ≤4, Threshold level of LCC is 20 kg N/ha), one levels of recommended dose found significant. Effect of leaf color chart score T3: LCC Score ≤ 4 was found significant and highest for character *viz.,* panicle length, panicle weight, panicles/m^2, grain yield (5720 and 5928 kg/ha respectively 2016 and 2017) and straw yield (8768 and 7652 kg/ha, respectively in 2016 and 2017) over the rest of treatment. It was statistically at par with treatment T4: 100% RDN (80 kg and 120 kg N/ha, three split 40% basal, 40% at tillering and 20% at PI stages) and T2: LCC Score ≤ 3, with respect to panicle length, panicle weight, panicle/m^2, grain yield and straw yield during the both the year. The increment of grain yield in this study at higher nitrogen levels might be due to efficient absorption of nitrogen and other elements which raise the production and translocation of dry matter from source to sink (Morteza *et al*., 2011). Same result was revealed by Yadvinder-Singh *et al*., (2007. LCC score was threshold, found an average saving of 26% fertilizer N across villages and seasons in 100 on-farm experiments with irrigated rice conducted during 4 years in the northwestern India.

Table 2: Growth and yield attributes influenced by various treatment of LCC

Treat	Panicle length (cm)		Panicle weight (g)		Panicle/m^2		Grain yield kg/ha		Straw yield kg/ha		Benefit:cost ratio	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Variety (V)												
V_1	24.23	21.98	3.96	3.53	283	228	5155	5109	7905	6131	2.22	2.13
V_2	22.71	22.93	4.18	3.68	294	246	5562	5445	8380	7440	2.39	2.31
S.Em. ±	0.77	0.48	0.16	0.12	9.69	7.98	151	174	250	217	-	-
C. D.	NS	NS	NS	NS	NS	NS	NS	NS	NS	658	-	-
Treat.												
T_1	19.12	20.33	3.06	3.12	230	203	4519	4588	6567	5911	1.91	1.91
T_2	24.57	22.42	4.17	3.48	295	232	5543	5255	8554	6728	2.34	2.17
T_3	25.11	23.83	4.68	4.05	320	261	5720	5928	8768	7652	2.40	2.43
T_4	25.09	23.25	4.38	3.76	309	253	5653	5336	8683	6851	2.37	2.19
S.Em. ±	1.09	0.67	0.23	0.17	13.70	11.28	213	246	353	307	-	-
C. D.*	3.30	2.05	0.69	0.52	41	34	646	746	1071	930	-	-

*C.D. at 0.05%, Selling price: Paddy300 Rs/20 kg, 15 Rs/ kg (Three year average), Paddy Straw 1 Rs / Kg
Input cost: Urea Rs. 350/50 kg, DAP Rs. 1250/50 kg, ZnSo4 750 Rs / 25 kg

Conclusion

The highest cost benefit ratio was incurred under the treatment T_3 (LCC Score ≤ 4) followed by treatment T_4(100 % RDN) and T_2 (LCC Score ≤ 3) (**Table 2**). As per the results the farmers of middle Gujarat Agro Climatic Zone-III are advised to use Leaf Color Chart critical score "4" for nitrogen management in mid late maturing rice varieties to get higher net return and save 17 % Nitrogen.

References

Kacha DJ, Patel AS, Kacha RP, Thorat SS and Parmar MB 2023. Growth and yield of rice (*Oryza sativa* L.) are influenced by different levels of nitrogen, phosphorus and biofertilizers. *Journal of Rice Research,* 16(2): 81-86.

Morteza S, Alireza N, Shankar LL 2011. Effect of Organic Fertilizer on Growth and Yield

Components in Rice (*Oryza sativa* L). *Journal of Agricultural Science*, 3:217-224.

Nedunchezhiyan M and Laxminarayan K 2011. Site specific nutrient management for rice. *Orissa Review*. June: 62-64.

Peng S, Buresh RJ, Huang J, Zhong X, Zou Y, Yang J, Gaunghuo Wang G, Liu Y, Hu R, Tang Q, Cui K, Zhang F, Dobermann A 2010. Improving nitrogen fertilization in rice by site-specific N Management. A review. *Agronomy for Sustainable Development* 30(3): 649-656.

Ruiz Sánchez, Michel, Polón Pérez, Ricardo, Vázquez Del Llano, Bannie, Muñoz Hernández, Yaumara, Cuéllar Olivero, Nelson, Ruiz-Lozano and Juan M 2012. Arbuscular mycorrhizal symbiosis in rice plants (*Oryza sativa* L.) subjected to water stress: Part I. Improves physiological response. *Tropical Crops*, 33(4), 47-52.

Shrestha, RK and Maskey, SL 2010. Associative Nitrogen Fixation in Lowland Rice. *Nepal Agriculture Research Journal*, 6: 112–121. https://doi.org/10.3126/narj.v6i0.3373

Singh Y, Singh B, Ladha JK, Bains JS, Gupta RK, Singh J, Balasubramanian V 2007. On-farm evaluation of leaf color chart for need-based nitrogen management in irrigated transplanted rice in north-western India. *Nutrient Cycling in Agroecosystems*, 78:167–176.

Subbaiah, SV 2006. Rice Meeting Challenges. The Hindu Survey of Indian Agriculture, pp. 50-54.

Tabar, YS 2013. Evaluation use leaf color chart in rice for nitrogen management. *Scientia Agriculturae*, 3(3): 66-69.

Vallino M, Greppi D, Novero M, Bonfante P and Lupotto E 2009. Rice root colonization by mycorrhizal and endophytic fungi in aerobic soil. *Annals of Applied Biology*, 154:195-204. http://dx.doi.org/10.1111/j.1744-7348.2008.00286.x.

RESEARCH ARTICLE https://doi.org/10.58297/LKMQ9208

Impact of Agricultural Inputs on Gross Value Added by Agriculture in Indian Economy

Sukhdeep Singh[1*], Jatinder Sachdeva[1] and Sangeet Ranguwal[1]

[1]Department of Economics and Sociology, Punjab Agricultural University, Ludhiana-141 004, India
*Corresponding author Email: sukhbuttar94@gmail.com; sachdeva8@pau.edu; sangeet@pau.edu

Received: 15th August, 2025, Accepted: 12th October, 2025

Abstract

This study analyses secondary data for 2011-12 to 2022-23 to quantify the role of agricultural inputs in India's productivity and economic growth. Our objective is to assess how variability in input use particularly fertilizers, pesticides, irrigation, and seeds affects agricultural gross value added (GVA) and production stability. using a combination of variability metrics and ridge regression. We document substantial variability in fertilizer and pesticide consumption relative to irrigation and seeds availability, indicating higher production risk associated with fluctuations in these inputs. The Instability Index shows that fertilizer and pesticide use are the main sources of input-related volatility, whereas irrigation and seeds availability exhibit comparatively greater stability. Ridge regression results indicate that irrigation ($\beta = 0.22$, $p < 0.05$) positively influence agricultural GVA, with quality seeds availability also contributing ($\beta = 0.05$, $p < 0.1$) to GVA by crops. These estimates support the view that expanding and stabilizing core inputs can enhance output, while input variability poses a material constraint. To promote sustainable growth, the focus should be on improving input use efficiency through precision agriculture, stabilizing critical inputs (notably irrigation), and implementing risk management strategies. Integrated input subsidies, increased R&D via PPP arrangements, and targeted farmer education can mitigate volatility and strengthen producer resilience, contributing to more stable agricultural growth and economic performance.

Keywords: Agricultural Inputs, GVA, Impact, India and Productivity

Introduction

Agriculture serves as a primary source of raw materials for numerous allied industries such as food processing, textiles, and biofuels, underscoring its critical role in the overall economic framework besides employment generation (Shareya *et al.*, 2024). Indian agriculture demonstrated resilience, employing about 55 per cent of the workforce and contributing nearly 18 per cent to GDP during 2019–2020 despite the COVID-19 outbreak, (Raghu, 2022). Further, agricultural inputs including seeds, fertilizers, pesticides, irrigation, machinery, and labour are essential drivers of productivity and efficiency in agriculture. The efficient and optimal use of these inputs contributes directly to increasing the GVA by enhancing crop yields, reducing input costs, and improving crop quality (Government of India, 2025). Numerous studies have examined the impact of these inputs on agricultural output and GVA in India. Irrigation expansion significantly raised productivity in rainfed areas, contributing 25–30% to GVA growth through yield stabilization (Birthal *et al.*, 2014). Public investments in fertilizers and electricity generated high returns, with each rupee invested yielding ₹9–12 in agricultural GVA (Fan *et al.*, 2000). Rainfall and electricity volatility linked to GVA fluctuations via input instability (Bhattacharya and Mitra, 2013).

In recent decades, the use of advanced agricultural technologies such as precision farming, genetically improved seeds, micro-irrigation techniques, and integrated pest management has further enhanced productivity (Gawande *et al*., 2023). The availability of agricultural credit and government subsidies for inputs have played a crucial role in enabling farmers to adopt these technologies, leading to a more resilient and sustainable agricultural sector (Choudhary and Kumar, 2023).

However, challenges such as regional disparities in input availability, inefficient input use, environmental concerns from excessive fertilizer and pesticide use, and climate variability affect the consistent growth of agricultural GVA. Therefore, policy measures focused on promoting balanced and sustainable usage of inputs, improving input quality, and ensuring timely availability are vital to sustaining growth in agricultural output and its contribution to the economy. In this context, analysing the impact of various agricultural inputs on the Gross Value Added by agriculture is critical to understanding sectoral dynamics and framing targeted interventions. With this backdrop, present study aims to assess how different inputs contribute to agricultural productivity and thus to value addition in the Indian economy.

Materials and Methods

This study focuses on the Indian agricultural sector as a whole, utilizing secondary data covering the time period from 2011–12 to 2022–23. Data were sourced from reputed publications including FAOSTAT, *Agricultural Statistics at a Glance* (Government of India) and Indiastat.com.

Analytical Framework

The analysis employed three key tools:

- Compound Annual Growth Rate (CAGR) to measure temporal growth trends in agricultural inputs and GVA.
- Cuddy-Della Index to quantify instability in input usage and outputs.
- Ridge regression to estimate the impact of key inputs on agricultural GVA, addressing multi-collinearity among explanatory variables.

Ridge Regression Model

The relationship between agricultural inputs and GVA was estimated using the following ridge regression equation:

$$GVA_t = \beta_0 + \beta_1 Area_t + \beta_2 Fertilizer_t + \beta_3 Pesticide_t + \beta_4 Irrigation_t + \beta_5 Seeds_t + \beta_6 Rainfall_t + \epsilon_t$$

where:

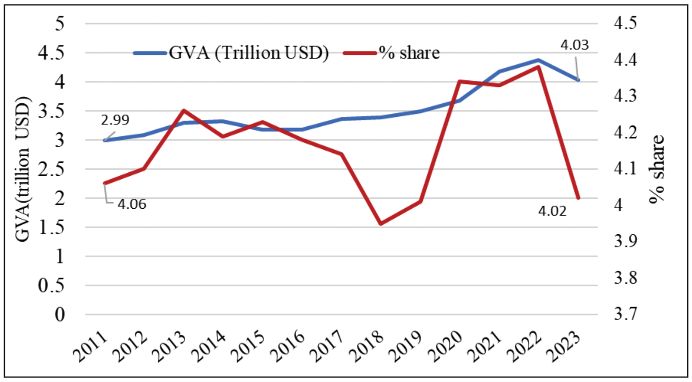
- GVA_t: Gross Value Added by agriculture (in Rs Billions)
- $Area_t$: Net sown area (in million hectares)
- $Fertilizer_t$: Fertilizer consumption (in Lakh tonnes)
- $Pesticide_t$: Pesticide consumption (in 000 tonnes)
- $Irrigation_t$: Net irrigated area (in million hectares)
- $Seeds_t$: Quality Seeds Availability for agriculture (in lakh quintals)
- $Rainfall_t$: Average annual rainfall (in mm)
- ϵ_t: Error term

Ridge regression parameters were estimated using R statistical software, selecting the optimal shrinkage parameter (λ) via cross-validation.

Results and Discussion

A. Contribution of Agriculture to Gross Value Added

The percentage share of agriculture, forestry, and fishing in global GDP and GVA reflects the economic contribution of these sectors over time (**Figure 1**). From 2011 to 2023, the share of GVA in global GDP indicated a relatively stable share, fluctuating between 4.01 to 4.38 per cent. During 2011, the share was 4.06% with a Gross Value Added (GVA) of $2.99 trillion out of a total GDP of $73.63 trillion which increased slightly to 4.10% in 2012 as GVA rose to $3.08 trillion while GDP grew to $75.19 trillion.

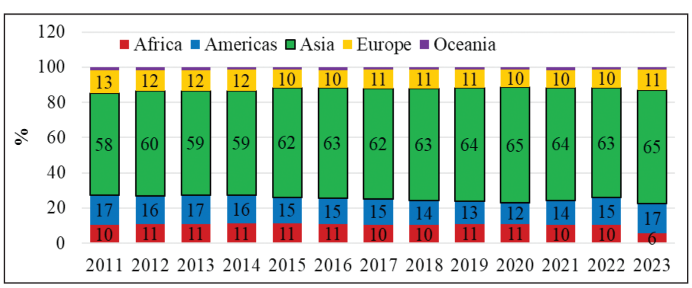


Source: FAOSTAT

Figure 1: Percentage Share of Agriculture, Forestry, and Fishing in Global GDP

The COVID-19 pandemic in 2020 caused an artificial spike in the agriculture sector's contribution to GDP as non-agricultural sectors experienced declines while agriculture-maintained growth, resulting in a share of 4.34 per cent. By 2023, the percentage share had slightly decreased to 4.02 per cent, with a GVA of $4.03 trillion and a GDP of $100.13 trillion. Overall, these figures illustrate that while agriculture, forestry, and fishing continue to play a critical role in the global economy, their relative contribution has faced pressures from the growth of other sectors, highlighting the ongoing dynamics within global economic structures and the importance of these sectors for food security and rural livelihoods.

The data presented in **figure 2** outlines the percentage share of agriculture, forestry, and fishing across different global regions from 2011 to 2023. In Africa, the share has remained relatively stable, being 10.42% in 2011 and 2022 but declined to 5.65% by 2023. This decrease may reflect broader economic changes and diversification efforts within African economies.



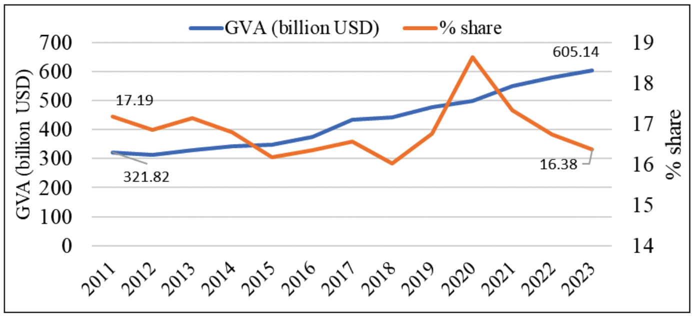
Source: FAOSTAT

Figure 2: Region-wise percentage share to the GVA by Agriculture, Forestry and Fishing

In the Americas, the percentage share has varied, beginning at 16.81% in 2011 and showing a slight increase to 16.75% in 2023 indicating that agriculture continues to play a significant role in the region's economy, despite pressures from industrialization and service sector growth. Asia exhibited a rising trend in agricultural share, increasing from 57.91% in 2011 to 64.74% in 2023 indicating a strong reliance on agriculture within many Asian economies, likely due to the significant agricultural populations and their importance in food security. In Europe, a decline in its agricultural share from 13.17% in 2011 to 11.34% in 2023 was observed reflecting a shift towards more industrial and service-oriented economic activities within the region. Oceania showed a decreasing trend as well, with its agricultural share dropping from 1.70% in 2011 to 1.50% in 2023. This decline may indicate a transition towards other economic sectors or changes in agricultural productivity. Overall, these trends highlight the varying importance of agriculture across different regions, influenced by factors such as economic development, population dynamics, and policy changes related to agricultural practices and food security.

The percentage share of agriculture, forestry, and fishing in India's GDP exhibited notable trends from 2011 to 2023 which were shown in **figure 3**. In 2011, the sector contributed significantly to the economy with a Gross Value Added (GVA) of $321.82 billion, (17.19% of the total GDP of $1,871.92 billion). A significant increase was observed in 2020, where the share rose sharply to 18.64%, likely due to the impact of the COVID-19 pandemic, which affected various sectors differently and may have led to increased reliance on agriculture for food security during that period. However, this was followed by a return to a lower percentage share in the following years, with contributions of 17.33% in 2021 and further declining to 16.73% in 2022 and 16.38% in 2023.Throughout this period, while the absolute GVA from agriculture has generally increased from $321.82 billion in 2011 to $605.14 billion in 2023 the relative contribution to

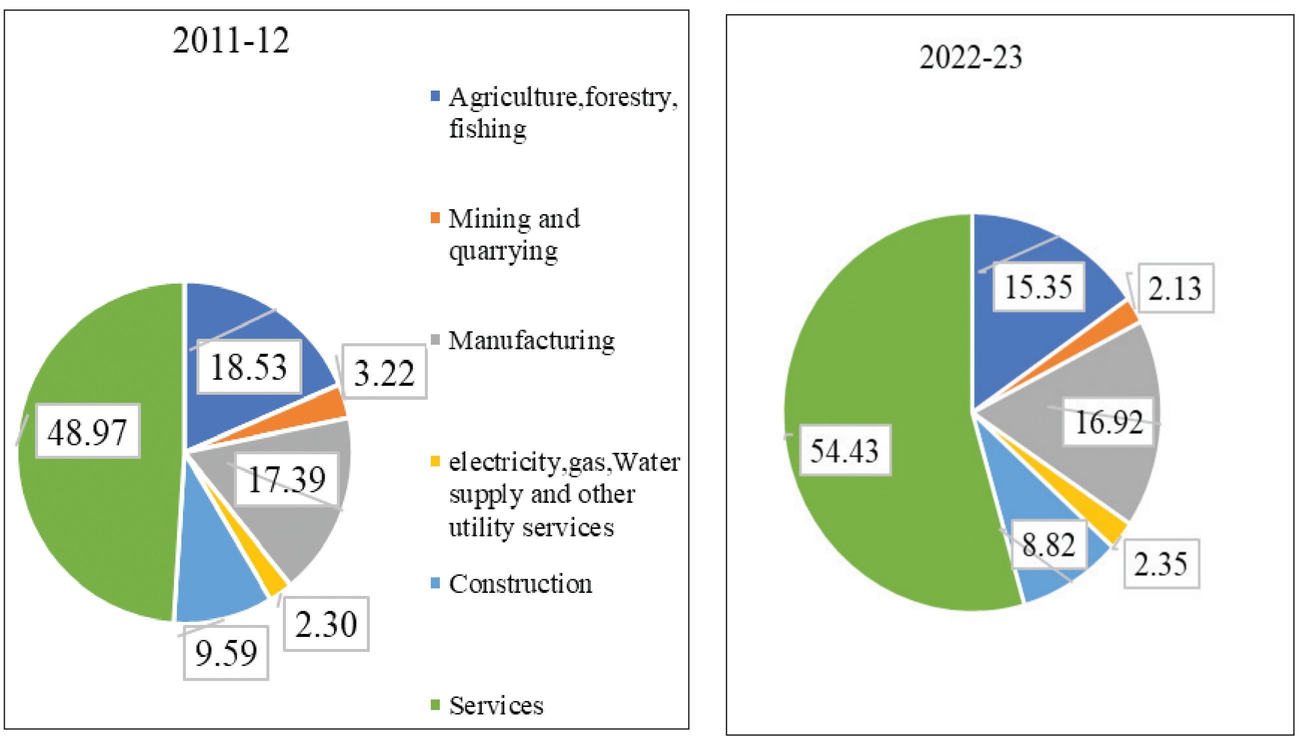
GDP has been affected by faster growth rates in other sectors such as services and manufacturing. Overall, these figures illustrate the dynamic nature of India's economic landscape, where agriculture remains a vital sector but faces challenges from competing industries and changing economic priorities.



Source: FAOSTAT

Figure 3: Percentage Share of Agriculture, Forestry and Fishing in India's GDP

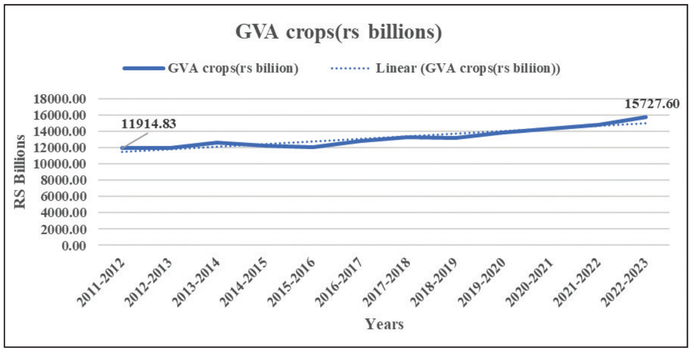
The percentage of Gross Value Added (GVA) by economic activities at constant (2011-12) basic prices provides insight into the structural changes in the Indian economy from 2011-12 to 2022-23 **(Figure 4)**. In this period, the contribution of agriculture, forestry, and fishing decreased from 18.53% in 2011-12 to 15.35% in 2022-23 reflecting a gradual shift towards more industrial and service-oriented sectors, indicating that agriculture's relative importance in the economy is diminishing despite its essential role in food security and employment. Overall, these changes reflect significant economic transformations within India, highlighting a shift away from traditional sectors like agriculture towards more modern industries and services, which are becoming increasingly vital for economic growth and development.



Source: Agricultural Statistics at a Glance 2023

Figure 4: Percentage of Gross Value Added by Economic Activities at Constant (2011-12) Basic Prices

GVA by agriculture crops at constant 2011-12 prices shows a steady upward trajectory from ₹9,822 billion (2011-12) to ₹12,301 billion (2022-23), achieving a 25.2% cumulative increase over 12 years (average ~1.9% annual growth). The series exhibits two distinct phases: modest gains during 2011-16 (₹9,822 → ₹9,693; slight dip in 2015-16 due to possible weather/input shocks) followed by consistent acceleration post-2017 (₹10,751 → ₹12,301; +14.4%). Notable yearly jumps occurred in 2013-14 (+5.4%), 2017-18 (+5.3%), and 2022-23 (+4.6%), reflecting policy interventions and productivity improvements. Despite minor fluctuations (e.g., 2014-16 dip), the long-term trend is unambiguously positive, with GVA crossing ₹12,000 billion in the final year confirming sustained agricultural sector resilience amid stable prices and gradual intensification rather than area expansion **(Figure 5)**.



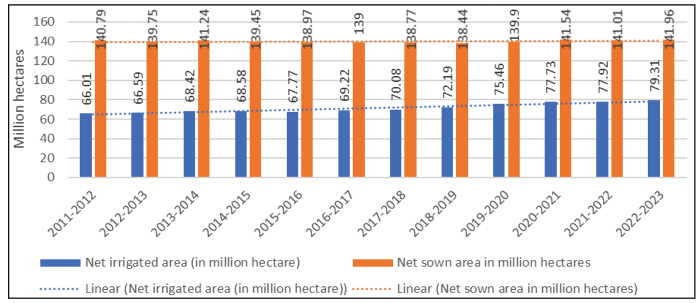
Source: Indiastat.com

Figure 5: Trends in Gross Value Added (GVA) by Agriculture Crops at constant 2011-12 prices in India, 2011-12 to 2022-23

B. Utilisation of different inputs at national level

In agriculture sector, different inputs are crucial for successful crop production and overall farm productivity. These inputs can be broadly categorized into consumable inputs like seeds, fertilizers, and pesticides, and capital inputs like machinery and irrigation systems.

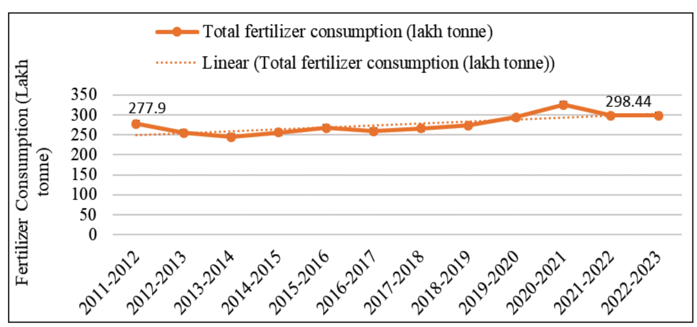
It was observed that the net sown area in India exhibited fluctuations over the years. Being at 140.79 million hectares in 2011-12, it reached a peak of 141.54 million hectares in 2020-21 before stabilizing at 141.96 million hectares in 2022-23. These fluctuations may be influenced by factors such as climatic conditions, market demands, and farmers' decisions regarding crop planting. On the other hand, the net irrigated area has shown a consistent upward trend, increasing from 66.01 million hectares in 2011-12 to 79.31 million hectares in 2022-23 (**Figure 6**). This increase signifies ongoing efforts to improve irrigation infrastructure and expand water availability for agriculture.



Source: Indiastat.com

Figure 6: Trends in net sown area and net irrigated area in India, 2011-12 to 2022-23

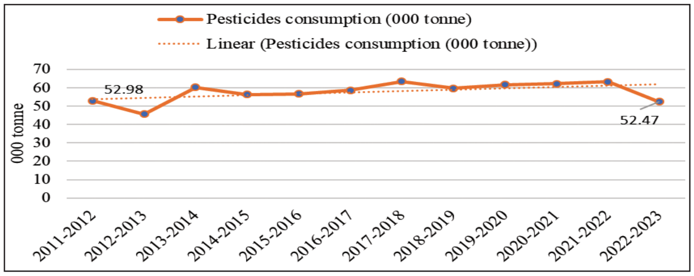
Data on fertiliser consumption revealed an upward trend which continued through 2018-19, culminating in a consumption of 273.75 lakh tonnes (**Figure 7**). The increase during these years suggests a renewed focus on fertilizer application as farmers sought to improve yields amidst rising food demand. The most notable increase occurred between 2019-20 and 2020-21, where fertilizer consumption surged from 293.69 lakh tonnes to 325.36 lakh tonnes. This sharp rise can be attributed to several factors: Increased agricultural activity due to heightened food security concerns during the COVID-19 pandemic, Government initiatives aimed at ensuring the availability of fertilizers and enhancing subsidies, A greater emphasis on high-yielding varieties that require more fertilizer input. Following the peak in 2020-21, fertilizer consumption slightly decreased to 297.96 lakh tonnes in 2021-22, and then stabilized at 298.44 lakh tonnes in 2022-23. This stabilization may reflect a return to pre-pandemic agricultural practices and market conditions, as well as potential challenges related to fertilizer availability and pricing.



Source: Indiastat.com

Figure 7: Trends in Fertilizer consumption in India, 2011-12 to 2022-23

Further, the trends in pesticide consumption in India from 2011-12 to 2022-23 reveal a complex landscape characterized by initial stability, fluctuations, and a significant decline in recent years. Starting at 52.98 thousand tonnes in 2011-12, pesticide use dropped to 45.62 thousand tonnes in 2012-13 (**Figure 8**), likely reflecting growing awareness of the health and environmental impacts of pesticides.

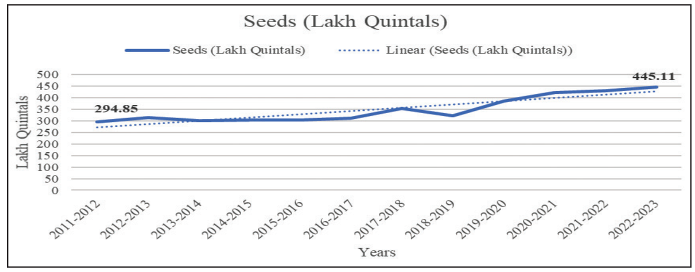


Source: Indiastat.com

Figure 8: Trends in Pesticides consumption in India

A recovery phase began in 2013-14, with consumption rising to 63.41 thousand tonnes by 2017-18 due to increased reliance on pesticides to combat pest pressures, particularly in high-value crops. This trend continued with sustained high usage, peaking at 63.28 thousand tonnes in 2021-22, driven by crop intensification and government initiatives promoting pesticide availability. However, a notable decline to 52.47 thousand tonnes in 2022-23 suggests a shift towards integrated pest management practices and heightened awareness of the adverse effects of chemical pesticides. Overall, these trends highlight the need for sustainable agricultural practices that balance productivity with environmental health, emphasizing the importance of education and policy support for farmers to adopt safer pest management strategies moving forward.

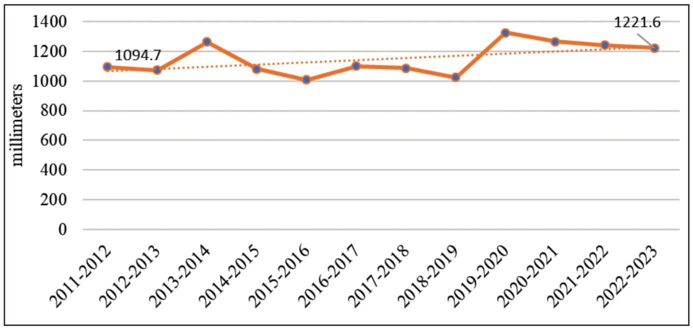
Quality seed availability in Indian agriculture shows a steady upward trend from 294.85 Lakh Quintals (2011-12) to 445.11 Lakh Quintals (2022-23), achieving a 51% cumulative increase over 12 years. The series exhibits two phases: gradual growth during 2011-17 (294-311 range, ~5.6% total) followed by sharp acceleration post-2017 with major jumps in 2017-18 (+13%), 2019-20 (+20%), and consistent 5-8% annual gains thereafter. Minor dips in 2013-14 and 2018-19 reflect possible supply chain disruptions, but the long-term trajectory confirms successful seed sector modernization. This expansion parallels GVA growth acceleration, indicating policy-driven improvements in hybrid/high-yield varieties that boosted productivity without area expansion. Average annual growth accelerated from 0.8% (2011-17) to 5.8% (2018-23), underscoring seeds as a key driver of agricultural efficiency gains (**Figure 9**).



Source: Indiastat.com

Figure 9: Trends in availability of quality seeds for agriculture in India,2011-12 to 2022-23

The trends in actual rainfall in India from 2011-12 to 2022-23 reveal significant fluctuations, which have implications for agricultural productivity and water resource management **(Figure 10).** In 2011-12, actual rainfall was recorded at 1,094.7 mm, setting a relatively high baseline. However, this figure declined slightly to 1,073.4 mm in 2012-13, indicating a minor decrease in precipitation. The following year, 2013-14, saw a notable increase to 1,262.4 mm, likely benefiting agricultural output due to improved water availability. However, this was followed by another decline in 2014-15, with rainfall dropping to 1,081.8 mm. The trend of fluctuating rainfall continued, with 1,007.3 mm recorded in 2015-16, marking one of the lower points in the period under review. From 2016-17 onward, rainfall figures began to stabilize somewhat, with 1,099.4mm in 2016-17 and slight variations thereafter: 1,086.4 mm in 2017-18, and a further drop to 1,025.6 mm in 2018-19. The years 2019-20 and 2020-21 experienced higher rainfall levels again, with 1,327 mm and 1,265.2 mm, respectively. This resurgence may have been influenced by favourable monsoon conditions.



Source: Indiastat.com

Figure 10: Trends in actual rainfall in India, 20o11-12 to 2022-23

In the subsequent years, rainfall levels slightly decreased again, recording 1,241.7 mm in 2021-22, followed by 1,221.6 mm in 2022-23. Overall, these trends illustrate the variability of rainfall patterns in India over the years and highlight the importance of effective water management strategies to cope with both droughts and excessive rainfall events that can impact agriculture and livelihoods across the country.

The Compound Annual Growth Rates (CAGR) of various agricultural inputs and Gross Value Added (GVA) by agriculture in India from 2011-12 to 2022-23 reveal significant trends. In the first period (2011-12 to 2016-17), fertilizer consumption declined slightly at -0.45%, while pesticides consumption grew modestly at 3.17%. Net irrigated area increased by 0.83%, but net sown area experienced a slight decline of -0.27%. The quality seeds availability for agriculture rose at 0.54%, despite a decline in actual rainfall by -0.92%, leading to minimal GVA growth of 0.99%. In the second period (2017-18 to 2022-23), fertilizer consumption increased by 2.70%, while pesticides consumption declined by -2.16%. Net irrigated area saw robust growth at 2.54%, and quality seeds availability surged dramatically to 6.34%. Actual rainfall improved by 3.23%, contributing to a stronger GVA growth of 3.51%. Overall, from 2011-12 to 2022-23, fertilizer consumption grew modestly at 1.74%, net irrigated area increased by 1.77%, and quality seeds emerged as a key productivity driver (3.99% CAGR) to achieve sustained GVA growth (2.40%), confirming policy effectiveness in input modernization over the period (**Table 1**).

Table 1: Compound annual growth rates (CAGR) of different Agricultural Inputs and GVA by Agriculture in India, 2011-12 to 2022-23

Period	Years	Fertilizer consumption	Pesticides consumption	Net irrigated area	Net sown area	Quality Seeds Availability	Actual rainfall	GVA by Agriculture crops at Constant (2011-12) Basic Prices
I	2011-12 to 2016-17	-0.45	3.17	0.83**	-0.27*	0.54	-0.92	0.99
II	2017-18 to 2022-23	2.7	-2.16	2.54***	0.52***	6.34**	3.23	3.51***
Overall	2011-12 to 2022-23	1.74**	1.32	1.77***	0.07	3.99***	1.26	2.40***

Note: ***, ** and * denote significance at 1 % ,5% and 10 %, respectively

The Instability Index of various agricultural inputs and Gross Value Added (GVA) by agriculture at national level from 2011-12 to 2022-23 indicates varying levels of volatility across different factors. In the first period (2011-12 to 2016-17), fertilizer consumption had an instability index of 4.78, while pesticides consumption was higher at 8.63, reflecting greater variability in pesticide use. The net irrigated area showed low instability at 1.07, and net sown area had an index of 0.51, suggesting stability in land cultivation practices (**Table 2**). In the second period (2017-18 to 2022-23), fertilizer consumption's instability rose to 5.89, while pesticides decreased to 6.34.

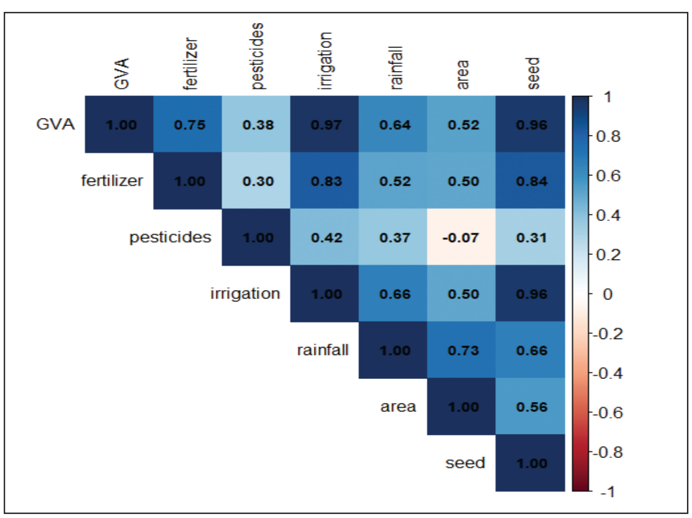
Overall, from 2011-12 to 2022-23, fertilizer consumption had the highest overall instability at 8.82, followed by pesticides at 8.41 and actual rainfall at 8.55. These variations highlight the challenges faced in agricultural practices and inputs over the years, emphasizing the need for strategic interventions to enhance stability and productivity in the sector (**Table 2**).

Table 2: Instability in use of different Agricultural inputs and GVA by Agriculture in India

Periods	Years	Fertilizer consumption	Pesticides consumption	Net irrigated area	Net sown area	Quality Seeds Availability	Actual rainfall	GVA by Agriculture Crops at Constant (2011-12) Basic Prices
I	2011-12 to 2016-17	4.78	8.63	1.07	0.51	0.39	8.38	0.25
II	2017-18 to 2022-23	5.89	6.34	1.35	0.45	1.07	8.68	0.20
Overall	2011-12 to 2022-23	8.82	8.41	1.96	0.86	1.18	8.55	0.32

The correlation matrix reveals severe multi-collinearity among agricultural inputs that compromises OLS regression reliability. GVA exhibits very strong positive correlations with irrigation (r=0.971) and seeds (r=0.958), indicating these are primary productivity drivers, while irrigation and seeds themselves show near-perfect collinearity (r=0.956), directly explaining the high VIF values (>14) observed earlier. Moderate correlations exist with fertilizer (r=0.752), rainfall (r=0.639), and area (r=0.523), suggesting supplementary roles, whereas pesticides display consistently weak relationships (r<0.42 across all variables), confirming its limited explanatory power (**Table 3**). This pattern underscores the need to either drop one of irrigation or seeds from the model preferably retaining irrigation as the broader infrastructure measure or rely on ridge regression results, which effectively handle shrinkage. Pesticides can be safely excluded, while a composite irrigation-seed index represents a theoretically sound alternative for capturing shared variance in GVA determination.

Table 3: Correlation matrix of GVA by Agriculture and Agricultural Inputs in India



The diagnostic tests reveal critical violations of OLS assumptions that undermine model reliability. The ADF test confirms non-stationarity in GVA levels (test statistic = -0.79, p=0.95), necessitating first-differenced specification for valid inference. Severe multi-collinearity exists with irrigation (VIF=14.82) and seeds (VIF=14.81), both exceeding the critical threshold of 10, confirming their near-perfect correlation (r=0.956) and rendering individual coefficients unstable. Other VIFs (fertilizer=3.80, rainfall=4.05, area=3.46) indicate moderate collinearity concerns, while pesticides (VIF=1.97) show no issue. The Durbin-Watson test (DW=1.71, p=0.08) suggests mild positive autocorrelation but fails conventional significance (p>0.05). Breusch-Pagan test confirms homoskedasticity (BP=6.62, p=0.36), satisfying that assumption (**Table 4**).

Table 4: Diagnostic Tests for Regression Model Analysis

Test		p-Value
ADF (GVA levels)	-0.79	0.95
VIF (Fertilizers)	3.80	<5
VIF (Pesticides)	1.97	<5
VIF (Irrigation)	14.82	>5
VIF (Area)	3.46	<5
VIF (Seed)	14.81	>5
VIF (Rainfall)	4.05	<5
Durbin-Watson	1.71	0.08
Breusch-Pagan	6.62	0.36

The ridge regression results (K=0.047, R^2=54.95%) reveal area expansion as the dominant driver of GVA growth (coefficient=0.79), with irrigation showing statistical significance at 5% level (0.22**), confirming its critical infrastructure role despite multicollinearity concerns. Fertilizer exhibits a surprising negative effect (-0.05), suggesting possible over-application or diminishing returns, while seeds (0.05*) and rainfall (0.04) show marginal positive contributions at 10% significance. Pesticides remain negligible (0.01), consistent with weak correlations.

Table 5: The estimates of regression coefficients through ridge regression model with ridge constant K=0.047

R^2=54.95%

Parameters	Coefficients
Intercept	0.02
Fertilizers	-0.05
Pesticides	0.01
Irrigation	0.22**
Area	0.79
Seeds	0.05*
Rainfall	0.04

Note: ***, ** and * denote significance at 1 % ,5% and 10 %, respectively

Conclusion

Despite varied consumption levels of fertilizer and pesticide, significant increases in electricity consumption and a positive overall GVA growth rate of about two per cent highlight the critical role of agricultural inputs in enhancing productivity and sustaining economic growth in India's agricultural sector. Further, the Instability Index for agricultural inputs and GVA revealed heightened variability, particularly in fertilizer and pesticide consumption, highlighting the challenges of production volatility driven by fluctuations in critical inputs like rainfall and electricity consumption, which ultimately affect agricultural productivity and economic stability. The ridge regression analysis indicated that area under cultivation and electricity consumption significantly enhance the GVA from agriculture, while irrigation also positively impacts GVA, highlighting the importance of these factors in boosting agricultural productivity.

Policy implications

1. Enhancement of Input Efficiency: Given the significant role of fertilizers, pesticides, seeds and irrigation in boosting Gross Value Added (GVA), policies should focus on improving the input use efficiency by promoting precision agriculture techniques, which optimize input usage and minimize waste, thereby enhancing productivity while reducing costs.

2. Stabilization Measures: The observed instability in agricultural input consumption and GVA highlights the need for policies aimed at stabilizing production. Implementing risk management strategies, such as crop insurance and weather-indexed insurance products, can help farmers mitigate the impacts of fluctuations in rainfall and electricity consumption.

3. Integrated Input Subsidy Programs: Given the rising costs of agricultural inputs, a comprehensive subsidy program that integrates fertilizers, pesticides, irrigation, and seeds could provide farmers with the necessary support to enhance productivity without incurring excessive costs. Such programs should be carefully designed to avoid over-reliance on inputs that may lead to environmental degradation.

4. Research and Development: Increased investment in agricultural research and development is essential to innovate new practices that can improve crop yields while ensuring sustainability. Collaborative efforts between public institutions and private sectors can foster advancements in high-yield varieties (HYVs), pest-resistant crops, and efficient irrigation methods.

5. Education and Training: Implementing educational programs aimed at training farmers on best practices for input usage can lead to more informed decisions regarding fertilizer and pesticide applications, ultimately enhancing productivity while minimizing negative environmental impacts.

References

Agricultural Statistics at a glance.2023. Directorate of Economics and Statistics, India.

Birthal PS, Hazell P and Kendhammer A. 2014. Impacts of public investments on agricultural productivity and rural poverty in India. *Indian Journal of Agricultural Economics,* 69(1), 1-20.

Bhattacharya M and Mitra A. 2013. Climate variability, agricultural inputs and output fluctuations in Indian agriculture. *Economic and Political Weekly,* 48(52), 59-65.

Choudhary P and Kumar S. 2023. Role of agricultural credit and subsidies in technology adoption among Indian farmers. *Journal of Rural Development*, 42(4): 446-463.

Fan S, Hazell P and Thorat S. 2000. Government spending, growth and poverty in rural India. *American Journal of Agricultural Economics, 82*(4), 1038–1051.

FAOSTAT. 2024. Food and Agriculture Organization of the United Nations. Available at https://www.fao.org/faostat/ . Accessed on 11th December, 2024.

Gawande V, Saikanth DRK, Sumithra BS, Aravind SA, Swamy GN, Chowdhury M and Singh, BV. 2023. Potential of precision farming technologies for eco-friendly agriculture. *International Journal of Plant and Soil Science*, 35(19): 101–112.

Government of India. 2025. Agriculture and Food Management: Sector of the Future. P. [245-270]. In Economic Survey 2024-25. Ministry of Finance, Department of Economic Affairs, Economic Division, North Block, New Delhi-110001. Available at https://www.indiabudget.gov.in/economicsurvey/doc/eschapter/echap09.pdf

Indiastat. "Socio-economic Statistical Data for India." Available at https://www.indiastat.com. Accessed on 23rd December, 2024.

Raghu T. 2022. A study on agriculture and foodgrain management in India. *Journal of Development Economics and Management Research Studies*, 09(13): 30-40.

Shareya, Sharma DD and Sharma V. 2024. Role of agriculture and allied sectors in Indian Economy-Some Challenges. *International Journal of Multidisciplinary Research*, 10(3): 164-166.

RESEARCH ARTICLE https://doi.org/10.58297/KPUP8813

In vitro Efficacy of Essential Oils, Fungicides and Botanicals Against *Bipolaris oryzae* Causing Brown Spot of Rice

Basavaraj K*, Prashanth Pandi, Jasudasu GS, Prakasam V, Ladhalakshmi D, Kannan C, Laha GS and Srinivas Prasad M

ICAR- Indian Institute of Rice Research (IIRR), Hyderabad

*Corresponding author E mail *basavaraj4229@gmail.com*

Received : 9th October, 2025, Accepted : 5th December, 2025

Abstract

Bipolaris oryzae, the causal agent of rice brown spot, is a major constraint to rice production, necessitating effective eco-friendly and chemical management options. A series of *in vitro* studies were conducted to evaluate the essential oils, fungicides and botanical extracts against *B. oryzae* using the poisoned food technique. Among essential oils, clove oil showed the highest inhibition (75.6%) at 500 ppm concentration, followed by lemon grass oil (64.9%). Among fungicides, azoxystrobin 23% SC was most effective, recording 67.3% mean inhibition and 88.9% inhibition at 500 ppm, while difenconazole 25% EC and propiconazole 25% EC showed 84.4% and 81.5% inhibition, respectively. Fifteen botanical extracts were tested at 1-3% concentrations, of which soap nut extract was most effective, causing 61-86% inhibition, followed by garlic, datura and ocimum whereas turmeric and ginger were ineffective up to 3% concentration. The study highlights clove and lemongrass oils, soapnut extract and effective fungicides (azoxystrobin, difenconazole and propiconazole) as promising options for managing rice brown spot.

Keywords: Rice brown spot, *Bipolaris oryzae,* essential oils, fungicides *and Oryza sativa*

Introduction

Rice (*Oryza sativa*- Asian rice; less commonly *Oryza glabberima* – African rice) second most important cereal crop and is staple food for over more than half of the world's human population. World's rice production is challenged by many biotic stresses. Brown spot of rice caused by *Bipolaris oryzae* (*syn-Helminthosporium oryzae*; telemorph-*Cochliobolus miyabeanus*) is second important leaf spot disease after blast and causes substantial quantitative and qualitative losses in grain yield (Savary *et al*., 2000). The disease of historic importance, responsible for two major epidemics in India; one in 1918-19 in Godavari delta areas and other being Great Bengal famine in 1943 leading to death of nearly 1.5 million people in present day areas belonging to Bengal in India and Bangladesh (Padmanabhan, 1973). In present times, brown spot occurs widely in all the rice-growing tracts of India causing severe yield loss from 4 to 52% (Barnwal *et al.,* 2013). There are evidences that disease becoming more severe in direct seeded rice (Savary *et al*., 2000) and in areas of water scarcity combined with soil nutritional deficiency (Barnwal *et al*., 2013). The symptoms of brown spot include small, oval to spindle-shaped lesions on leaves. The lesions are typically brown in colour and surrounded by a yellowish halo (Sunder *et al*., 2014). The disease occurs at different of crop growth stages; glume blotch phase results in poor seed germinability and seedling death while at booting stage affects the number of tillers, total photosynthetic leaf area and lowers the quality and weight of individual grains when pathogen reaches panicle (Sunder *et al*., 2014).

At present, rice cultivars with an adequate level of resistance are not available in India, which is partly attributed to limitations in reliable and precise screening protocols (Sunder *et al.*, 2014), as well as the specific nutritional and light requirements of *Bipolaris oryzae* that are essential for consistent and adequate sporulation (Basavaraj *et al.*, 2023). Although cultural and nutrient-management practices can reduce disease intensity, traditional management of rice brown spot has heavily relied on synthetic fungicides. In recent years, several new fungicide molecules have been identified to be effective against brown spot disease (Lore *et al*., 2007; Poudel *et al*., 2019; Baite *et al*., 2025; Balgude *et al*., 2017; Balgude and Gaikwad, 2016); while many of the fungicides reported earlier have become outdated. This situation necessitates in identifying the most effective molecules against the pathogen. In recent years, attention has been given towards alternative and sustainable approaches, including botanicals and essential oils derived from plant sources (Nikiema *et al*., 2017; Akila and Mini, 2020). Extracts from medicinal and aromatic plants (*Lippia multiflora*) have shown significant *in vitro* antifungal activity against *B. oryzae* by inhibiting mycelial growth at low concentrations (Nikiema *et al*., 2017). Plant essential oils have shown strong potential in disease management. *In vitro* studies demonstrated that essential oils of *Callistemon citrinus* and *Cymbopogon citratus* completely inhibited the mycelial growth of *Bipolaris oryzae*, while field experiments reported a 20–80% reduction in brown spot severity in rice (Nguefack *et al*., 2013). Amaredra Kumar *et al.,* (2020) reported citronella oil and lemon grass oils were effective in reducing the brown spot severity under field conditions. Plant extracts from *Lawsonia inermis* and other botanicals have demonstrated strong inhibitory effects against *B. oryzae* in poisoned food and diffusion assays, offering environmentally benign alternatives to chemical fungicide (Akila and Mini, 2020). In this perspective, the present study has been conducted with objective to test the *in vitro* efficacy of selected fungicides, essential oils and botanicals against *B. oryzae*.

Materials and Methods

In vitro experiments were conducted in the Department of Plant Pathology, ICAR- Indian Institute of Rice Research (ICAR-IIRR), Rajendranagar, Hyderabad during 2020-2021.

Isolation of the brown spot pathogen *Bipolaris oryzae*

The infected leaves showing typical brown leaf spot symptoms were collected from naturally infected rice fields of ICAR-IIRR farm. Small tissue segments were excised from the lesion margins, surface-sterilized in 0.1% sodium hypochlorite for 1 min, rinsed thrice with sterile distilled water, and blotted dry. The tissues were aseptically placed on Potato Dextrose Agar (PDA) supplemented with streptomycin (50 mg L^{-1}) and incubated at 26 ± 1°C. Emerging fungal colonies were sub-cultured using the hyphal-tip method to obtain pure cultures. The pathogen was identified as *Bipolaris oryzae* based on cultural and microscopic characteristics, and cultures were maintained on PDA at 4^{o}C for further studies.

In vitro evaluation of essential oils against *Bipolaris oryzae*

The essential oils of Citronella (*Cymbopogon winterianus*), Eucalyptus (*Eucalyptus globules*), Cedar wood (*Cedrus atiantica*), Nirgundi (*Vitex negundo*), Lemon grass (*Cymbopogon citratus*), Clove (*Syzygium aromaticum*) and Neem (*Azadirachta indica*) obtained from different parts of the plants were collected from open market as 100 per cent pure and reliable commercial preparations. Different concentrations of the essential oil *viz*., 100, 200, 300, 400 and 500 ppm were prepared in ethylene glycol and tested for their efficacy against *B. oryzae* by following the standard protocol (Nene and Thapliyal, 2000). Different concentrations of essential oils were prepared by mixing in sterile Tween 20 (0.1% w/v) solution and added to a 60 ml lukewarm PDA in flasks to obtain the required concentrations. After solidification of the medium, about 8 mm diameter of 5-day old fungal culture (*B. oryzae*) was taken with the help of sterile cork borer and placed in the petridishes with PDA media with the help of sterile inoculation needle and incubated at 26±1°C. After 10 days of incubation, when the growth of the fungus in the control plates fully covered, the radial growth of the fungus (cm) was measured in different treatments. The percentage inhibition of the radial growth of fungus was calculated using the formula I= ((C-T)/ C) ×***100***) where C and T are the growth of fungal colony (cm) in the control and treated plates, respectively. The experiment was replicated three times, essential oil free PDA medium, containing only SDW and Tween 20 (0.5% v/v), was used as a control (Mounira *et al*., 2011).

In vitro* fungicides against *Bipolaris oryzae

The efficacy of six fungicides *viz*., hexconazole 5% EC, difenconazole 25% EC, prochloraz 45% EC, azoxystrobin 23% SC, propiconazole 25% EC and metiram 70% WG 70% WG were tested at 10, 50, 100, 250 and 500 ppm concentrations against the *B. oryzae* using poison food technique. Required quantity of individual fungicide was added to cooled potato dextrose agar to get the desired concentration of the fungicide. Later, 20 ml of the poisoned medium was poured into Petri plates. Mycelial disc of 5 mm in diameter was placed at the centre of the poisoned agar plate. The medium without any fungicide served as control. Inoculated plates were incubated at 26±1°C and colony diameter was measured in different treatments after 10 days when mycelial growth covered the entire Petri plates in control. The efficacy of the fungicides was expressed as per cent inhibition of mycelial growth, which was calculated by using the formula I = ((C-T)/ C) ×100 where C and T are the growth of fungal colony (cm) in the control and treated plates, respectively given by Vincent (1947).

In vitro* evaluation of different plant extracts against *B. oryzae

Fifteen plant extracts prepared from neem (*Azadiracta indica*), tulasi (*Ocimum sanctum*), aloe vera (*Aloe barbadensis*), soapnut (*Sapindus mukorossi*), datura (*Datura stramonium*), turmeric (*Curcuma longa*), ginger (*Zingiber officinale*), garlic (*Allium sativum*), marigold (*Tagetes erecta*), clove (*Syzygium aromaticum*), pepper (*Piper nigrum*), curry leaf (*Murraya koenigii*), lemon grass (*Cymbopogon citratus*), lemon (*Citrus limon*) and jamun (*Syzygium cumini*) were used in the study. Fresh and healthy plant parts were thoroughly washed and aseptically macerated in sterile distilled water in a 1:1 (w/v) ratio to obtain aqueous extracts. The homogenate was filtered through double-layered muslin cloth followed by membrane filtration using bacterial filter (0.45 µm) to obtain a clear filtrate, which was considered as the aqueous stock solution. The aqueous plant extracts were evaluated at three concentrations (1, 2 and 3%) using the poisoned food technique on potato dextrose agar. Mycelial discs (5 mm) from actively growing cultures of the pathogen were placed at the centre of the plates and incubated at 25 ± 1°C. Radial mycelial growth was colony diameter was measured in different treatments when mycelial growth covered the entire Petri plates in control, and per cent inhibition of mycelial growth was calculated using the formula of Vincent (1947).

Statistical analysis

Statistical package of program OPSTAT was used for analysis of variance (ANOVA) in analysing the *in vitro* data. To ensure homogeneity of variances and normality of the distribution of each variable, data in percentages were arcsine transformed.

Results and Discussion

***In vitro* evaluation of essential oils**

Seven essential oils along with emulsifier (tween 20) were tested for their ability to inhibit the mycelial growth *in vitro* against *Bipolaris oryzae* at concentrations ranging from 100 to 500 ppm. It was found, all the essential oils tested were effective in inhibiting the growth of mycelium at higher concentration (500 ppm) but not at lower concentration. Citronella oil (*Cymbopogon winterianus*) recorded a progressive reduction in radial mycelial growth from 6.0 cm at 100 ppm to 3.4 cm at 500 ppm, corresponding to the highest mean inhibition of 44.5%. Clove oil (*Syzygium aromaticum*) followed Lemongrass oil (*Cymbopogon citratus*) and Citronella oil (*Cymbopogon winterianus*) were highly effective at 500 ppm concentration showing mycelial inhibitions of 75.6%, 64.8% and 61.9% respectively (**Table 1 and Figure 1**). Eucalyptus oil (*Eucalyptus globulus*) and nirgundi oil (*Vitex negundo*) showed comparatively lower mycelial inhibition at 500 ppm (21.9 and 25.2% respectively). Overall, the inhibitory effect increased with concentration for all essential oils, with clove, citronella and lemongrass oils emerging as the most potent against *B. oryzae*. Essential oils are complex mixtures typically composed of terpenoids, phenolics biosynthesized by plants as part of their defense and metabolic systems and known to have potential antifungal action against plant pathogens (Kaur *et al*., 2025). Nikiama *et al*., (2017) reported that, essential oil of *Lippia multiflora* at 0.01% concentration significantly reduced the growth of the *B. oryzae* to 62.64%, and the concentration of 0.1% completely inhibited its growth with 100% efficiency. *In vitro* studies demonstrated that essential oils of *Callistemon citrinus* and *Cymbopogon citratus* completely inhibited the mycelial growth of *Bipolaris oryzae*, while field experiments reported a 20-80% reduction in brown spot severity in rice (Nguefack *et al*., 2013). Amaredra Kumar *et al.* (2020) reported citronella oil

Table 1: *In vitro* efficacy of different essential oils on the mycelial growth of *B. oryzae*

Essential oil	Radial growth of fungus (cm)						Per cent mycelial inhibition					
	100 ppm	200 ppm	300 ppm	400 ppm	500 ppm	Mean	100 ppm	200 ppm	300 ppm	400 ppm	500 ppm	Mean
Citronella oil	6.0	5.9	5.2	4.4	3.4	5.0	33.0 (35.0)*	34.1 (35.7)	42.2 (40.5)	51.5 (45.8)	61.9 (51.9)	44.5 (41.9)
Eucalyptus oil	8.7	8.1	7.3	7.3	7.0	7.7	3.7 (11.1)	10.4 (18.8)	19.3 (26.0)	19.3 (26.0)	21.9 (27.9)	14.9 (22.7)
Cedar wood oil	7.6	5.2	4.9	4.6	4.3	5.3	15.6 (23.2)	42.6 (40.7)	45.9 (42.7)	48.5 (44.2)	52.4 (46.4)	41.0 (39.8)
Nirgundi oil	7.9	7.4	7.5	7.3	6.7	7.4	12.6 (20.8)	17.4 (24.7)	17.0 (24.4)	18.9 (25.8)	25.2 (30.1)	18.2 (25.3)
Lemon grass oil	8.3	6.9	6.2	4.4	3.2	5.8	7.8 (16.2)	23.0 (28.6)	31.5 (34.1)	50.7 (45.4)	64.8 (53.6)	35.6 (36.6)
Clove oil	7.8	6.8	5.2	4.1	2.2	5.2	13.3 (21.4)	24.1 (29.4)	42.2 (40.5)	54.4 (47.5)	75.6 (60.4)	41.4 (40.4)
Neem essential oil	6.5	5.9	5.6	5.1	4.7	5.6	28.1 (32.0)	34.4 (35.9)	37.8 (37.9)	43.3 (41.2)	47.4 (43.5)	38.2 (38.2)
Emulsifier	9.0	8.9	8.8	8.7	8.8	8.8	0.4 (3.5)	1.1 (6.1)	2.2 (8.6)	3.0 (9.9)	2.2 (8.6)	1.8 (7.7)
Control	9.0	9.0	9.0	9.0	9.0	9.0	-	-	-	-	-	
C.D.	0.26	0.30	0.26	0.31	0.35							
CV	1.82	2.47	2.27	2.92	3.73							

*values in parenthesis are arcsine-transformed values and lemon grass oils were effective in reducing the brown spot severity under field conditions (**Figure 2**). Zerumbone, an isolated constituent from *Zingiber zerumbet* rhizomes has the antifungal potential against three major rice fungi: *Bipolaris oryzae*, *Fusarium moniliforme*, and *Rhizoctonia solani* (Kaur *et al*., 2025).

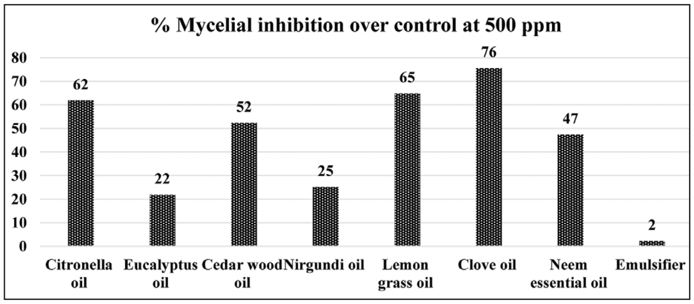


Figure 1: Effect of different essential oils on the percent mycelial growth inhibition at 500 ppm concentration

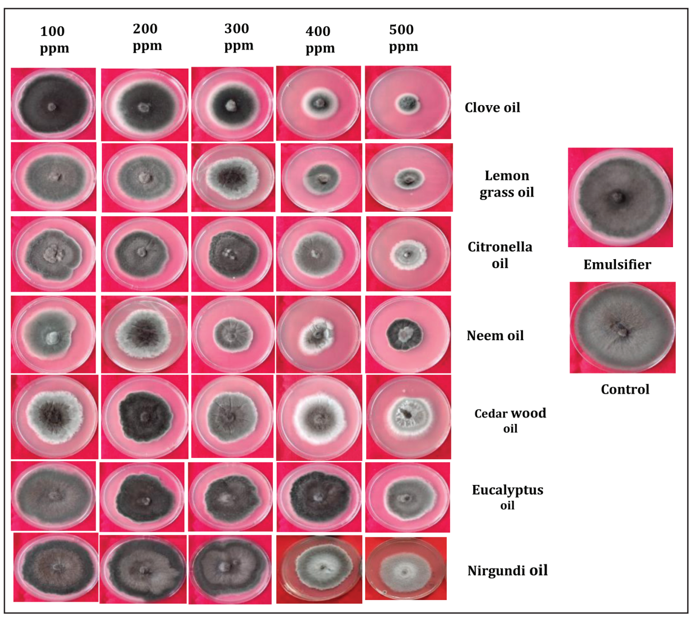


Figure 2: Effect of different essential oils on the inhibition of mycelial growth of *B. oryzae*

In vitro evaluation of fungicides

Six fungicides were tested *in vitro* against *B. oryzae* for their ability to inhibit the mycelial growth at five different concentrations (10 ppm, 50 ppm, 100 ppm, 250 ppm, and 500 ppm). Significant variation in inhibitory effects was observed across concentrations, and all tested fungicides showed their effectiveness at the highest concentration (500 ppm). Azoxystrobin was found as most effective fungicide with lowest mean radial growth (2.9 cm) and the highest mean inhibition (67.3%), with inhibition reaching 88.9% at 500 ppm (**Table 2 and Figures 3 and 4)**. This was followed by difenconazole, propiconazole and prochloraz which showed 84.4%**,** 81.5% and 79.3% inhibition respectively at 500 ppm concentration. The non-systemic fungicide metiram showed the least effectiveness at lower concentrations; however, its inhibitory activity increased substantially with increasing dose, reaching 67.0% inhibition at 500 ppm. In contrast, the untreated control recorded complete mycelial growth with a radial expansion of 9.0 cm. Overall, all fungicides exhibited a clear dose dependent suppression of fungal growth, with azoxystrobin, followed by difenconazole and propiconazole emerging as the most effective molecules against *B. oryzae* under *in vitro* conditions. The results of the present study are in accordance with observations of several earlier workers. In the past, several workers have tested the *in vitro* efficacy of different fungicides and reported some effective molecules against *B. oryzae*. Channakeshava and Pankaj (2018) reported that azoxystrobin could inhibit the mycelial growth up to 46% at 250 ppm concentration, however, in our study the same molecule showed maximum effectiveness (69.6%) at same concentration. The effectiveness of propiconazole in inhibiting the growth of *B. oryzae* aligns with earlier reports against *B. oryzae* (Karan *et al*., 2021; Channakeshava and Pankaja, 2018; Baite *et al*., 2025). Baite *et al*., (2025) had identified tebuconazole, tricyclazole, and propiconazole as effective molecules in inhibition of *B. oryzae* growth under *in vitro* conditions. Gupta *et al*., (2013) made similar observation of propiconazole as most effective with maximum inhibition of 97% at 250 ppm concentration. Propiconazole is a triazole group of fungicide inhibit the action of 14- α- sterol demethylase which is a precursor of ergosterol.

Table 2: *In vitro* efficacy of selected fungicides on the mycelial growth of *B. oryzae*

Sl No.	Fungicide	Radial growth of fungus (cm)						Per cent inhibition					
		10 ppm	50 ppm	100 ppm	250 ppm	500 ppm	Mean	10 ppm	50 ppm	100 ppm	250 ppm	500 ppm	Mean
1	Hexconazole 5% EC	6.6	6.5	6.3	5.1	3.5	5.6	26.3 (30.9)*	27.4 (31.6)	30.0 (33.2)	43.3 (41.2)	60.7 (51.2)	37.6 (37.8)
2	Difenconazole 25% EC	6.2	5.8	4.6	3.9	1.4	4.4	31.1 (33.9)	35.6 (36.6)	49.3 (44.6)	56.3 (48.6)	84.4 (66.8)	51.3 (45.8)
3	Prochloraz 45% EC	4.5	4.0	3.5	3.2	1.9	3.4	50.4 (45.2)	55.9 (48.4)	61.1 (51.4)	64.1 (53.2)	79.3 (62.9)	62.1 (52.0)
4	Azoxystrobin 23% SC	4.0	3.6	3.5	2.7	1.0	2.9	55.9 (48.4)	60.4 (51.0)	61.5 (51.6)	69.6 (56.6)	88.9 (70.5)	67.3 (55.1)
5	Propiconazole 25% EC	6.5	5.9	5.3	4.9	1.7	4.9	27.4 (31.6)	34.1 (35.7)	41.5 (40.1)	45.6 (42.5)	81.5 (64.5)	46.0 (42.7)
6	Metiram 70% WG	8.6	8.4	7.5	5.3	3.0	6.6	4.4 (12.2)	6.7 (15.0)	16.7 (24.1)	40.7 (39.7)	67.0 (55.0)	27.1 (31.4)
7	Control	9.0	9.0	9.0	9.0	9.0	9.0	-	-	-	-	-	-
	C.D.	0.33	0.24	0.37	0.37	0.15							
	CV	3.0	2.4	4.0	4.8	4.1							

*values in parenthesis are arcsine-transformed values

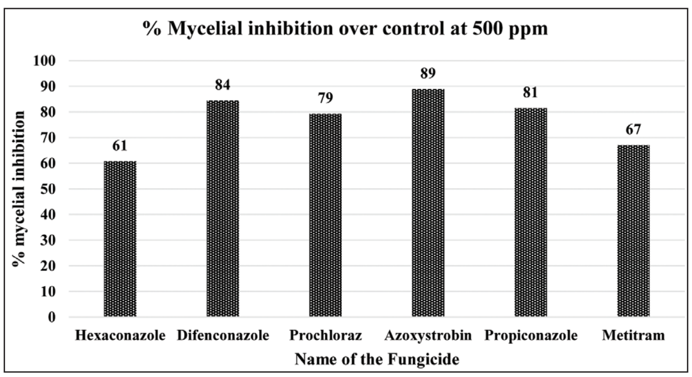


Figure 3: Effect of fungicides on the inhibition of mycelial growth of *B. oryzae* at 500 ppm concentration

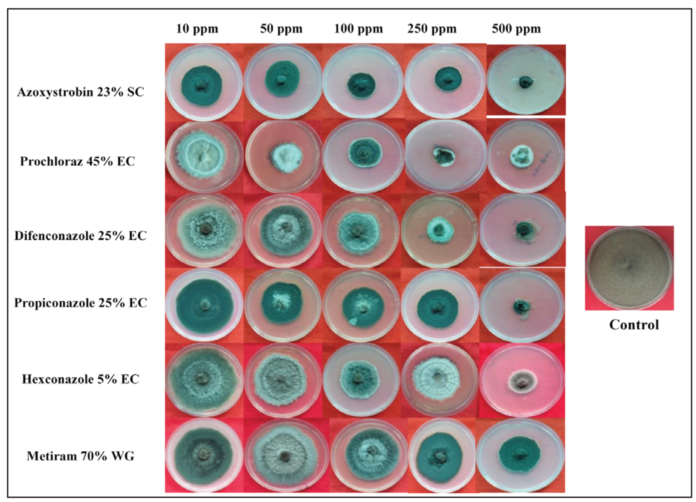


Figure 4: Effect of fungicides on the inhibition of mycelial growth of *B. oryzae*

Effect of different plant extracts against *Bipolaris oryzae in vitro*

Antifungal activity of 15 plant extracts tested *in vitro* following poison food technique, showed considerable variation in antifungal activity across plant species and concentration levels. Soapnut (*Sapindus mukorossi*) exhibited the strongest inhibitory activity, recording the lowest mean mycelial growth (2.5 cm) and the highest mean inhibition (72.6%), with suppression increasing from 61.5% at 1% to 85.9% at 3%. Garlic (*Allium sativum*) also showed substantial antifungal potential, achieving a mean inhibition of 56.0% and its highest inhibition of 64.4% at 3% concentration. Moderate inhibition was recorded with Ocimum (*Ocimum sanctum*) and datura (*Datura stramonium*), with mean inhibition values of 43.6% and 48.5%, respectively. Lemon grass (*Cymbopogon citratus*), marigold (*Tagetes erecta*), jamun (*Syzygium cumini*), pepper (*Piper nigrum*), and clove (*Syzygium aromaticum*) extracts displayed low to moderate activity. In contrast, neem, aloe vera, turmeric, ginger, and curry leaf extracts exhibited minimal or no inhibition, with turmeric and ginger showing complete ineffectiveness at all concentrations (**Table 3 and Figures 5 and 6**). The untreated control maintained full radial growth (9.0 cm). Overall, soapnut and garlic emerged as the most effective plant-based inhibitors of *B. oryzae* under *in vitro* conditions. Several studies in the past have shown effectiveness of plant based extracts in inhibition of mycelial growth of *B. oryzae*. The effectiveness of garlic in our study corroborate with the findings of Channakeshava and Pankaja (2018) wherein they reported, clove and garlic extracts as most effective plant extracts against *B. oryzae*. Plant extracts from *Lawsonia inermis* and other botanicals have demonstrated strong inhibitory

Table 3: Effect of different plant extracts (botanicals) on the radial growth of *Bipolaris oryzae*

Sl. No	Botanical name	Plant part used	Radial growth of fungus (cm)				Per cent inhibition			
			1%	2%	3%	Mean	1%	2%	3%	Mean
1	Neem	Leaf	9.0	8.1	7.1	8.1	0.0 (0.0)	9.6 (18.1)	21.1 (27.4)	10.2 (18.7)
2	Ocimum Spp.	Leaf	6.9	4.8	3.5	5.1	23.7 (29.1)*	46.3 (42.9)	60.7 (51.2)	43.6 (41.3)
3	Aloe vera	Leaf	9.0	8.7	6.7	8.1	0.0 (0.0)	3.7 (11.1)	25.6 (30.4)	9.8 (18.2)
4	Soapnut	Nuts	3.5	2.7	1.3	2.5	61.5 (51.6)	70.4 (57.0)	85.9 (68.0)	72.6 (58.4)
5	Datura	Leaf	6.2	3.9	3.8	4.6	31.1 (33.9)	56.3 (48.6)	58.1 (49.7)	48.5 (44.2)
6	Turmeric	Powder	9.0	9.0	9.0	9.0	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
7	Ginger	Rhizome	9.0	9.0	9.0	9.0	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
8	Garlic	Bulb	4.5	4.2	3.2	4.0	50.0 (45.0)	53.7 (47.1)	64.4 (53.4)	56.0 (48.5)
9	Marigold	Leaf	5.9	5.7	4.9	5.5	34.4 (35.9)	36.7 (37.3)	45.2 (42.2)	38.8 (38.5)
10	Clove	Flower buds	9.0	6.7	5.6	7.1	0.0 (0.0)	25.2 (30.1)	37.8 (37.9)	21.0 (27.3)
11	Pepper	Pepper berries	8.0	7.1	5.7	6.9	11.5 (19.8)	21.1 (27.4)	36.7 (37.3)	23.1 (28.7)
12	Curry leaf	Leaf	9.0	8.0	5.6	7.5	0.0 (0.0)	10.7 (19.1)	38.1 (38.1)	16.3 (23.8)
13	Lemon grass	Leaf	6.2	5.2	4.3	5.3	30.7 (33.7)	42.2 (41.5)	51.9 (46.2)	41.6 (40.2)
14	Lemon	Leaf	7.5	7.2	6.8	7.2	17.0 (24.4)	19.6 (26.3)	24.8 (29.9)	20.5 (26.9)
15	Jamun	Leaf	6.5	5.9	5.2	5.9	27.4 (31.6)	34.8 (36.2)	42.2 (40.5)	34.8 (36.2)
16	Control		9.0	9.0	9.0	9.0				
			C.D.	**SE(d)**	**SE(m)**					
	Factor (A-Botanicals)		0.151	0.076	0.054					
	Factor (B-Concentrations)		0.065	0.033	0.023					
	Factor (A X B)		0.262	0.132	0.093					

*values in parenthesis are arcsine-transformed values effects against *B. oryzae* (Akila and Mini, 2020). Bhat *et al*. (2024) demonstrated that extracts of several medicinal plants possess strong antifungal activity against *Bipolaris oryzae*, with methanolic extract of *Syzygium aromaticum* and *Inula racemose* showing mycelial inhibition 100% and 90 % respectively at 4000 ppm concentration under *in vitro* testing.

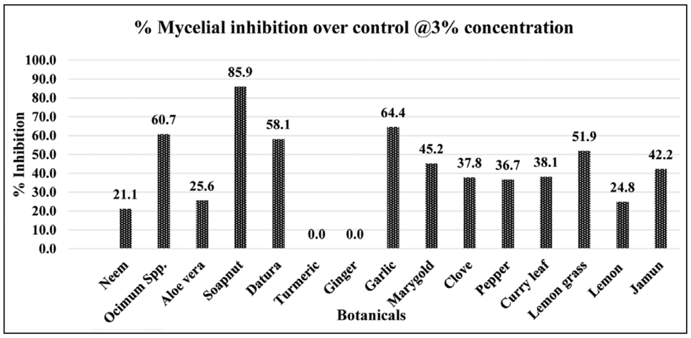


Figure 5: Effect of different plant extracts (botanicals) on the radial growth of *Bipolaris oryzae* at 3% concentration

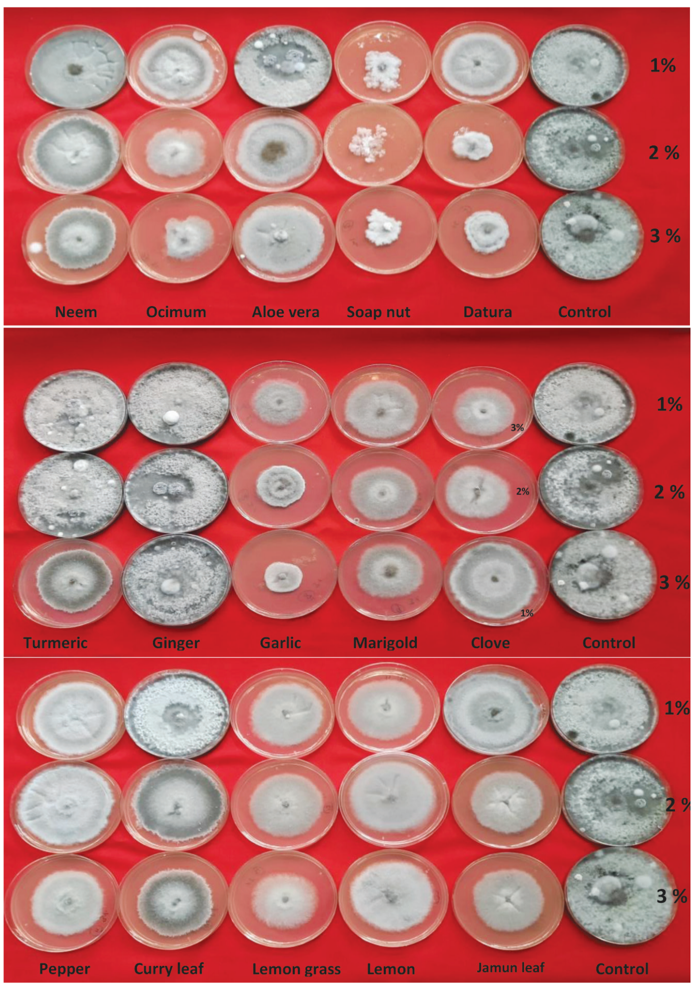


Figure 6: Effect of different plant extracts (botanicals) on the radial growth of *Bipolaris oryzae*

Conclusion

The present study demonstrated distinct *in vitro* antifungal efficacy of essential oils, fungicides, and botanical extracts against *Bipolaris oryzae*. Clove oil, followed by lemongrass oil, showed the highest inhibitory activity among essential oils, highlighting their potential as eco-friendly disease management options. Among fungicides, azoxystrobin, difenoconazole, and propiconazole were highly effective, particularly at higher concentrations, confirming their strong activity against *B. oryzae*. Soapnut extract was the most effective botanical, while garlic, *Datura*, and *Ocimum* extracts also exhibited moderate inhibition. Overall, the findings identify promising chemical and non-chemical agents that may be integrated into brown spot management programs; however, field-level evaluation is necessary to validate their efficacy and consistency under natural conditions.

References

Akila R and Mini ML. 2020. Solvent extraction and antifungal assay of *Lawsonia inermis* Linn. against the brown spot fungus *Bipolaris oryzae*. *Journal of Pharmacognosy and Phytochemistry*, 9(1): 05-08.

Baite, MS, Kumar, P, Rathinam, PKS, Shivappa, R, Umapathy, K and Dash, D. 2025. Evaluation of the efficacy of fungicides in controlling brown spot (*Bipolaris oryzae*) disease in rice. *Discover life*, 55(3):1-9. https://doi.org/10.1007/s11084-025-09678-5.

Balgude, YS and Gaikwad, AP. 2016. Evaluation on the efficacy of modern fungicides against rice diseases. *Journal of Rice Research*, 9(1): 53-57.

Balgude, YS, Gaikwad AP and Kshirsagar CR. 2017. *Pseudomonas fluorescens*, a potential bioagent for effective management of diseases in organic rice production. *Journal of Rice Research*, 10(2): 80-84.

Basavaraj, K, Jasudasu, GS, Prakasam, V, Ladhalakshmi, D, Kannan, C, Krishnaveni, D, Laha, GS, Ch Suvarna Rani and Prasad, MS. 2023. Enhanced sporulation by different light and nutritional sources in *Bipolaris oryzae* causing brown spot disease of rice. *Journal of Environmental Biology* 44(3): 380–389.

Barnwal MK, Kotasthane A, Magculia N, Mukherjee PK, Savary S, Sharma AK, Singh HB, Singh US, Sparks AH, Variar M and Zaidi N. 2013. A review on crop losses, epidemiology and disease management of rice brown spot to identify research priorities and knowledge gaps. *European Journal of Plant Pathology*, 136: 443-457.

Bhat S, Rather M, Gani S, Nabi A, Ganai SA, Shah MD, Sofi P, Jeelani F, Hussain A, Ashraf S, Anwar A, Iqbal I, Un Nisa T, Summuna B and Banday S. 2024. Identification of plant-based potential antifungal compounds against BMK-1 protein of *Bipolaris oryzae* using molecular docking approach. *Scientific Reports*, 14: 15665. https://doi.org/10.1038/s41598-024-61431-6.

Channakeshava C and Pankaja NS. 2018. In vitro evaluation of fungicides, plant extracts and biocontrol agents against brown leaf spot of paddy. *International Journal of Current Microbiology and Applied Sciences*, 7(05): 127-132.

Gupta V, Shamas N, Razad VK, Sharma BC, Sharma R, Kaur K, Singh I, John D and Kumar A. 2013. Foliar application of fungicides for the management of brown spot disease in rice (*Oryza sativa* L.) caused by *Bipolaris oryzae*. *African Journal of Agricultural Research*, 8(25): 3503-3309.

Karan R, Renganathan P and Balabaskar P. 2021. *In vitro* evaluation of selected fungicides against *Bipolaris oryzae* causing brown leaf spot of rice. *Journal of Agricultural Science*, 12(5): 1583-1584.

Kaur N, Kaur R, Bhardwaj U and Sharma P. 2025. Isolation and derivatization of bioactive compounds from *Zingiber zerumbet* essential oil with antifungal activity against rice pathogens. *Discover Plants*, 2: 249. https://doi.org/10.21203/rs.3.rs-6116554/v1

Kumar A, Choudhary SK, Kumar U, Singh RN and Haque M. 2020. Eco-friendly management of brown spot disease of rice by the application of essential oils in Bihar. *Journal of Pharmacognosy and Phytochemistry*, 9(4): 285-289.

Lore JS, Thind TS, Hunjum MS and Goel RK. 2007. Performance of different fungicides against multiple diseases of rice. *Indian Phytopathology*, 60(3): 296-301.

Mounira S, Ibtissem S, Mouna K, Boujemaa K and Boughalleb N. 2011. Downy mildew of sunflower in Tunisia and evaluation of four fungicides. *Research in Plant Biology*, 1(5): 27-32.

Nene YL and Thapliyal PN. 2000. *Fungicides in Plant Disease Control*. 3rd ed. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi. pp. 531-533.

Nguefack J, Nguikwie SK, Fotio D, Dongmo B, Leth V and Nkengfack AE. 2007. Fungicidal potential of essential oils and fractions from *Cymbopogon citratus*, *Ocimum gratissimum* and *Thymus vulgaris* to control *Alternaria padwickii* and *Bipolaris oryzae*. *Journal of Essential Oil Research*, 19(6): 581-587.

Nikiema WF, Koita K, Zida EP and Kabore KB. 2017. In vitro management of *Bipolaris oryzae*, the causal pathogen of brown spot of rice, by plant extracts. *International Journal of Sciences*, 6(12): 42-47.

Padmanabhan SY. 1973. The great Bengal famine. *Annual Review of Phytopathology*, 11( ): 11-26.

Poudel NS, Bharatee P and Acharya M. 2019. Influence of different chemical fungicides against rice brown leaf spot disease caused by *Bipolaris oryzae*. *International Journal of Current Microbiology and Applied Sciences*, 8(01): 441-446.

Savary S, Willocquet L, Elazegui FA, Castilla N and Teng PS. 2000. Rice pest constraints in tropical Asia: quantification of yield losses due to rice pests in a range of production situations. *Plant Disease*, 84(3): 357-369.

Sunder S, Singh R and Agarwal R. 2014. Brown spot of rice: an overview. *Indian Phytopathology*, 67(3): 201-215.

Vincent JM. 1947. Distribution of fungal hyphae in the presence of certain inhibitors. *Nature*, 150: 850.

SHORT COMMUNICATION https://doi.org/10.58297/QGIF4123

GR-27 (Bhim): A High Yielding Rice Variety Suitable for Value Addition in Gujarat State

Mistry PM*, Patel PB, Mungra KS, Parth Patel and Patil VA

Main Rice Research Centre, Navsari Agricultural University, Navsari – 396450 Gujarat
*Corresponding author E mail: mrrc@nau.in

Received : 15th December, 2025, Accepted : 25th December, 2025

Abstract

Navsari Bhim (JGL 3655 x Z-31, IET-29918) is a medium duration white kernel rice variety suitable for value addition released form Main Rice Research Centre, NAU, Gujarat for the whole state. The variety has maturity duration of 125-130 days with an average grain yield of 5700-5800 kg/ha with a very good poha recovery. The Bhim is developed by crossing JGL-3855, a high yielding variety of MH and Z-31, a fine grain variety of Gujarat. It has long bold grain, medium maturing and more productive tillers per plant. NVSR-687 produce good quality poha and puffed rice with high poha recovery (57.4 %) and puffed rice recovery (61.8 %). NVSR-687 is moderately resistant against bacterial leaf blight, grain discoloration, sheath rot and leaf blast. It showed tolerant reaction against brown plant hopper whereas moderately resistant reaction against stem borer, leaf folder and sheath mite. Navsari Bhim (GR-27) was released by 58th State Seed committee meeting of the Government of Gujarat, suitable for the whole state in *kharif* season.

Keywords: GR 17 (Bhim), high yielding, value added, puffed rice and medium duration variety

Introduction

Rice is the staple food and main source of nutrition for about 50% world and 70% of the Indian population. In the Gujarat, rice occupies about 5 % of the gross cropped area and it is being grown on about 7.8 to 8.0 lakh hectares, of which about 60-70 % is under a low land (Transplanted) and remaining 30-35 % under upland rice (drilled) situation. More than 90 % of the area under rice is confined to South and Middle Gujarat.

Value added products helps farmers to get better price of their produce. Beaten rice (Poha) and puffed rice are the value added products of bold grain rice. Large number of beaten rice (Poha) and puffed rice industries are present in Gujarat state. About 50% of rice area in our state is under bold grain varieties. Very few choices are available for farmers under bold seeded rice varieties in Gujarat. Hence, there is an urgent need to develop such rice variety which is suitable for beaten and puffed rice preparation of superior quality, so that the farmers can have a viable option of variety. This will also lead to multi-culture combination of rice varieties.

In this context, the proposed Variety Navsari Bhim derived from a cross JGL-3855 x Z-31 was bulked from the advanced generation in the year 2018. The proposed variety was evaluated 20 trials/locations in various categories of trial from 2019 to 2024 in Gujarat. The variety, Navsari Bhim performed very well in Gujarat with an average yield of 5781 kg/ha which was 13-23% higher as compared to previously released bold grain type rice variety *viz.,* GNR-3, GNR-5 and Jaya.

Table 1: Mean grain yield of Navsari Bhim in various yield Trials

Name of variety	Grain yield (kg/ha)	% Increase over
Navsari Bhim	5781	
GNR-3	5057	14.31
GNR-5	4640	24.59
Jaya	4685	23.39

The proposed variety was evaluated under All India Coordinated Research Project on Rice during *kharif*-2021 under IVT-L trial. On pooled basis in Zone-VI (Western zone), it recorded 6227 kg grain yield per hectare with yield increment of 8.4 per cent, 24.2 per cent, 13.5 per cent over the checks Swarna (NC), NDR-8002 (ZC) and Local check (LC), respectively.

The artificial and natural screening for the various diseases and pests was conducted at Main Rice research Centre, NAU, Navsari and the results were presented in **Table 2**. Where it showed moderately resistant against bacterial leaf blight, grain discoloration, sheath rot and leaf blast, whereas, it showed tolerant reaction to pest like brown plant hopper and moderately resistant reaction against stem borer, leaf folder and sheath mite.

Table 2: Reaction of Navsari Bhim to pest and diseases

Variety	Score							
	Blast	BLB	Sheath Rot	GD	SB	LF	Sheath Mite	BPH
Navsari Bhim	0	3	5	5	0	1	1	0
GNR-3	0	3	5	5	3	1	3	0
Jaya	0	3	7	5	5	3	5	1

The proposed variety Navsari Bhim contains intermediate amylose (23.51%) and high head rice recovery (61.70 %) as compared to checks *viz.,* GNR-3, GNR-5 and Jaya. (**Table 3**). The proposed strain, NVSR-687 possesses 7.55 mm kernel length with the kernel width of 2.71 mm having the L/B ratio of 2.79 which is more than enough to categorize it into Long Bold grain group (**Table 3**). The traders' opinion was also obtained, which indicated that it is superior in terms of economic return, beaten rice and puffed rice quality over the checks GNR-3, GNR-5 and Jaya.

Table 3: Quality characteristics of proposed variety with checks during 2024

Sl. No.	Name of the culture	Protein content (%)	Zinc content (ppm)	Iron content (ppm)	Vol. Exp. Ratio	Water uptake (ml)	Amylose content (%)	Hulling Recovery (%)	Milling recovery (%)	HRR (%)
1	Navsari Bhim	6.48	15.30	7.49	4.30	320	23.51	78.30	69.20	61.70
2	GNR-3	6.52	14.25	5.96	3.92	335	25.74	78.02	69.06	60.50
3	GNR-5	5.29	14.47	7.68	4.01	308	22.84	75.60	68.20	61.40
4	Jaya	5.74	13.95	6.45	4.23	340	26.20	78.00	68.40	60.00

SHORT COMMUNICATION https://doi.org/10.58297/RVDK3058

Him Palam Dhan 4 (HPR 3201): A Long Grained High-Yielding Rice Variety for Transplanted Irrigated Conditions of Himachal Pradesh and Uttrakhand

Neelam Bhardwaj*, Daisy Basandrai, Dhirendra Singh, Shivani and Surbhi Patyal

Department of Genetics and Plant Breeding, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur-176062

*Corresponding author Email: neenabhardwaj@gmail.com

Received : 17th December, 2025, Accepted: 28th December, 2025

Abstract

Him Palam Dhan 4 (HPR 3201) is a high-yielding, lodging-resistant and fine grained rice variety that has been developed for the Medium Northern Hills' transplanted irrigated conditions. With an average yield of 4429 kg/ha, which is 13.6–16% more than Vivekdhan 86 and 20–72% more than Shalimar Rice 3, the variety consistently outperformed national and regional checks when evaluated as IET 28882 under All India Coordinated Rice Improvement Project (AICRIP) trials conducted at 12 locations between 2020 and 2022. It showed good grain characteristics, such as long, slender grains, 79.2% hulling, 67.7% milling, L/B ratio of 3.30 and amylose content of 25.28%. It also showed moderate resistance to leaf and neck blast and decreased occurrences of stem borer and leaf folder. Its high agronomic performance, pest and disease resistance, and outstanding grain quality make it a potential variety for hill ecosystems.

Keywords: HPR 3201, Blast resistance, Grain quality, Rice

Introduction

Rice (*Oryza sativa* L.) farming in hill regions makes a considerable contribution to regional food supply and farm-based livelihoods, but ecological restrictions often limit crop yields. Cooler growing temperatures, frequent cloud cover, and extended periods of precipitation during the growing season are characteristics of the Medium Northern Hill zone that collectively foster the growth of diseases and pests. These factors collectively contribute to yield reduction and production instability in rice-based systems.

Blast disease, caused by *Magnaporthe oryzae*, is a recurring problem in rice as it can infect plants at several growth stages and produce considerable losses under favorable conditions. Insect pests like leaf folder and stem borer exacerbate production decline by destroying photosynthetic tissues and impeding nutrient transportation. Similarly, grain quality metrics have emerged as essential criteria for varietal acceptability, since milling recovery, grain appearance, and cooking quality have a direct impact on market demand and choice among consumers. Because of the combined effects of these challenges, rice varieties that can sustain production despite the impact of periodic disease and pest stress need to be developed.

To address these challenges, HPR 3201 (HPR 2143 / AC 19146), a high-yielding, lodging-resistant and quality rice variety developed for transplanted irrigated conditions of the Medium Northern Hills at Rice and Wheat Research Centre, Malan, CSK HPKV, followed pedigree selection from segregating generations to identify uniform lines combining high yield, agronomic stability, disease and pest tolerance and superior grain quality. This variety was evaluated as IET 28882 in the All India Coordinated Rice Improvement Project (AICRIP) trials during 2020–2022 at 12 locations along with national and regional checks Vivekdhan 86 (NC), Shalimar Rice 3 (RC) and HPR 1068 (LC).

HPR 3201 consistently outperformed the checks, recording an average yield of 4429 kg/ha compared to 3849 kg/ha and 2489 kg/ha for Vivekdhan 86 and Shalimar Rice 3, respectively, with yield increases over the national check ranging from 13.6% to 16% across the three-year evaluation period (**Table 1 and Figure 1**). At the state level, yield advantages of 11–19% in Himachal Pradesh and 15–72% in Uttarakhand were observed. HPR 3201 matures in 120–125 days with 90 days to flowering and exhibits resistance to lodging and shattering. Artificial screening under controlled inoculation revealed moderate resistance to leaf and neck blast during 2020–2022 and incidences of leaf folder and stem borer were comparatively lower than in other tested variety *i.e.* TN1 (**Tables 2 and 3**). Grain quality analysis indicated that HPR 3201 produces long, slender grains with 79.2% hulling, 67.7% milling recovery, a length-to-breadth ratio of 3.30 and amylose content of 25.28% (**Table 4 and Figure 2**). The combination of high yield, agronomic stability, moderate disease resistance, lower pest incidence and superior grain quality contributed to its eventual proposal for identification for transplanted irrigated conditions of the Medium Northern Hills.

Table 1: Mean data for different agro-morphological traits during *kharif* 2020, 2021 and 2022 at RWRC, Malan

Variety	Days to 50 % flowering			Plant height (cm)			Panicles/m^2			Yield (kg/ha)		
	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022
HPR 3201	93	91	98	190.26	104.05	109	334	281	336	3170	5771	4444
Vivekdhan 86	91	90	97	239.22	116.09	109	339	286	286	3795	5721	5061
Shalimar Rice 3	77	84	94	108.67	111.06	108	-	264	200	2641	4117	3849
HPR 1068	86	89	95	198.44	107.62	95	279	297	262	2232	3935	4293

Figure 1: Field View of Rice Variety Him Palam Dhan 4 (HPR 3201)

Table 2: Disease reaction of Him Palam Dhan 4 (HPR 3201) against leaf and neck blast during *kharif* 2020, 2021 and 2022

Sl. No.	Variety	Leaf blast			Neck Blast		
		2020	2021	2022	2020	2021	2022
1	HPR 3201	4	4	3	2	3	7
2	Vivekdhan 86	3	5	3	3	5	3
3	Shalimar Rice 3	4	8	5	7	7	7

Table 3: Reaction to major insect pests at different locations during *kharif* 2022

Entry	Leaf folder Damage (% DL)		Stem Borer Damage		
	MLN (97 DT)	CHT (80 DT)	LDN (90 DT)-%WE	MLN (97 DT)-% DT	PNT (113 DT)-%WE
Prop. Var. Him Palam Dhan 4 (HPR 3201)	16.7	30.3	5.8	16.7	10.6
Check -TN1	19.5	13.5	13.8	0.0	15.1

Table 4: Data on Quality Characteristics

Sl. No.	Variety	Hull	Mill	HRR	KL	KB	L/B	Grain Type	Grain Chalk	ASV	AC	GC
1	**HPR 3201**	**79.2**	**67.7**	**58.6**	**7.07**	**2.14**	**3.30**	**LS**	**VOC**	**3.0**	**25**	**24**
2	Vivekdhan-86	79.8	70.5	67.0	5.80	2.60	2.23	SB	VOC	4.0	24.46	22
3	Shalimar Rice-3	78.5	71.8	70.8	5.46	2.48	2.20	SB	OC	4.0	25.02	22
4	1068	79.3	70.9	68.7	7.12	2.15	3.31	LS	VOC	4.0	24.08	60

Figure 2: Grain Characters of HPR 3201

SHORT COMMUNICATION https://doi.org/10.58297/VVFY9393

Him Palam Dhan 3 (HPR 2865): A Medium Maturing Long Bold Rice Variety with Stable Yield and Acceptable Grain Quality for Himachal Pradesh and Uttrakhand

Neelam Bhardwaj*, Dhirendra Singh, Daisy Basandrai, Shivani and Surbhi Patyal

Department of Genetics and Plant Breeding, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur-176062

*Corresponding author Email: neenabhardwaj@gmail.com

Received : 16th December, 2025, Accepted: 29th December, 2025

Abstract

Him Palam Dhan 3 (HPR 2865), a variety developed from a cross between *Palampur Purple* and *Kasturi*, is a medium duration, long-bold grained rice variety evaluated for agronomic traits in the All India Coordinated Rice Improvement Project (AICRIP) across 13 testing locations in the Northern Hill Zone during *kharif* 2018 to 2020, along with three checks*, i.e.,* Vivekdhan 86, Shalimar Rice 3 and HPR 1068. The genotype exhibited consistent tolerance to both leaf and neck blast with low disease scores across seasons compared to the checks. HPR 2865 recorded stable grain yield over three years along with desirable plant height, early flowering and adequate panicle density. Grain quality analysis revealed satisfactory hulling, milling, head rice recovery, medium amylose content and acceptable cooking quality. The overall performance indicates that HPR 2865 is a promising blast tolerant rice variety suitable for possible release in blast-prone regions of the North Western Himalayas.

Keywords: HPR 2865, blast tolerance, early maturity, grain quality, long bold grains

Introduction

Rice (*Oryza sativa* L.) is one of the most important staple food crops, supporting the livelihood and food security of millions of people worldwide. In India, rice occupies a central position in agricultural production systems across diverse agro-ecological regions. However, rice productivity is frequently constrained by biotic stresses, among which blast disease caused by *Magnaporthe oryzae* remains the most devastating and widespread. The disease affects rice at multiple growth stages, including leaf, node and panicle, leading to severe yield losses, particularly when neck blast incidence coincides with the reproductive phase.

The North Western Himalayan region presents unique challenges for rice cultivation due to its variable climate, high humidity during the cropping season and frequent occurrence of blast epidemics. The adoption of blast-susceptible varieties often results in unstable yields and increased dependence on fungicidal management, which is neither economically sustainable nor environmentally desirable. Consequently, the development and deployment of blast-tolerant rice varieties remain the most effective and eco-friendly strategy for managing the disease in these regions. Grain and cooking quality characteristics also play a vital role in varietal acceptance by farmers, millers and consumers. Traits such as milling efficiency, grain type, amylose content and cooking quality determine market value and consumer preference.

In response to these challenges, a systematic varietal development programme was initiated at CSK HPKV, Rice and Wheat Research Centre, Malan, to breed high-yielding, lodging-resistant and quality rice cultivars. Germplasm with desirable grain type and tolerance to hill-specific stresses was identified from the available collections and strategic hybridization plans were implemented. The parental lines chosen for the crossing programme included *Palampur Purple*, a locally adapted genotype known for its robustness in hill ecologies and *Kasturi*, a quality rice type with favourable grain characteristics. The material from F_2 onwards was handled by the pedigree method, enabling systematic selection across segregating generations based on plant type, productivity potential, disease reaction and quality traits. A uniform line from one of the $F_{2}:_{9}$ was tested in a station trial from 2016. Once uniformity was achieved, it was included in the Initial Evaluation Trials (IET) under the All India Coordinated Rice Improvement Project (AICRIP). Following encouraging performance, the line was promoted to subsequent stages, including multi-location Preliminary Yield Trials and later to advanced yield trials across Low and Medium Northern Hill zones.

The three-year evaluation across 13 diverse testing locations confirmed the stability and superiority of HPR 2865, with the variety consistently ranking among the top performers when compared with established national and regional checks. The variety showed a yield advantage of 0.59-82.34% and 21.38-93.31% over the national check Vivekdhan 86 and the regional check Shalimar Rice 3, respectively (**Table 1 and Figure 1**). Artificially screening for pests and diseases was done at Rice and Wheat Research Centre, Malan, CSK HPKV and the results are presented in **Table 2**. The variety showed moderate resistance to leaf and neck blast during 2018, 2019 and 2020. The infestation of brown plant hopper, white-backed plant hopper, leaf folder and stem borer was found to be comparatively lower in this variety as compared to other tested varieties *i.e.,* TN-1 (SC) and W-1263 (RC) (**Table 3**).

Table 1: Mean data for different agro-morphological traits during *kharif* 2018, 2019 and 2020

Variety	Days to 50 % flowering			Plant height			Panicles/m^2			Yield (kg/ha)		
	2018	2019	2020	2018	2019	2020	2018	2019	2020	2018	2019	2020
HPR 2865	99	100	88	103	117	129	185	338	222	3387	3670	2657
Viveldhan 86	92	92	90	108	117	127	271	307	210	3367	3083	2243
Shalimar rice 3	91	84	82	108	104	124	254	249	196	2553	2594	1742
1068	109	95	86	93	106	98	294	298	228	3743	3243	1881

Figure 1: Field View of Rice Variety Him Palam Dhan 3 (HPR 2865)

Table 2 Disease reaction of Him Palam Dhan 3 (HPR 2865) against leaf and neck blast during *kharif* 2018, 2019 and 2020

Sl. No.	Variety	Leaf blast			Neck Blast		
		2018	2019	2020	2018	2019	2020
1	HPR 2865	1	2	3	3	1	3
2	Vivekdhan 86	1	2	3	3	3	3
3	Shalimar Rice 3	5	4	4	7	7	7

Table 3: Reaction to Insect Pests

Variety	Brown Plant Hopper	White-backed Plant Hopper	Stem Borer	Leaf Folder
HPR 2865	5.8	6.6	16.1	8.7
TN-1 (SC)	8.3	9.0	27.6	15.2
W-1263 (RC)	6.1	9.0	24.5	7.6

Grain qualities of the variety were analyzed based on standard laboratory procedures (**Table 4**). This variety had long, bold white grains with 86.6% hulling, 68.8% milling, L/B ratio of 2.51and amylose content of 24.5% (**Figure 2 and Table 4**). Its strong agronomic behavior, moderate resistance to leaf and neck blast, lower pest incidence and favorable grain quality contributed to its advancement for large-scale testing and eventual proposal for identification.

Table 4: Data on Quality Characteristics

Sl. No.	Variety	Hull	Mill	HRR	KL	KB	L/B	Grain Type	Grain Chalk	ASV	AC	GC
1	**HPR 2865**	86.6	68.8	53	6.34	2.52	2.51	LB	OC	4	24.49	22
2	Vivekdhan-86	80.6	69.3	57.7	5.42	2.6	2.08	SB	OC	4	24.17	22
3	Shalimar Rice-3	80.6	68.2	62.1	5.1	2.53	2.01	SB	OC	4	25.81	22
4	1068	77.2	64.4	18.1	5.48	2.3	2.3	SB	VOC	4	24.4	28

Rice Germplasm Registered during July-December 2025 at ICAR-National Bureau of Plant Genetic Resources, New Delhi

SI No.	Crop Name	Botanical Name	National Identity	Donor Identity	INGR No.	Novel Unique Features
1	Rice	*Oryza sativa*	IC658167	TKM 85/ Pokka-li-BJJ/10-2	25042	Saline submergence tolerant at germination stage: Germination % (5 DAS) =90.749%, Survival % (10 DAS) =91.58% (EC= (5 dSm-1; 42.92 mM NaCl and 10 dSm-1; 85.83 mM NaCl).
2	Rice	*Oryza sativa*	IC256568	AC-34975/ Chadhei nakhi; PB-56	25043	Least reduction in root dry weight (0.02gm) and Enhancement in shoot dry weight (0.06gm) under drought stress 12.8 % mean leaf chlorophyll content enhancement under salinity stress Least reduction in shoot dry weight (0.03gm) under salinity stress.
3	Rice	*Oryza sativa*	IC658168	CRAC4423-14 (Savitri X Pokkali)	25044	Osmotic/dehydration tolerance at seedling stage with higher shoot dry weight (0.052g) under severe osmotic stress (2% mannitol) compared to tolerant genotypes Vandana and FL 478(0.02g).
4	Rice	*Oryza sativa*	EC1076003	Binnaful EC1076003	25045	Tolerant to osmotic stress (-4.0 bar Mannitol induced) – High shoot weight (0.055 g) and high chlorophyll content (2.2 mg/100g) Highly tolerant to anaerobic germination (germination rate = 65.5%, high epicotyl length 35 cm) Tolerant to salinity (NaCl induced 12 dSm-1) lowest decline in root biomass (10.49%), High chlorophyll content (1.0 mg g-1 FW), high shoot growth. Salt injury score 5.0 (moderate).

SI No.	Crop Name	Botanical Name	National Identity	Donor Identity	INGR No.	Novel Unique Features
5	Rice	*Oryza sativa*	IC658169	IR 73784-5-28-B-HWR-1 (IR31917-45-3-2 x O. latifolia Acc 100914// IR31917-45-3-2 in BC1F11 generation)	25046	Resistance to Brown planthopper (BPH) *Nilaparvata lugens* with a damage score of 4.1 Resistance to brown planthopper at vegetative and reproductive stages
6	Rice	*Oryza sativa*	IC658170	RP 5177-86 (GP SS RIL-86)	25047	Resistance (Damage score: 3.1) against Brown planthopper in seedling stage It possesses three known genes namely bph2, Bph 21 and Bph 32 governing BPH resistance.
7	Rice	*Oryza sativa*	IC658171	BPT 3194 (BPT 5204 and MTU 1075)	25048	Resistance to BPH damge score= 3.1), WBPH (DS= 4.1), mixed planthopper populations (43.5 no./10hills) in Vegetative and Reproductive Stages.
8	Rice	*Oryza sativa* var. *indica*	IC658172	RP 6619 (RP 5933-1-19-2 R/ Tetep // RP 5933-1-19-2 R/ *O. minuta* (IR 71033-121-15 derived from *O. minuta*))	25049	Broad-spectrum blast resistance genes Pi9 and Pi54 in this male fertility restorer.
9	Rice	*Oryza sativa* var. *indica*	IC658173	NLRBL-1 (UB1066) ((MTU1010 x 5809-7-1-1-1) (where 5809-7-1-1-1 is a derivative of NLR 34417 x NLR 34449))	25050	Resistance to leaf and neck blast (with mean leaf blast score of 3.1 over ten locations and mean neck blast score of 2.3 over six locations across India).
10	Rice	*Oryza sativa*	IC658174	IET31956 (RP6615-MK/RIL-FB-MI-45-1-5-1) (MTU1010 × Karuppunel)	25051	Possesses micronutrient (Zn) content (25.87ppm) in polished rice grain Posseses Protein content of 7.69% in polished rice grain.
11	Rice	*Oryza sativa*	IC658175	IET 31933; [RP6615-MK (RIL-FBMI-2-1)] (MTU1010 × Karuppunel)	25052	Possesses micronutrient (Zn) content (25.25ppm) in polished rice grain Possesses Protein content of 8% in polished rice grain.

Journal of Rice Research - Author Guidelines

Scope: Journal of Rice Research is a channel for publication of full length papers covering results of original research, invited critical reviews or interpretative articles related to all areas of rice science, rice based crop systems and rice crop management. The journal also publishes short communications, book reviews and letters to the editor.

Articles reporting experimentation or research in any field involving rice or rice based cropping systems will be accepted as original articles while critical reviews are generally invited. Short articles concerned with experimental techniques or observation of unique nature will be accepted as short communication. Letters to the editor concerning previous articles are welcome and are published subject to review and approval by the editorial board. The original authors will be invited to reply to the points raised in these letters for their response which are also published together.

General Requirement:

Submission to the journal must be reports of original research of at least two crop seasons and must not be previously published or simultaneously submitted to any other scientific or technical journal. At least one of the authors (in case of joint authorship) should be member of the Society for Advancement of Rice Research (SARR) and not in arrears of subscription. Authors of invited articles are exempted from this.

Submission of Manuscript:

Manuscripts should be sent by email to the chief editor (jrrchiefeditor@gmail.com) as an attachment. All the enclosed figures (as ppt/jpg files), graphs (as MS Excel worksheet with original data) and photographs (as jpg or ppt files with high resolution) may be submitted as separate files. Avoid using more than one font. The manuscript should be typed in double spaced times new roman font with margins of at least 2.5 cm. On the first page give the title, a byline with the names of authors, their affiliation and corresponding author's e-mail ID. Abstract should be followed by a list of key words. The usual order of sections to be included after title and abstract pages are: Introduction which includes literature review; materials and methods; results and discussion; conclusion (optional), acknowledgements and references followed by figures and tables.

Title should give a clear idea what the articles is about. It should be brief and informative (12-15 words).

Materials and Methods should include experimental design, treatment details, replications and techniques/ methods employed.

Results and Discussion should be supported by sound scientifically analysed data along with explanatory text with relevant tables and figures.

References should be quoted in author-year notation system only. All the references should be arranged alphabetically by author. All single author entries precede multiple author entries for the same first authors. Use chronological order within entries with identical authorship and add a low case letter a, b, c, etc., to year for same year entries of the same author. References should be presented in the format given below:

Research papers

1. Durvasula V. Seshu**.** 2017. Networking a Pivotal Strategy for Rice Genetic Improvement. *Journal of Rice Research*, 10: 1-8.
2. Kemparaju KB, MS Ramesha, K Sruti, AS Hari Prasad, RM Sundaram, P Senguttuvel and P Revathi**.** 2018. Breeding strategy for improvement of rice maintainer lines through composite population for short term diversity. *Journal of Rice Research*, 11: 27-30
3. Paul M and Keegstra K. 2008. Cell-wall carbohydrates and their modification as a resource for biofuels. *Plant Journal,* 54: 559-568.

Thesis

Bhuiyan MDAR. 2010. Phenotypic and genotypic evaluation of selected transgressive variants derived from *Oryza rufipogon* Griff. x *Oryza sativa* L. cv. MR219. Ph D. Thesis. University Kebaangsaan Malaysia, Malaysia, 150 p.

Book chapter

Scott JM 1984. Catabolism of folates. P. 307-327. In R.L. Blackley and S.J. Benkovic (ed.) Folates and Pterims Vol.1. John Wiley & Sons, New York

Book

Subba Rao LV, Shobha Rani N, Chiranjeevi M, Chaitanya U, Sudharshan I, Suneetha K, Jyothi Badri and Dipal R Choudhary 2013 DUS Characterization of Rice Varieties. Directorate of Rice Research, Rajendranagar, Hyderabad-500 030, AP, India. 524 pp

Figures: Photographs and drawings for graphs and charts should be prepared with good contrast of dark and light. Figure caption should be brief specifying the crop or soil, major variables presented and year. Give careful attention to the width of lines and size, and clarity of type and symbols.

Tables: Tables are used for reporting extensive numerical data in an organized manner and statistically analyzed. They should be self explanatory. Prepare tables with the word-processing tables feature and tabs or graphics boxes should not be used. Table head should be brief but complete and self contained. Define all variables and spell out all the abbreviations. An exponential expression (eg. x 10^3) in the unit's line is often needed to keep length of the data reasonably short, and referenced with an explanatory note. Unless otherwise required, two decimal place values are suggested.

Published by :

Dr. RM Sundaram, President, Society for Advancement of Rice Research, Hyderabad.

Printed at :

Balaji Scan Pvt. Ltd., Hyderabad - 500 004. Ph: 040-23303424 / 25 E-mail: bsplpress@gmail.com

Society for Advancement of Rice Research

ICAR-Indian Institute of Rice Research (ICAR-IIRR)

Rajendranagar, Hyderabad - 500 030 (India)

Phone No: +91 40 24591218; Fax: +91 40 24591217

www.sarr.co.in