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Society for
Advancement of
Rice Research



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- 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.
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Pests of Rice in India and their Management: An Overview

Padmakumari AP*, Chitra Shanker, Padmavathi Ch, Sridhar Y, Chinna Babu Naik V and Raghavendra KV

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Abstract

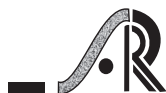
Rice is grown in diverse ecosystems in India as the major staple cereal food crop. Currently, India is ranked as the largest producer of rice in the world with a production of 150.2 million tonnes in 2025-26. The statistics show that the market share of insecticides is 22% of the total pesticide market of which the major share is on rice crop. So, it is pertinent to know the status of various insects as pests of rice. Among the pests, rice yellow stem borer, plant hoppers, leaf folders, rice gall midge and rice *gundhi* bug continue to be categorised as pests of national importance causing significant yield losses. There are other pests like rice hispa, thrips, case worms, cutworms, army worms, black bug, termites, root grubs, grass hoppers etc which are of regional significance. However, in recent times, an upsurge could be seen in other stem borers, whorl maggot, sheath or panicle mite and spread of white-backed plant hopper to non-traditional areas. During the last 3-4 years, incidence of Southern Rice Black Streaked Dwarf Virus (SRBSDV) vectored by WBPH and tungro virus by green leaf hopper have been recorded. In certain pockets of rice growing areas, the infestation of mealy bug, white fly and blood worms was observed. This paper discusses the effect of demography, various seasons, cultivation practices, cropping systems, weather conditions, policy decisions etc. that favour the pest infestations in paddy resulting in change of pest status.

Keywords: Rice, insect pests, changing pest scenario, management options

Introduction

Rice is the staple food for more than half of the global population and India ranks first in rice production in 2025-26 with 150.2 million tonnes surpassing China despite low productivity levels. Many factors influence the rice yield and biotic stresses are the chief components which influence grain production. In India herbicides occupy a largest market share at 44%, followed by fungicides (27%) and insecticides (22%). Pesticide consumption in India is 0.5 kg per hectare, compared to other countries where it is as high as 17 kg per hectare. This data suggests that farmers do apply insecticides on a global scale to save their crops. Insect-pests are known to cause major losses of 35.5 million tonnes in rice which may amount up to USD 8467.4 million in India (Dhaliwal *et al.*, 2015). Since

the introduction of high-yielding varieties, distinct changes occurred in the insect pest complex of rice in India. The overall yield losses due to insect-pests vary in rice between 24.6-40.9% (Savary *et al.*, 2019). Deutsche *et al.*, (2018) projected that the global yield losses to the staple cereals like rice, maize and wheat would increase by 10 to 25% per degree of global mean surface warming. The losses would be more in areas where warming increases both population growth and metabolic rates of insects. Apart from climate change there are various other factors that influence the occurrence of the pests. So far, 46 pesticides have been banned or phased out and most of the insecticides that were used in early stage pest control in rice have been phased out. (Standing Committee Report



Summary Insecticides and Pesticides - Promotion and Development, December 22, 2023).

In India rice is the only crop that is grown across various ecosystems. Rice cultivation in India extends from 8° to 35° N latitudes across very diverse ecosystems such as irrigated, rainfed upland, rainfed lowland, semi deep, deep water, areas below sea level as in Kerala as well as coastal and inland saline regions. More than 100 species of insect-pests are known to attack the rice crop in India (Pathak and Khan, 1994), out of which 20 are of significance (Krishnaiah and Verma, 2011). Based on the regularity in occurrence, extent of distribution, intensity of damage and the economic loss they inflict,

only a dozen species are of economic significance in India and they are categorized as National Pests, Regional, Sporadic and emerging pests. (**Table 1**). But, of late, though the major pests continue to maintain their status there is a shift in the status of some of the regional and sporadic pests. Some of the minor pests like whorl maggot and case worm have gained the status of major pests in certain pockets in India. With the increase in knowledge through in depth studies and availability of taxonomic resources more species have been identified. In some pest complexes like stem borers and leaf folders, it was observed that though they share the same niche there is variation in time and space.

Table 1: Common Pests of Rice in India

Sl. No.	Common name	Scientific name	Order: Family
National Pests			
1	Rice yellow stem borer (YSB)	<i>Scirpophaga incertulas</i> (Walker) <i>Sesamia inferens</i> (Walker) <i>Chilo</i> spp; <i>Scirpophaga</i> spp.	Lepidoptera: Crambidae Lepidoptera: Noctuidae Lepidoptera: Crambidae Lepidoptera: Crambidae
2	Asian Rice Gall midge (ARGM),	<i>Orseolia oryzae</i> (Wood-Mason)	Diptera: Cecidomyiidae
3	Brown plant hopper (BPH)	<i>Nilaparvata lugens</i> (Stal)	Hemiptera: Delphacidae
4	White-backed plant hopper (WBPH)	<i>Sogatella furcifera</i> (Horvath)	Hemiptera: Delphacidae
5	Leaf folder	<i>Cnaphalocrocis medinalis</i> (Guenee)	Lepidoptera: Crambidae
6	Gundhi bug	<i>Leptocoris oratoria</i> , <i>L. acuta</i> , <i>L. lepida</i>	Hemiptera: Alydidae
7	Green leafhopper, (GLH)	<i>Nephotettix virescens</i> (Distant); <i>Nephotettix nigropictus</i> (Stal)	Hemiptera: Cicadellidae
Regional pests			
8	Whorl maggot	<i>Hydrellia philippina</i> Ferino, <i>Hydrellia sasakii</i> Yuasa and Isitani	Diptera: Ephydriidae
9	Rice hispa	<i>Dicladispa armigera</i> (Olivier)	Coleoptera: Chrysomelidae
10	Case worm	<i>Paraponyx stagnalis</i> (Zeller)	Lepidoptera: Crambidae
11	Thrips	<i>Stenchaetothrips biformis</i>	Thysanoptera: Thripidae
12	Black bugs	<i>Scotinophara coractata</i> and <i>Scotinophara lurida</i>	Hemiptera: Pentatomidae
13	Blue beetle	<i>Leptispa pygmaea</i> Baly	Coleoptera: Chrysomelidae
14	Chaffer beetles	<i>Popillia lucida</i> Newman	Coleoptera: Scarabaeidae
15	Grass hoppers	Grass hoppers (<i>Oxya nitidula</i> , <i>Hieroglyphus</i> spp. <i>Attractomorpha pscittacina</i> & Long-horned grass hopper	Orthoptera: Acrididae
Sporadic pests			
16	Climbing cutworm/ Rice Ear cutting caterpillar	<i>Mythimna separata</i> Walker <i>Mythimna loreyi</i> Duponchel	Lepidoptera: Noctuidae
17	Army worm or swarming caterpillar	<i>Spodoptera mauritia</i> Boisduval	Lepidoptera: Noctuidae
18	Leaf mites	<i>Oligonychus indicus</i>	Acarina: Tetranychidae
Emerging pests			
19	Panicle mites	<i>Stenotarsonemus spinki</i> (Smiley)	Acarina: Tarsonemidae
20	Rice mealy bug	<i>Brevinnia rehi</i> (Lindinger)	Hemiptera: Pseudococcidae
21	Termites	<i>Microtermes obesi</i> Holmgren	Blattodea: Termitidae
22	Whitefly	<i>Bemisia formosana</i> Takahashi	Hemiptera: Aleyrodidae

But in recent times there is a change in the pest scenario though the number of pests that cause damage remain almost same. Case worm and whorl maggot have become regular pests in most of the locations. The details of the pest complex and the causes there of are detailed below:

A. National Pests

1. Rice stem borers

Rice stem borers belong to families Crambidae and Noctuidae. The Crambid borers are most common and destructive with high degree of host specificity. The noctuid borers are polyphagous, and occasionally cause severe economic losses. Katti *et al.*, (2011) reported six species of stem borer. Currently, In India, apart from yellow stem borer, which is the dominant species, eight other stem borer spp. have been reported to cause damage though restricted to small pockets. Other stem borer sp. that have been recorded till date are: Pink rice borer or Pink stem borer of rice, *Sesamia inferens* (Walker) in Indo-Gangetic plains (Srivastava *et al.*, 2003); in rice-cereal based cropping system (Swarupa *et al.*, 2025); white stem borers - *Scirpophaga fusciflua* (Srivastava *et al.*, 2012a, Ankit Kumar *et al.*, 2018, Tandon, 2018), *S. virginia* from Tamil Nadu (Varun *et al.*, 2017a), *Scirpophaga spp*, Gold fringed stem borer (GFSB), *Chilo auricilius* (Dudgeon), (dark headed striped borer (DHSB), *Chilo polychrysa* (Meyrik) (Swarupa *et al.*, 2024), Striped stem borer (SSB) *Chilo suppressalis* (Walker), and Spotted stem borer, *Chilo partellus* Swinhoe. However, Horgan (2023) in his review on stem borer assemblages referred to presence of six sps - *Scirpophaga incertulas*, *Sesamia inferens*, *S. innotata*, *Chilo polychrysus*, *Chilo partellus* and *Chilo suppressalis* from various regions of India between 2000-2009.

But in rice, all the above borers cause similar symptoms of damage like “dead hearts” at vegetative phase and “white ear” in reproductive phase. Thus, it is very difficult to identify the species unless we

dissect out the infested tillers. The species can be identified only through a detailed study of the male genitalia. Among the listed species, yellow stem borer is the most dominant species showing its presence in all the rice ecosystems in time and space. Study by Sanyal *et al.*, (2025) demonstrated that bioclimatic variables - annual mean temperature (30 °C), and annual precipitation (10-700 mm) favour its multiplication, infestation, and further spread to new areas. The other stem borers listed do cause damage in rice crop but restricted to certain pockets in India. Data on reaction to insect pests from National Screening Nurseries from AICRPR Entomology program indicates that in most of the locations in India the damage is above ETL (**Figure 1a and 1b**) (IIRR-IIRR, 2021-2025) warranting 2-8 of insecticide sprays. At times in certain areas we find damage by two or more species at a time within the same plant. Other stem borers (*Chilo* sps and *S. inferens*) species are predominant in Rice based cropping systems. All the insecticides are equally effective against all the species. The identity of the pest species plays a crucial role when we need to deploy any species specific behavioural component of pest management like sex pheromones. Horgan (2023) opined that regional assemblages of stem borers typically include a single dominant lepidopteran species (primary species) that is largely restricted to rice and for which the climate is optimal; one or more secondary species that vary based on the age of rice attacked, rice anatomy, and the proximity to other habitats (including other crops); and occasional species that probably spill over from adjacent grasslands. He suggested that the co-occurrence of lepidopteran with dipteran rice stemborers requires further research attention.

2. Plant hoppers: Under field conditions brown plant hopper (BPH), *Nilaparvata lugens* (Stal) and White-backed plant hopper (WBPH), *Sogatella fucifera* (Horvath) co-exist in most of the locations in various proportions and cause typical symptom of ‘hopper burn’. WBPH colonises the crop early but BPH takes

over due to its competitive ability. In all the command areas and high production systems BPH is a regular pest. It colonises at the plant base and sucks the sap leading to death of tillers and when severe the plants dry in patches leading to the typical symptom of “hopper burn” (**Figure 2**). Sahoo *et al.*, (2026) revealed that temperature-related variables accounted for 61.04% of habitat suitability for *N. lugens*, with annual mean temperature identified as the most critical environmental factor. While precipitation played a secondary role, contributing 38.96% to the population spread and establishment, the projection indicated extensive areas of high habitat suitability for *N. lugens*, especially in the eastern and southern rice-growing states of Odisha, West Bengal, Tamil Nadu and Andhra Pradesh. Currently, 54.92% of India’s

and Nawans in 2025. Early sowing (before June 15), has been one of the major causes of the spread of the virus. Virus causes dwarfing of plants and the infected plants had narrow upright leaves, weak roots, and are nearly half or one-third of their normal height. When severe, the plants dry and farmers just uproot or plough back the fields. In severe cases, plants may wither and die prematurely, resulting in substantial yield loss. Most of the farmers had uprooted infected crops and re-sown paddy in 2025 amounting to an additional cost of Rs 10,000 to Rs 15,000 per acre on re-sowing and about Rs 15,000/acre for insecticides. PR 131 was the highly susceptible variety (source: <https://timesofindia.indiatimes.com/city/chandigarh/dwarf-virus-hits-paddy-fields-farmers-forced-to-re-sow-stare-are-financial-loss/articleshow/122860132.cms> dated July 23, 2025). *Saccharum officinarum* and *Echinochloa colonum* have been proven as alternate hosts for this virus through RT-PCR studies (Vats *et al.*, 2026). PAU, Ludhiana had issued advisories for the management of WBPH.

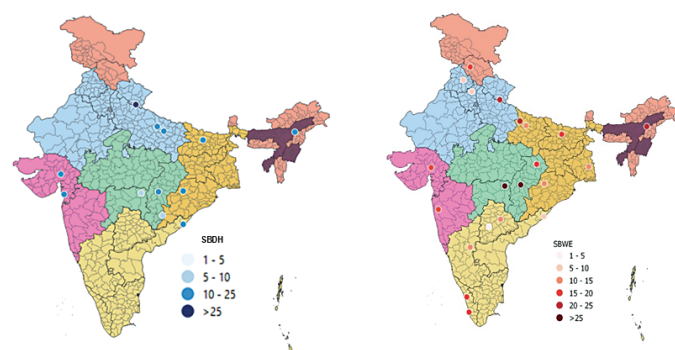


Fig1: Mean damage by stem borer from 2020-2024 in India at vegetative phase (1a- dead hearts) and reproductive phase (1b- white ears)

ICAR-IIRR, 2021-2025. Reaction to insect pests. National screening Nurseries In Screening Nurseries Diseases and Insect pests. Indian Institute of Rice Research, Rajendranagar, Hyderabad

land area is suitable for *N. lugens* establishment, with 7.80% categorised as high-risk zones. The population structure *i.e.*, proportion of BPH to WBPH at a given location which is variable, is also crucial in the development and deployment of resistant varieties as there are very few lines resistant to WBPH. In recent times since 2022, WBPH has gained prominence as it was attributed to the transmission of Southern Rice Black-streaked Dwarf Virus (SRBSDV), also known as Fiji virus (Sharma *et al.*, 2022). The affected states were Punjab, Haryana, Himachal Pradesh and Union territory of Jammu & Kashmir. Patiala district of Punjab has also reported infestations in villages like Ropar, Fatehgarh Sahib, Sangrur, Patiala, Mohali,

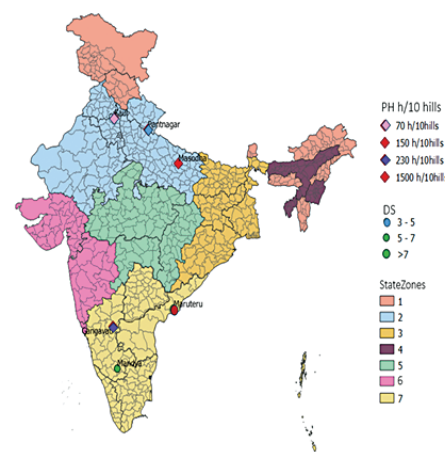


Fig 2. Mean damage by planthoppers from 2020-2024 in India
Source: ICAR-IIRR, 2021-2025

3. Asian Rice Gall midge: Among the major insect pests that limit the potential yield of the crop, the Asian rice gall midge [*Orseolia oryzae* (Wood- Mason)] is ranked third most important insect pest in India, following stem borers and plant hoppers. The immature stage of this dipteran insect feeds on the growing shoot meristem turning them into a tubular structure popularly known as “gall” or “silver shoot” or “onion shoot”. This pest occurs in all the major rice growing regions along the

coast of Bay of Bengal and Arabian sea apart from Central Maharashtra and Chhattisgarh. It is an endemic pest in rice growing regions of Assam, Tripura, Manipur, Odisha, Telangana, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Goa, Central Maharashtra and Chhattisgarh. The larva (maggot) is the only feeding stage, the duration of which varies from 12-15 days in one generation. The pupa is active and motile and is a non-feeding stage. In these endemic areas it was found to infest the crop from August to September in *kharif* season and during *rabi* peak infestation is observed in the months of January and February. Late planting and humid conditions favour the survival and perpetuation of the insect thus leading to huge infestation in the rice crop. For the past few years, the damage by this pest is increasing largely in the command areas of Cauvery, Tungabhadra and Godavari where there is assured irrigation/ or late release of canal water which leads to late planting of the susceptible varieties and is also causing extensive damage in the *rabi* rice. The damage in endemic areas is above ETL in terms of both plant damage (**Figure 3a**) and silver shoot damage. Till date seven biotypes have been reported from India (**Figure 3b**).

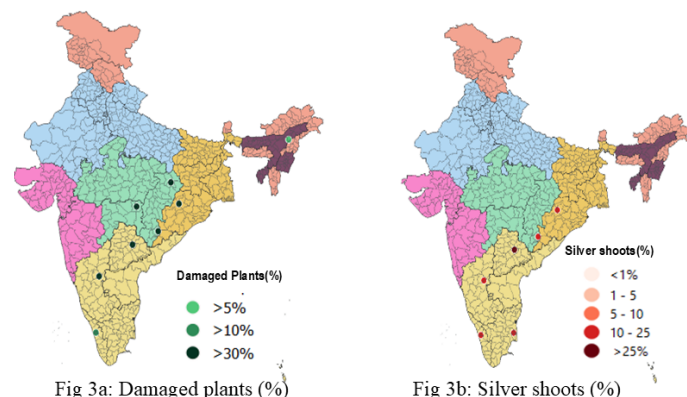


Fig 3. Mean damage by Asian rice gall midge from 2020-2024 in India - per cent damaged plants (2a) and Silver shoots (2b)
Source: ICAR-IIRR, 2021-2025

4. Leaf folders: Though *Cnaphalocrocis medinalis* (Guenée), is the dominant species across India, presence of other species have been reported by many rice workers: Six species from Tamil Nadu viz., *C. medinalis* (Guenée), *C. patnalis* (Bradley), *C. ruralis* (Walker), *C. trapezalis* (Guenée), *C. exigua* (Butler) and *C. poeyalis* (Boisduval) (Lepidoptera:

Crambidae) (Varun *et al.*, 2017b); *Marasmia exigua* (Bradley) and *Brachimea arotraea* (Meyrick) from Odisha (Rautaray *et al.*, 2019); *Cnaphalocrocis patnalis* (Bradley) and *Cnaphalocrocis poeyalis* (Boisduval) from West Bengal (Moulita *et al.*, 2023) were reported on rice. Baby Rani *et al.*, (2007) reported that the sex ratio varied amongst the species reported from Madurai, Tamil Nadu and males dominated the females. But all these species cause almost similar type of damage, that is folding the leaves and scraping of the chlorophyll. There is an increase in per cent leaf damage (>10% damaged leaves) and spread across locations as depicted in **Figure 4**.

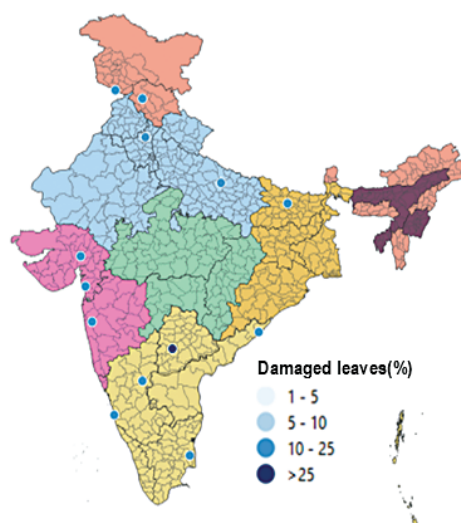
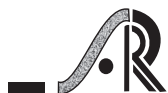


Fig 4. Mean damage by rice leaf folder in India (2020-2024) represented as percent leaf folder damaged leaves
Source: ICAR-IIRR, 2021-2025

5. Gundhi bug: Lahari *et al.* (2024) reported three species of *Leptocoris* in India on rice of which *Leptocoris oratoria* is predominant followed by *L. acuta*. *L. lepida* was collected only from Southern Karnataka. Both adult bugs and their nymphs feed on the sap of rice grains, starting at the flowering stage leading to yield reduction with a chaffy pecked appearance and loss of grain quality at the dough stage.

6. Green leafhoppers: Two species have been reported on rice from India. *Nephotettix virescens* and *N. nigropictus* Distant. Both nymphs and adults



are xylem feeders. They suck sap from leaves causing symptoms like yellowing of leaves from tip to downward, Uniform yellowing from mid half of leaf and when the infestation is severe the leaves turn brown with small scratch like marks on leaf. But they are more famous as vectors of Rice Tungro Virus. Rice Tungro has been reported in parts of West Bengal, Assam, Punjab and Tamil Nadu. It results in retarded vigour and stunted growth and withering of plants causing heavy monetary losses.

B. Regional pests

Case worm, Rice hispa, Rice thrips and whorl maggot are the pests of vegetative phase. Among these, incidence of case worm, rice thrips (Figure 5) and whorl maggot (Figure 6) is on the increase. The caseworm, *P. stagnalis* is commonly found in low lands with poor drainage and flooded fields. Stagnation of water results in pest build-up and causes severe loss in early vegetative phase. The larvae cut the leaf blade, form tubular cases and enclose themselves within these cases. The larva attaches itself to the rice plant and feed on the leaves. Feeding damage includes cutting off the leaf cases and it may result in patches of severe defoliation, stunted growth and death of plants. The entire crop may have to be resown and replanted in case of damaged leaves. (Srivastava *et al.*, 2012b). Whorl maggot which was hitherto a vegetative pest has now been found to occur in the booting phase of the crop causing yield loss. Mangal Sain (2000) in his review suggested that whorl maggot was found at ripening phase of the crop and damaged the boot leaf and developing panicles which can lead to only partial filling of grains. Rice hispa is a pest in states like Assam, Telangana, Karnataka and Kerala. Sharma and Srivastava (2018) elaborated on the significant losses caused by rice hispa at different stages of crop growth in hill ecosystem.

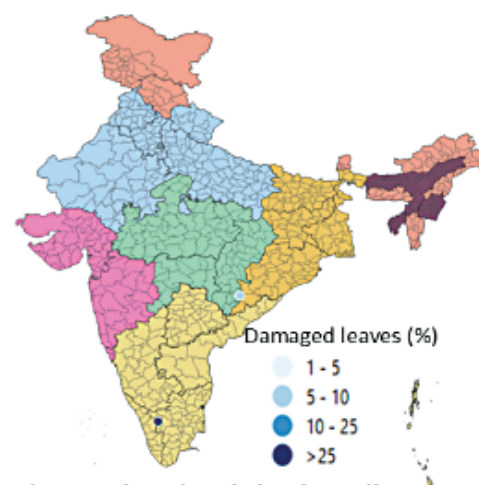


Fig 5. Mean damage by rice thrips in India (2020-2024) represented as percent thrips damaged leaves

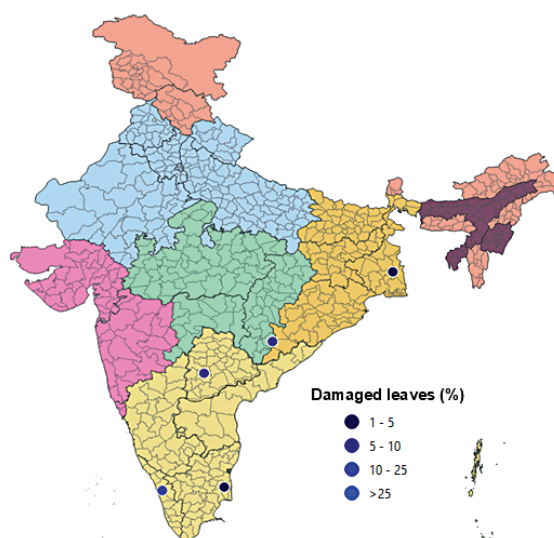


Fig 6. Mean damage by rice whorl maggot in India (2020-2024) represented as percent damaged leaves

Source: ICAR-IIRR, 2021-2025

Rice Black bugs or Malayan black rice bug: Two species are found to be important. *Scotinophara coarctata* is the dominant species that damages rice plants by sucking the sap from stem. The heavily infested field plants turn yellowish brown and die causing characteristic ‘bug burned’ areas. Incidence of *Scotinophara lurida* (Burm.) was reported from Arunachal Pradesh. Young seedling seemed to be preferred in heavily infested plots (Anandhi *et al.*, 2023).

Grass hoppers: Rice large grass hopper, *Hieroglyphus banian* and small grass hopper, *Oxya nitidula*

(Acrididae: Orthoptera) are mostly pests of hilly areas or areas near vegetation. Nymphs and adults feed on foliage by irregularly cutting leaf margins. In severe cases only midribs and stalks remain. They also cut the panicle at heading stage and are very active at night time. Scraping field bunds and summer ploughings to destroy eggs, application of malathion 5D @ 10 kg/acre found effective in their management.

C. Sporadic pests

Rice swarming caterpillars, army worm and climbing cut worms are reported as sporadic pests on rice. In India, swarming caterpillar *Spodoptera mauritia* Boisduval (Noctuidae: Lepidoptera) was considered as a sporadic and a minor pest of rice but for the last one decade, it has emerged as a serious pest of rice seedlings. It has attained the status of a major pest of rice in eastern India especially in Orissa, Chhattisgarh, Jharkhand and Bihar. But in recent times it is also reported from parts of Telangana, Kerala, Karnataka and Assam. Some of the other species reported are *Spodoptera exigua*, *Spodoptera litura* and Armyworm (*Pseudaletia unipuncta*). Neonate larvae nibble at first and later feed voraciously on the seedlings in the nursery and reduce the plants to mere stumps. They migrate from field to field feeding at night and hide during the day. Flooding the nursery brings out hiding larvae which are picked up by birds (Tanwar *et al.*, 2010).

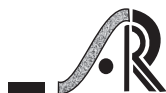
Paddy armyworm, true armyworm (*Mythimna separata* and *Mythimna loryei*) (Noctuidae: Lepidoptera): also known as climbing cut worm. Mature larvae are 3-4 cm long, green to pink in colour and provided with longitudinal light grey to black stripes running along the entire length of their bodies. Head is brown to orange with an A-marking. It appears in swarms at ear head stage in Nov-Dec. Late instars have the characteristic habit of climbing and cutting the ear heads. The cutworms are becoming serious in many rice growing areas in the eastern part of the country. For last few seasons, the climbing cutworm, *Mythimna separata*, has been regularly occurring in coastal

Andhra Pradesh and in the Eastern States. Similarly, the swarming caterpillar, *Spodoptera mauritia* has acquired a status of major pest in Odisha, Bihar and Jharkhand during *kharif* -2007-09, 2012, 2013 and devastated paddy crop in early stage in considerable areas (Prakash *et al.*, 2014) and continue to affect the crop in various parts of India in the early stages of crop growth leading to resowing of the crop.

Factors affecting pest incidence

a. Rice pests vs crop growth stages: Rice is affected by insect pests right from nursery till harvest. But the niche is important. Leaf folder, case worm, thrips, whorl maggot, hispa, leaf mite affect the leaves of the plant thus affecting the photosynthesis. In case of leaf folder, the damage is more critical if flag leaf is affected as it directly affects the grain filling (Padmavathi *et al.*, 2013). Identification of correct species plays a major role when adopting biorational approaches like pheromones. Case worm and thrips are important both in the nursery and in the early seedling stage warranting insecticide sprays. Gall midge, stem borers, brown plant hopper, white-backed plant hopper, green leaf hoppers, black bug, affect the primary yield components like tillers at both vegetative and reproductive phase, leading to significant yield losses. Hence careful monitoring is essential to keep the population below ETL. *Gundhi* bug and Panicle Mite affect the panicles and the milky grains leading to chaffy grains. So, the damage to the major traits for yield, translates to direct yield losses.

b. Ecology and rice pest dynamics: Based on the available information the list of pests that occur on paddy in different ecologies are summarized in (Table 2). Most of the major pests like Yellow stem borer, gall midge, leaf folder, and plant hoppers and leaf hoppers are pests of the irrigated ecology. Yellow stem borer is the pest of deep water ecology. Caseworm and cut worms are found in ill drained and water logged fields. Army worms, Cutworms are recorded when there is long dry spell in the early *kharif* season. White stem borer, Grass hoppers, Chaffer beetles, and hispa are often found in hilly regions. However,



it also depends on the altitude of the location. Grass hoppers, root aphids, mealy bugs, termites are reported from upland/ aerobic or in fields with alternate wetting

and drying. It is clearly evident that the prevailing climatic conditions, micro climate and various other factors influence the occurrence of the pests.

Table 2: List of pests that infest rice crop grown in various ecologies in India

Sl No.	Irrigated/ Transplanted	Direct seeded/ AWD/ Aerobic	Upland rice	Shallow low land / Low land	Kuttanad rice (Below sea level.)	Hill rices*	Deep Water
1	Yellow stem borer	Yellow stem borer	Yellow stem borer	Yellow stem borer	Yellow stem borer	White stem borer	Yellow stem borer
2	BPH	BPH	BPH	BPH	BPH	BPH	Case worm
3	WBPH	WBPH	WBPH	WBPH	WBPH	WBPH	
4	Leaf folder	Leaf folder	Leaf folder	Leaf folder	Leaf folder	Leaf folder	
5	Gall midge	Gall midge	Gall midge	Gall midge	Gall midge	Hispa	
6	Green leaf hopper	Green leaf hopper	Green leaf hopper	Green leaf hopper	Case worm	case worm	
7	Case worm	Whorl maggot	Whorl maggot	Case worm	Whorl maggot	Whorl maggot	
8	Whorl maggot	Gundhi bug	Gundhi bug	Whorl maggot	Gundhi bug	Gundhi bug	
9	Gundhi bug	Mealy bug	Leaf mite	Gundhi bug	Blue beetle	Chaffer beetles	
10	Black bug	Thrips	Mealy bug	Swarming caterpillar	Leaf mite	Scarabaeid beetles	
11	Rice Hispa	Leaf mite	Thrips		Pink stem borer	Grass hoppers	
12	Thrips	Root aphid	Root aphid		White stem borer	Green stink bug	
13	Blue beetle	Root weevil	Swarming caterpillar				
14	Swarming caterpillar	Swarming caterpillar	Army worms				
15	Army worms	Army worms	Pink stem borer				
16	Pink stem borer and other stem borer species	Pink stem borer	Root knot nematode				
17	Panicle mite	Root knot nematode					

D. Changing pest scenario: Jena *et al.*, (2018) reviewed the changing pest dynamics in rice ecosystem in 2017, and 21 insect pests were documented. It was observed that we could record a change in the status of the pests and the current number is 23 which includes the mite pests and the root knot nematode (**Figure 7**). Since last five years we could not observe damage by blue beetle, chaffer beetle, termites, but there was an increase in the incidence of black bug, case worm, whorl

maggot, panicle mite, climbing cutworm and various stem borer species; spread of WBPH, BPH and leaf folder to non- traditional areas. White fly was reported on rice (Mallikarjuna, personal communication), in KVK, Undi, Andhra Pradesh. Damage manifests as yellowing, formation of sooty mould, crinkling and twisting of panicles leading to chaffy panicles and the reason attributed was injudicious use of insecticides especially spraying of pyrethroids. Mealy bug is

reported from upland rice, but the etiology is not well studied. Incidence of mealy bug is not well documented due to the cryptic nature of the pest. The non insect pest like panicle mite and root knot nematode have also increased their presence. There are also reports of a chironomid, commonly called as ‘blood worm’ which is soil borne. It is suspected to have been feeding on the roots leading to drying of plants in the early stage. More detailed studies are required to quantify the actual loss by this pest.

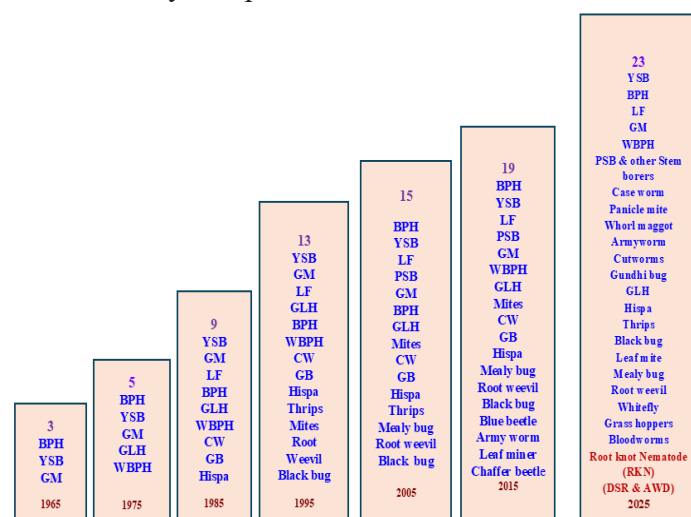


Fig 7. Changing Scenario of insect pests, mites and nematodes in rice -Decadal changes

YSB-Yellow stem borer, GM-Gall midge, BPH-Brown plant hopper, WBPH-White- backed plant hopper, LF-Leaf folder, GLH-Green leaf hopper, CW-Case worm, GB-Gundhi bug, PSB-Pink stem borer, DSR- direct seeded rice, AWD- Alternate wetting and drying

Mite pests: Panicle mite / Sheath mite, *Steneotarsonemus spinki* (Tarsonemidae: Acarina) is reported from states of Andhra Pradesh, Telangana, Chhattisgarh, Odisha, Gujarat, West Bengal, Tamil Nadu, Karnataka. It occurs at vegetative phase. Both nymphs and adults colonise midribs of leaves and lacerate tissues up to maximum tillering stage causing brown necrotic patches on midribs. At panicle initiation stage mites move to leaf sheath to feed causing brown necrotic lesions on leaf sheath. Maximum incidence occurs at boot leaf stage. At panicle emergence, mites enter florets, feed on ovaries and stamens causing sterile and discoloured grains in the panicle. Later these grains turn black invaded by saprophytic fungus. It was reported that the major fungus associated with

S. spinki was the sheath rot fungus, *Sarocladium oryzae* (*Acrocylindrium oryzae*) and *S. spinki* acted as vector of this fungus. Paddy leaf mite / yellow mite, *Oligonychus oryzae* (Tetranychidae: Acarina) infestation is found on the under surface of the rice leaves whenever there is a prolonged dry spell. This mite damages rice in nymphal and adult stages by sucking the sap of leaves and inflicting damage on mesophyll cells of the interveinal tissues. This results in characteristic whitish patches on leaves, which later turn to ash colour and dry from tip down-ward.

Nematode Pests: There is an increase in Root knot nematode *Meloidogyne graminicola* infestation in direct seeded rice (Katti and Padmavathi, 2022)

c. Effect of Cultivation Practices:

System of rice cultivation: Stem borer is one pest which may create havoc, if not properly managed. Similarly, wider spacing adopted in SRI cultivation may favour increased hispa but reduced gall midge incidence in early stage. In the tillering stage, vigorous plant growth with cluster of tillers may attract defoliators such as cut worms, ear cutting caterpillars and leaf folder. However, significant increase in number of tillers and leaves should be able to sufficiently compensate the loss due to defoliation. In the later stages, SRI cultivation may reduce BPH incidence due to increased aeration resulting from wider spacing. Studies over a period of 5 years under All-India Coordinated Rice Improvement Project (AICRP) concluded that SRI methods of cultivation showed a lower incidence of stem borer, plant hoppers, and gall midge compared to conventional methods. Whorl maggots and thrips, on the other hand, were observed to be higher (Padmavathi *et al.*, 2023).

Transplanted vs direct seeded rice: The population of plant hoppers was significantly lower in direct seeded rice (DSR), population of *N. lugens* [370.0 and 420.7 BPH/10 hills; *S. furcifera* was 255.0 and 349.0 WBPH/10 hills; and *N. virescens* 3.9 and 4.2 GLH/10 hills] during *kharif*, 2019 and 2020, respectively



(Kamboj *et al.*, 2025) in rice wheat system of Indo-gangetic plain.

There is a shift in weed species in direct seeded rice. The dominance and increasing occurrence of *Echinochloa colona* over *Echinochloa crusgalli* in weed population and weed dry biomass was recorded across the locations in the long term trial on weed dynamics in Direct Seeded Rice (ICAR-IIRR, 2026). *E. colona* is the major alternate host for most of the major insect pests of rice like gall midges (Padmakumari *et al.*, 2004), gundhi bug, leaf folders (Padmavathi *et al.*, 2015) etc. Hence, appropriate measures should be taken to maintain clean cultivation.

Effect of organic manuring on rice pest incidence:

Field trials on effect of five organic manures compared to recommended fertilisers under protected and unprotected conditions revealed that: Neem cake and poultry manure applications reduced stem borer damage as well as rice root nematode populations. Vermicompost application also resulted in low nematode population and decrease in whorl maggot damage.

d. Use of right insecticides: With the ban imposed on many broad spectrum insecticides which were commonly used on rice, the early stage pest control has become a challenge. Even today, the use of insecticides is governed by the dealers. Most of the dealers favour a spray of synthetic pyrethroids in the early season which leads to resurgence of the sucking complex. There is an increase in the trend in the availability of combination products. Though the situation warrants a single spray of a particular molecule, farmer is forced to buy a combination product and apply, which is not necessary. Sometimes the recommended molecules are not very much available in the market or some of the states impose legislation and restrict the use. For example, in Punjab, thiamethoxam is not recommended on Basmati rice. Similarly, in Kerala carbofuran 3 CG is not advocated though it is very effective against rice gall midge. Apart from this,

increase in labour cost for spraying and use of drones for pesticide application is bringing a silent revolution in rice plant protection scenario. Farmers are now looking for compatibility of insecticides, fungicides and herbicides to reduce cost of application. Hence more research is essential to advocate the right dose and combination of pesticides.

e. State policy: Late planting in the tail end areas of the canal irrigated fields are more prone to pests like gall midge. A policy for cutoff date for plantings and restrict the movement of infested nurseries is very much essential to minimize the incidence of rice gall midge in endemic areas. Similarly, for stem borers in Punjab and WBPH in North western states is very much essential.

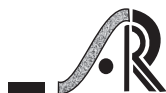
Some of the practices advocated for management of major pests of rice are:

Host plant resistance (HPR): A successful variety is one which has good level of resistance to one or two major insect pests along with high grain yield and good cooking quality. Such varieties would keep the pest populations below ETL but it is very rare to have all these traits in an acceptable background. Padmakumari *et al.*, (2024) reviewed the status of host plant resistance in rice. Through extensive screening of germplasm and breeding lines in both field and glass houses, donors conferring resistance to BPH, WBPH, gall midge, leaf folder and stem borer have been identified under AICRPR program. PTB33, RP 2068-18-3-5, IC 76013, IC75975, IR 75870-5-8-5-B-5-HWR15, IR 33382-80-9-3-13-2-2-1-3-B-HWR 16, RP6837-RMS-ISMA13, RPBio4918-230S for brown plant hopper and IC0641981 for both BPH and WBPH; Aganni, INRC3021 and INRC202 for gall midge; two BPT mutants, SM92 (IC646828) for resistance to stem borer and INGR 22104 (IC 646826) for leaf folder were registered as genetic stocks and can be effectively used as donors in the breeding program for developing pest resistant varieties (Balakrishnan *et al.*, 2025). Monitoring virulence to BPH and rice gall midge in endemic areas is carried out through a

set of host plant differentials to identify the changes in the virulence. To tackle gall midge, pyramided lines of *Gm4+Gm8* in the back ground of WGL 14, ISM and Akshayadhan, Tellahamsa and MTU1010 have been developed.

Cultural practices: Xu *et al.*, (2017) have given an overview of the non- chemical and eco-friendly management practices which can reduce the pest population and consequently minimise the number of chemical sprays and most of the practices can be adopted under Indian conditions also. Some of the cultural practices that can be practised are:

- Rice stubbles serve as a major source of inoculum for all the major insect pests like yellow stem borer, gall midge, brown plant hopper. Deep ploughing minimizes the survival of immature stages in the stubbles. But in recent times mechanical transplanters are used for harvesting and they leave stubble of 10-15 cm height which serves as niche for the survival of immature stages and helps in build-up and carry over of most rice pests like stem borers, gall midge, plant hoppers, panicle mite to the next season. Xu *et al.*, (2015) reported that if rice stubble heights are adjusted to a range of 5–10 cm, the survived stem borers (*Chilo* sp.) can be reduced by 70%–90%.
- Harvest crop close to soil surface and deep ploughing or flooding after harvest to be practiced.
- Selection of resistant / tolerant varieties against key pests suitable to local situations and protection of nursery from pests.
- Timely planting is recommended. Late planting will increase pest infestation.
- Monitor the crop for pests that occur regularly in your area.
- Bird perches may be placed in the field at 2-3 ft height in the field @ 15 to 20 per acre.
- Apply nitrogenous fertilizers at recommended doses.
- Clipping tips of leaf blades before transplanting to eliminate eggs of rice yellow stem borer and hispa.
- Formation of alleys or path ways of 20 cm width for every 2 metres of planting to facilitate spraying at the base of the plants and for ease in mobility aeration and light.
- Avoid close spacing in BPH endemic areas.
- Ensure proper drainage and water and weed management.
- Alternate wetting and drying to be followed in plant hopper endemic areas.
- Monitoring incidence of pests through light traps or pheromone traps for rice stem borer, leaf folder is essential.
- Ensure that the natural enemy to pest ratio is maintained at 2:1.
- Passing a rope over the crop in vegetative phase against leaf folder and caseworm
- **Trap crops:** Planting of one row of a susceptible aromatic rice for every 9 rows of main crop had minimised the damage by yellow stem borer with a favourable cost benefit ratio by adjusting the sowing date of the trap crop so that the trap crop flowers one week before the main crop (Padmakumari *et al.*, 2017)
- **Bund crops:** Lemon grass was planted in bunds to discourage rice black bug from making the rice crop a primary target, while Azolla application aimed to limit pest proliferation. Lemon grass, known for its mosquito-repelling properties, showed relative effectiveness in deterring black bugs, with a significant reduction in their incidence. Azolla @ 25 kg/ha, lemon grass in bunds and neem oil (3%) foliar spray at 10, 30, and 60 days after transplanting resulted in the lowest pest incidence. (Leena *et al.*, 2024).
- **Ecological engineering practices:** Increasing floral diversity selectively will improve both longevity and parasitism rates of egg parasitoids and can be effectively harnessed to keep the hopper pests at lower population levels. The positive impact of bund flora on parasitization of hoppers, indicate



a viable cultural strategy for their management. Due to injudicious use of insecticides, brown plant hopper outbreaks are increasing globally. Such techniques offer a viable, ecofriendly option as an integral part of rice pest management. In addition to *in situ* conservation of flowering weeds, studies on various bund crops such as *Tagetes erecta* L. (Asteraceae), *Vigna unguiculata* L., *V. mungo* (L.) Hepper, *V. radiata* (L.) R. Wilczek, *Crotalaria juncea* L. (Fabaceae), *Coriandrum sativum* L. (Apiaceae), and *Abelmoschus esculentus* (L.) Moench (Malvaceae) were tested and validated in multi-location Trial under AICRP-rice (Shanker and Katti, 2017). Commercial flowers, pulses, vegetables green manure crops can be grown on bunds. Flowering plants on rice bunds had significant impact on biodiversity of parasitoids such as *Anagrus*, *Oligosita* and others parasitoids. Field studies through baiting and laboratory studies for longevity indicated enhanced parasitization

rates and six to ten times increase in longevity of parasitoids. Plants from families Fabaceae and Asteraceae are amenable for habitat management (Shanker and Rani, 2022).

Chemical control

- Use of botanical pesticides such as neem seed kernel extract, neem oil or citronellol oil or eucalyptus oil are useful. But when botanical insecticides alone are used, 2-3 sprays at 10 day interval are required to minimise the damage.
- Application of insecticides to be carried out on the basis of economic threshold level. (ETL).
- Apply right insecticide at the right dose at the right time for effective control.
- Do not repeat the application of same insecticide. Rotation of insecticide molecules based on mode of action to be practiced.
- Do not apply Synthetic pyrethroids in rice.

A General Schedule of application of insecticides in rice for tackling major insect pests of rice

Nursery	Stem borer, gall midge, thrips	- Seed treatment with Thiamethoxam 25% WG in gall midge endemic areas - In gall midge/stem-borer-endemic areas apply carbofuran 3CG @ 33 kg/ha 5 to 7 days before pulling the seedlings for transplanting - or Fipronil 0.3 GR @ 25 kg/ha of nursery, 5 to 7 days before pulling the seedlings for transplanting - In the yellow stem-borer endemic areas, install sex pheromone traps with 5 mg lure @ 3 traps placed in a triangular fashion at a distance of 60 m per acre for pest monitoring. A pheromone threshold catch of 30-33 moths/week / per trap suggests that there is a need for insecticide spray.
Main field		
Vegetative Phase	Gall midge	- In gall midge endemic areas use carbosulfan 25% DS 10 g/kg seed or thiamethoxam 70% WS 7.5 g for seed treatment. - Apply carbofuran 3 CG @ 33 kg/ha in the nursery - Cartap hydrochloride 4G @ 25 kg/ha in the main field - or Fipronil 0.3 GR @ 25 kg/ha - Spray formulations are less effective for gall midge
	Yellow Stem-borer Other stem borers Leaf folder	- Apply carbofuran 3 CG @ 33 kg/ha - Apply Cartap hydrochloride 4G @ 25 kg/ha - or Fipronil 0.3 GR @ 25 kg/ha - Or Chlorantraniliprole 0.4% GR @ 40 g ai/ha or 10 kg/ha
	Rice Hispa Whorl maggot Thrips	- Apply Fipronil 0.3 GR @ 25 kg/ha or Fipronil 0.6 GR @ 15 kg/ha - Or Spray Fipronil 5 SC @ 1500 ml/ha or Acephate 75SP @ 950 g/ha
	Plant hoppers / Green leafhopper	Spray Imidacloprid 200 SL @ 125 ml/ha or Thiamethoxam 25 WG @ 100 g/ha or Ethofenprox 10 EC @ 500 ml/ha or Acephate 75SP @ 950 g/ha or Clothianidin 50 WDG 30 g/ha. or Fipronil 5 SC @ 1500 ml/ha

Reproductive Phase	Stem-borer	• Spray Cartap 50 WP @ 1000 g/ha • Or Chlorantraniliprole 18.5% Sc @ 150 ml/ha • Or Chlorantraniliprole 0.4% GR @ 40 g ai/ha or 10 kg/ha • (apply each molecule only once. Do not repeat the same molecule twice in a season) • *PS: In stem borer endemic areas a prophylactic spray of any of the above insecticides at booting stage is recommended.
	Brown plant hopper, White backed plant hopper or mixed population of plant hoppers	Spray Imidacloprid 200 SL @ 125 ml/ha or Pymetrozine 50% WG @ 375 g/ha • or Triflumezopyrim @ 150 ml per ha at 50 -55 DAT (to be applied only once) • or Dinotefuran 20% SG150-200 g/ha (apply each molecule only once. Do not repeat the same molecule twice in a season) Do not apply Dinotefuran immediately after application of imidacloprid.
	Leaf folder	• Spray Cartap 50 WP / SP @ 1000 g/ha • or Acephate 75SP @ 950 g/ha • or Fipronil 5 SC @ 1500 ml/ha
	Gundhi bug	• Spray Imidacloprid 200 SL @ 125 ml/ha; Malathion 25EC 200 ml/acre or 1ml /litre of water
	Panicle mite	• Spiromesifin 240 at 72 g a.i/ha.or profenophos @ 1 ml/litre of water
Nursery / main field	Root-knot nematode, root nematode and white tip nematode	• Apply carbofuran 3 CG @ 33 kg/ha

B. Bio-rational components

- Use of pheromone traps: Install sex pheromone traps with 5 mg lure @ 8 traps/ha for pest monitoring or 20 traps /ha for direct control through mass trapping of male yellow stem borer moths. The lure has to be changed after a month to ensure effective trap catches. A pheromone action threshold of 33 male moths/ trap / week suggests the point where chemical control needs to be initiated.
- Application of silicon compounds either to soil or spray would enhance the resistance in the crop to insect pests. Soil application of imidazole, a silicon solublizer alone and in combination with rice husk ash through split application had minimised the yellow stem borer damage (Jeer *et al.*, 2018).
- **Biocontrol:** Inundative release of egg parasitoid, *Trichogramma japonicum* 5 to 6 times @ 100,000 adults / ha starting from 15 days after transplanting. The release of parasitoids has to be timed with the presence of adults in the field. For rice leaf folder too, inundative release of egg parasitoid, *Trichogramma chilonis* 5 to 6 times @ 100,000 adults/ ha starting from 15 days after transplanting has been proven to give good results. Care should be taken that no insecticides are sprayed at the time of release of these parasitoids.
- **Microbial pesticides:** Isolates of *Bacillus thuringiensis*, *Beauveria bassiana*, *B. alba* and *Metarrhizium anisopliae* when applied as spray have proven their efficacy under Indian conditions against major lepidopteran pests in terms of low damage (ICAR-IIRR, 2025). But 2-3 sprays to be given at frequent intervals of 10 or 15 days and they need to be timed with the pest incidence. However, Zhang *et al.*, (2026) discussed at length on the *pros and cons* on the use of microbials in pest management.



Conclusions

Keeping in view the changing pest scenario, we should have information on **KYP-Know Your Pest** and **KYE-Know Your Ecosystem** (cropping season, pattern, variety grown, pest incidence pattern, information on the prevailing natural enemies and the available insecticides). Pest surveillance and monitoring is an important activity. Monitoring virulence of major insect pests and insecticide resistance is crucial to maintain populations below ETL through appropriate control measures. It is very important to understand the behaviour of the pest with reference to crop stage. When multiple pests occur in the field their dynamics is very important in taking decisions for appropriate control measures. Location specific deployment of resistant varieties with durable, broad-spectrum resistance good yield and quality traits for BPH, GM and Stem borer is the need of the hour. We need to sensitize agricultural officers for dissemination of location specific IPM modules.

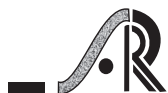
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Recent Advances in Direct-Seeded Rice Cultivation

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Abstract

Conventional puddled transplantation is unsustainable due to high water footprints, labour shortages, and methane emissions, making direct-seeded rice (DSR) a critical resource-efficient alternative. This review synthesizes recent genetic, mechanical, and digital breakthroughs aimed at modernizing DSR into a high-yielding, climate-resilient system. The integration of non-GM, imidazolinone-tolerant varieties, such as Pusa Basmati 1979, Pusa Basmati 1985, and CR Dhan 807, as well as hybrids like SAVA 127 and SAVA 134, facilitates effective post-emergence weed control, resulting in approximately 30% reduction in cultivation costs in DSR. Furthermore, mechanized row seeding and “Vattar” (soil mulch) techniques significantly enhance crop stand and moisture conservation, while seed priming with 2.0% KNO₃ has been shown to boost yields by 7–11%. Precision technologies, including drone-based ultra-low-volume herbicide application at 40 L/ha and drip irrigation, have demonstrated water savings of up to 50% and a 24% reduction in carbon footprint compared to conventional methods. However, the shift to aerobic conditions necessitates integrated management to mitigate the trade-off between reduced methane (CH₄) and increased nitrous oxide (N₂O) emissions. Ultimately, the convergence of herbicide-tolerant genetics with precision mechanization and smart irrigation represents a paradigm shift in rice cultivation. While high initial costs and potential herbicide resistance remain challenges, these innovations provide a robust framework for sustainable intensification, provided that future efforts prioritize standardized operating protocols and localized machinery manufacturing to ensure food security for smallholder farmers under changing climatic conditions.

Keywords: Herbicide-tolerant, Mechanized DSR, Drone DSR, Vattar DSR, Herbicide

Introduction

Rice serve as a staple food for over half of the global population, particularly in Asia. It is a cornerstone of food security and rural livelihoods. However, the traditional method of puddled transplanting has become increasingly water, labour, and energy resource-intensive, making it unsustainable in regions facing water scarcity (Mallareddy *et al.*, 2023). This method also contributes significantly to greenhouse gas (GHG) emissions, primarily methane. Consequently, rice cultivation exists in a precarious

position as both a victim and a contributor to climate change. On one hand, the crop is highly vulnerable to climate-induced stresses such as droughts, floods, and extreme temperature variability (Vijayakumar *et al.*, 2023). On the other hand, the flooded rice paddies act as a significant source of methane, a potent GHG with a global warming potential 28-34 times higher than carbon dioxide over a 100-year period. As the world seeks to balance food security with resource scarcity, direct-seeded rice (DSR) has emerged as a promising alternative for climate adaptation and mitigation.

Unlike traditional practices, DSR involves sowing seeds directly into the field, thereby bypassing labour intensive process of transplanting seedlings from nurseries (Kumar and Ladha, 2011). By eliminating the need for puddling (soil preparation in flooded conditions), this approach significantly reduces labour, water, and time requirements, making it a more resource-efficient alternative to conventional rice farming (Kumar *et al.*, 2018). Beyond immediate resource efficiency, DSR addresses critical systemic challenges, such as reducing methane emissions and preventing the delayed sowing of succeeding crops. Its feasibility has been further enhanced by technological innovations like seed priming and mechanization, which build climate resilience by enabling earlier planting. Furthermore, government support through policies such as carbon and water credits has strengthened DSR's position as an economically viable and productive method (Vijayakumar and Padma, 2023).

1.1. Current status of DSR in Asia

DSR adoption varies significantly across countries. Cambodia leads with 98% of rice area under DSR, followed closely by Sri Lanka and Malaysia at 95%. Vietnam and Thailand both have 69% adoption, while Myanmar stands at 63%. The Philippines, China and India lag behind, with DSR adoption rates of 36%, 30%, and 14%, respectively. This highlights a clear divide, with Southeast Asian nations embracing DSR more widely compared to larger rice-producing countries

like India and China, where traditional transplanting methods still dominate (**Figure 1**). In South Asia, the adoption of DSR remains low, except for Sri Lanka, where it is widely practiced. To enhance adoption in this region, it is crucial to address key constraints such as uneven crop establishment, poor weed control, and access to suitable technologies (Pooja *et al.*, 2021). In contrast, Southeast Asia has seen significant adoption of DSR, particularly wet-DSR, which relies on high seed rates (150-350 kg/ha) and broadcast methods. However, the practice is largely non-mechanized and lacks precision, leading to inefficiencies and challenges such as uneven crop establishment, higher seed costs, and suboptimal yields. To improve DSR systems in this region, there is a need to transition to more precise and mechanized methods, reduce seed rates, and address issues associated with broadcast DSR to enhance productivity and sustainability.

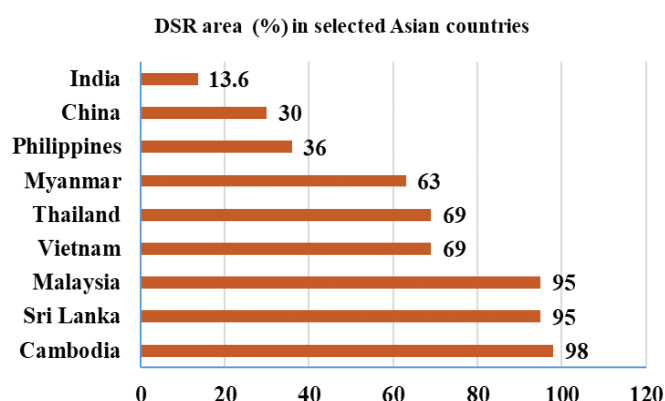
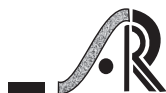


Figure 1: Current status of DSR in Asian countries

1.2. DSR area in India

DSR covers approximately 6.73 million hectares, accounting for 15.1% of the total rice-growing area in India (**Table 1**). The adoption of this method varies significantly by geography, with the highest concentration found in central and southern India. Broadcast DSR remains a common technique across India. Kerala leads the country in DSR percentage, with an impressive 91.5% of its rice area under DSR (primarily WDSR). Chhattisgarh follows with 71.6% adoption, representing the largest single-state footprint for DSR at over 2.7



million hectares. States like Odisha (28.0%), the North East region (28.2%), Tamil Nadu (25.5%), and Puducherry (24.4%) show significant reliance on DSR methods. Despite being massive rice

producers, states like West Bengal (1.0%), Uttar Pradesh (1.3%), and Bihar (2.0%) show the lowest levels of DSR implementation relative to their total rice area.

Table 1: Current status of DSR in India

States	Hectare (ha)	Total rice area	Percentage	Source	District	Method
Andhra Pradesh	378693	1920640	19.7	State government	Guntur, Bapatla, Krishna, Nandyal, Srikakulam, Tirupati, Visakhapatnam, Vizianagaram	DDSR converted WDSR
Assam	200000	2295720	8.7	Research article	Jorhat, Golaghat, Sivasagar, Sonitpur	Both DDSR & WDSR
Bihar	62202	3110130	2.0	Expert opinion	Darbhangha, Bhagalpur, Munger, Banka, Patna, Lakhisarai, Rohtas	DDSR (Broadcasting)
Chhattisgarh	2737000	3821550	71.6	Research article	Raipur, Balod	Broadcast direct seeding
Goa	1200	32480	3.7	Expert opinion	-	Both DDSR & WDSR (Broadcasting)
Gujarat	145000	968550	15.0	Expert opinion	Tapi, Dang, Surat, Bharuch, Dahod, Narmada, Mahisagar, Chhota Udaipur, Panchmahal, Navsari	DDSR
Haryana	70000	1563450	4.5	State government	Yamuna Nagar, Kurukshetra, Karnal, Kaithal, Ambala, Panipat	DDSR
Himachal Pradesh	10480	69870	15.0	Expert opinion	Mandi, Kangra, Bilaspur, Hamirpur, and Una	DDSR
Jammu & Kashmir	12911	258230	5.0	Expert opinion	Samba, Kathua, Jammu	DDSR
Jharkhand	90000	1099570	8.2	Research article	Hazaribagh, Koderma, East Singhbhum	DDSR
Karnataka	50000	953000	5.2	Expert opinion	Bellary, Raichur, Yadgir, Koppal	75% WDSR, 25% DDSR
Kerala	165000	180280	91.5	State government	Palakkad, Malappuram	70% WDSR, 30% DDSR
Madhya Pradesh	200000	3480220	5.7	Expert opinion	Balaghat, Mandla, Dindori, Anuppur, Shahdol, Umaria, Sidhi, Jabalpur, Katni, Seoni, and Satna	DDSR
Maharashtra	266000	1692900	15.7	Expert opinion	Raigad, Bhandara, Sindhudurg, Ratnagiri, Thane and Palghar	Both WDSR and DDSR
Odisha	1140143	4071940	28.0	Expert opinion	Bargarh, Bhadrak, Mayurbhanj, Ganjam, Bolangir, Khorda, Puri	Both wet and dry DSR (Broadcasting)
Punjab	117000	3179000	3.6	State government	Muktsar Sahib, Fazilka, Amritsar, Ferozepur, Bathinda	DDSR
Rajasthan	10000	267770	3.7	Expert opinion	Bundi	DDSR
Tamil Nadu	536724	2101600	25.5	State government	Tiruchirapalli, Perambalur, Karur, Thanjavur, Nagapattinam, Tiruvarur, Pudukottai, Erode, Tirunelveli, Kanyakumari, Thoothukudi	Both wet and dry DSR (Broadcasting)

States	Hectare (ha)	Total rice area	Percentage	Source	District	Method
Puducherry	4780	19570	24.4	Expert opinion	Puducherry, Karaikal	20% DDSR, 80% WDSR
Telangana	157310	4685150	3.4	State government	Khammam, Nalgonda, Siddipet	DDSR, WDSR, Broadcasting
Uttarakhand	4867	243380	2.0	Expert opinion	Udham Singh Nagar, Haridwar, Bageshwar	DDSR (Broadcasting)
Uttar Pradesh	72672	5767690	1.3	Internet	Deoria, Chandauli, Sonbhadra	DDSR
West Bengal	50000	5119390	1.0	Expert opinion	Birbhum, Bankura, Purulia, Western Midnapore, Eastern Midnapore	Both wet and dry DSR
North East	253000	898750	28.2	Expert opinion	-	Both wet and dry DSR
Total	6734982	47828290	15.1			

Note: The data presented in this table is derived from a preliminary estimation survey and should not be treated as official government statistics. As only a limited number of Indian states officially report rice cultivation areas by establishment method, this dataset relies heavily on the expert opinions of collaborators from the All India Coordinated Rice Improvement Project (AICRIP), state extension officers, university professors, and department officials. This effort seeks to fill the current data gap in official government records.

Despite several advantages, the adoption is often hindered by high weed pressure, nutrient deficiencies, difficulties in establishing an optimal crop stand and lower yields (Padma *et al.*, 2023). Addressing these technical barriers is essential to transitioning DSR from a “promising alternative” to a global standard for sustainable rice-based systems. In recent years, technological advancements have revolutionized DSR systems, addressing these challenges and paving the way for sustainable and high-yielding rice production. From drip-irrigated DSR, which ensures precise water and nutrient delivery, to herbicide-tolerant rice varieties that simplify weed control, modern innovations are reshaping the future of rice farming (Ramesh *et al.*, 2024; Chaudhary and Patel, 2018).

Uniform seed distribution is critical for optimal crop establishment and yield. Advanced seed drills ensure precise seed placement and spacing, minimizing seed wastage and promoting even growth. The integration of mechanical solutions, such as seeders, weeders, and laser land leveling, has further enhanced operational efficiency and crop performance (Kato and Katsura, 2014). Additionally, the advent of drone technology in DSR, enabling precision seeding, spraying, and

monitoring, has introduced a new era of smart farming (Kumar *et al.*, 2020). Together, these breakthroughs are not only overcoming the limitations of traditional DSR but also setting new benchmarks for productivity, sustainability, and resilience in rice cultivation. This review explores the key technological breakthroughs modernizing DSR, evaluating both its benefits and its limitations to provide a roadmap for sustainable implementation.

2. Herbicide-tolerant varieties

Weed management remains one of the most critical challenges in DSR. The transition to DSR has resulted in the proliferation of difficult-to-control weeds, such as *Ischaemum rugosum* and *Leptochloa chinensis*, as well as the emergence of herbicide-resistant weed species. These issues pose a significant threat to the sustainability and productivity of DSR systems. In response, herbicide-tolerant (HT) rice varieties have emerged as a promising solution, offering efficient weed control while minimizing crop damage and reducing labour costs. HT rice varieties are genetically engineered or bred to withstand specific herbicides, enabling farmers to manage weeds effectively without harming the rice crop. This technology addresses key weed-related challenges in DSR, including the spread



of weedy rice (*Oryza sativa* f. *spontanea*), shifts in weed flora, and the evolution of herbicide resistance in problematic weed species (Sudianto *et al.*, 2013). By facilitating the use of targeted herbicides, HT varieties provide a practical and effective solution, encouraging the adoption of DSR in regions where weed pressure is a major constraint.

2.1. Timeline of HT rice development and global adoption

The imidazolinone (IMI) herbicides, including imazamethabenz, imazamox, imazapic, imazapyr, imazaquin, and imazethapyr, belong to the class of acetohydroxyacid synthase (AHAS)-inhibiting herbicides. IMI herbicides are widely used in agriculture due to their minimal environmental impact, excellent crop selectivity, and broad-spectrum weed control. For instance, the mixture of imazapic and imazapyr (OnDuty™) is not only effective in controlling weedy rice but also efficiently controls other major rice weeds, such as *Echinochloa crus-galli*, *Leptochloa chinensis*, *Cyperus iria*, and *Fimbristylis littoralis* (Ruzmi *et al.*, 2021). Due to their effectiveness, HT rice varieties have been specifically developed to withstand IMI herbicides, enabling farmers to manage weeds more efficiently while safeguarding crop health.

Imidazolinone-tolerant (IMI-T) rice, widely known as Clearfield rice, is one of the three major herbicide-tolerant systems developed for rice cultivation. The other two systems include glyphosate-resistant (Roundup Ready) and glufosinate-resistant (Liberty Link, Provisia, and Jietian) rice. Among these, only IMI-Rice has achieved widespread commercialization and is currently used in several countries, including India, the United States, Brazil, Argentina, Uruguay, Italy, and Malaysia. The Liberty Link and Roundup Ready systems, developed by Aventis and Monsanto, respectively, are primarily used in the United States to control weedy rice (red rice). Liberty Link rice varieties, such as LLRICE 06 and LLRICE 62, were developed through transgenic methods involving the

pat gene derived from *Streptomyces hygroscopicus*. Liberty Link rice was approved for food and feed in the USA in 2000 and in Canada in 2006. LLRICE 62 also gained approval in Mexico, Russia, Australia, New Zealand, and Honduras (Quirasco *et al.*, 2008). Another transgenic variety, Provisia rice, developed by the Louisiana State University Agricultural Center, exhibits tolerance to the herbicide quizalofop, an acetyl coenzyme A carboxylase inhibitor. The first Provisia variety, PVL01 (a long-grain rice), was approved for commercial cultivation in 2017 (Famoso *et al.*, 2019).

In the non-GMO category, the development of Clearfield rice marked a significant milestone. This innovation, a collaborative effort between the Louisiana State University Agricultural Center and American Cyanamid-BASF, was achieved through induced mutagenesis targeting the endogenous ALS (acetolactate synthase) gene in rice. Clearfield rice, capable of tolerating imidazolinone herbicides, was first commercialized in the United States in 2002 (Jin *et al.*, 2022). Its adoption has been particularly impactful in regions like Malaysia and Vietnam, where weedy rice threatens rice production sustainability and transitioning from transplanted rice to DSR is hindered by persistent weed issues. In Malaysia, the collaboration between the Malaysian Agricultural Research and Development Institute (MARDI) and BASF (Malaysia) led to the release of two IMI-T rice varieties, MR220CL1 and MR220CL2, in 2010 (Azmi *et al.*, 2012). These varieties exhibit 98.5% and 92.5% genetic similarity with the local parent MR220, respectively. They have demonstrated remarkable yield potential, achieving up to 9,700 kg/ha (Sudianto *et al.*, 2013).

Similarly, in China, six Jietian rice varieties carrying the Trp548Met mutation in the ALS gene were released, developed through chemical mutagenesis using ethyl methane sulfonate. These varieties exhibit tolerance to the herbicide imazethapyr (Chen *et al.*, 2020). All GM and non-GM herbicide-

tolerant lines or genetic stocks developed globally are protected by patents and intellectual property rights (IPR) (Croughan, 1998; Livore, 2003). This restricts their availability for public sector research institutes in countries like India, limiting their use in rice breeding programs. As HT rice technology continues to evolve, addressing these accessibility barriers will be crucial to ensuring its benefits reach farmers worldwide.

2.2. Development of HT rice in India

The development of HT rice in India marks a significant milestone in addressing the challenges of weed management, particularly in DSR systems. The journey began with the creation of an EMS-mutant of N22 at ICAR-National Institute for Plant Biotechnology (NIPB) in 2014, followed by identification of the herbicide-tolerant mutant line 'HTM-N22,' later named 'Robin,' in 2017 from a mutant population of the popular rice variety N22. This mutant line exhibited tolerance to the herbicide Imazethapyr due to mutation in Acetohydroxy Acid Synthase (AHAS) gene, without any major phytotoxic effects. The discovery of Robin paved the way for the development of HT basmati and non-basmati rice varieties tailored to India's diverse agro-climatic conditions. The Indian Agricultural Research Institute (IARI) released herbicide-tolerant (imidazolinone herbicides) basmati varieties, such as Pusa Basmati 1979 and Pusa Basmati 1985, in 2021, marking a major breakthrough, India's first non-GM HT basmati rice varieties (Grover *et al.*, 2020). These varieties were developed by backcrossing popular basmati varieties Pusa 1121 and Pusa 1509 with the Robin mutant.

Researchers at the ICAR-National Rice Research Institute (NRRI), Cuttack, transferred the herbicide-tolerant trait from Robin (donor) to four popular rice varieties: Sahbhagidhan (for uplands), Naveen (for favourable uplands and irrigated conditions), Swarna Sub1, and Pooja (both for shallow lowlands) and

contributed significantly to HT rice development. Among these, the HT Near Isogenic Line (NIL) of Sahbhagidhan was released as CR Dhan 807, India's first non-GM HT rice variety in the non-basmati category, developed through marker-assisted backcross breeding, ensuring that over 95% of the recurrent parent (Sahbhagidhan's) genome was retained (Kar *et al.*, 2024). This variety has been notified for cultivation in six states (Jharkhand, Odisha, Chhattisgarh, Gujarat, Andhra Pradesh, and Tamil Nadu) under rainfed direct-seeded upland conditions and zero-tillage direct-seeded resource conservation practices. All HT rice varieties developed from the Robin mutant are marketed under the trademark RobiNOweed, symbolizing their weed management capabilities. The list of HT rice varieties developed and released for commercial cultivation in India is summarized in (Table 2) along with their key attributes.

2.3. Recommended weed control measures for RobiNOweed

For effective weed control, apply the herbicide Imazethapyr at a rate of 100 g a.i./ha, equivalent to 2.5 ml of the commercial formulation (10% SL) per liter of water, as a foliar spray. To improve efficacy, add 2.5 ml of adjuvant to the solution. Use a flat fan or flood jet nozzle for uniform application and better weed control. Ensure spraying is conducted within 15-17 days after seedling emergence (DAE) or 2-3 leaf stage of weed for optimal results. The soil should have adequate moisture but no standing water, and irrigation should be avoided for at least 48 hours after herbicide application. If irrigation is required, it should be applied or the field ponded only after 48 hours post-spray. The application of Imazethapyr can be extended up to 19-20 days after emergence. However, late application is generally discouraged to ensure effective weed control and prevent potential crop damage.

Table 2: List of herbicide tolerant rice varieties released in India along with their key attributes

Variety	Type	Maturity (Days)	Avg. Yield (t/ha)	Key attributes
Pusa Basmati 1979	Basmati	140-145 Days	4.5-5.0	The first non-GM herbicide-tolerant Basmati variety. It is specifically designed for DSR cultivation. It contains the <i>mu-Ali</i> gene, allowing farmers to spray Imazethapyr herbicide to control weeds without damaging the crop.
Pusa Basmati 1985	Basmati	115-120 Days	5.2	An early-maturing, HT variety. Similar to PB 1979, it supports DSR but matures significantly early. This shorter duration helps in saving 3–4 irrigations and allows timely sowing of <i>rabi</i> (succeeding) crop.
CR Dhan 807	Non-Basmati	125-130 Days	5.0-5.5	India's first non-GM herbicide-tolerant non-Basmati variety. It is highly suitable for rainfed conditions. It features high grain weight and resilience against drought.
CR Dhan 812	Non-Basmati	140-145 Days	8.0	A Near-Isogenic Line (NIL) developed through molecular breeding. It offers high yield and possess HT along with resistance to major pests like stem borers and leaf folders.
SAVA 134	Hybrid Rice	125-135 Days	6.5-7.5	A “Smart Rice” hybrid known for Bacterial Leaf Blight (BLB) tolerance. It has a strong culm (stem) providing high lodging resistance.
SAVA 127	Hybrid Rice	115-125 Days	7.0-8.5	A popular hybrid variety in regions like Punjab and Haryana. It is favoured for its very high yield potential and early-to-medium maturity. It possess tolerance to Blast and BLB.

2.4. Benefits of herbicide-tolerant varieties

Improved weed control: HT rice varieties represent a transformative technology for weed management in direct-seeded rice, offering significant benefits in terms of efficiency and yield. HT varieties offer greater flexibility in weed management, reducing the risk of crop phytotoxicity and enabling effective control of problematic weeds, including weedy rice. Environmental and economic advantages: HT varieties enable the replacement of older, less efficient herbicides with newer formulations that have better environmental profiles. This shift reduces the ecological footprint of rice farming while improving weed control efficacy (WCE). Additionally, HT varieties lower labour costs associated with manual weeding and herbicide application, making DSR more economically viable for farmers. The herbicide-tolerant rice CR Dhan 807, when grown under direct-seeded conditions, can reduce the cost of cultivation by 30% in normal rainfall years. Management of herbicide-resistant weeds: The continuous use of conventional herbicides has led to

the evolution of resistance in several weed species. HT varieties provide new options for managing these resistant weeds, ensuring the long-term sustainability of rice production systems.

2.5. Constraints and potential risks

Despite their advantages, HT varieties are not without challenges. Several potential risks must be addressed to ensure their safe and sustainable adoption. Gene flow to wild and weedy rice: One of the most significant concerns is the risk of gene flow from HT rice to wild or weedy rice populations. This can lead to the development of herbicide-resistant weedy rice, exacerbating weed management challenges. In tropical regions like Malaysia, where multiple rice crops are grown annually, the risk of gene flow and introgression of resistance traits is particularly high. Volunteer rice problem: HT rice varieties can give rise to volunteer plants in subsequent cropping seasons, complicating crop rotation and weed management strategies. Evolution of herbicide resistance: The over-reliance on a single herbicide mode of action can lead to the evolution of resistance in weed

populations, rendering the technology ineffective over time. However, the continuous and inappropriate use of IMI herbicides, such as OnDuty™, has led to the emergence of IMI-resistant weedy rice, highlighting the need for integrated weed management strategies (Ruzmi *et al.*, 2017). Herbicide drift and carryover: The risk of herbicide drift to neighboring fields and carryover effects on rotational crops poses additional challenges, particularly for herbicides with high residual activity.

2.6. Future prospects and recommendations

To maximize the benefits of HT rice varieties while mitigating risks, the following strategies are recommended. Integrated weed management: Combining HT varieties with cultural, mechanical, and chemical weed control methods can reduce the reliance on a single herbicide and delay the evolution of resistance. Monitoring and regulation: Continuous monitoring of weed populations and herbicide use patterns is essential to detect and manage resistance early. Regulatory frameworks should be established to ensure the responsible use of HT technologies. Farmer education and training: Educating farmers about the proper use of HT varieties and herbicides can minimize risks such as herbicide drift, carryover, and the development of resistant weeds. Research and development: Ongoing research is needed to develop new HT varieties with multiple herbicide tolerance traits and to explore alternative weed management solutions.

3. Mechanized DSR

As the global agricultural sector moves toward more eco-friendly practices, mechanization stands out as a promising solution for ensuring food security while preserving natural resources. Mechanization plays a vital role in reducing labour costs and improving the efficiency of DSR operations. Poor crop establishment remains a significant yield constraint in DSR, a method where seeds are broadcast on

the soil surface. This approach leaves seeds highly vulnerable to bird and rat damage, contributing to farmers' low adoption rate (Fenangad and Orge, 2015). To mitigate these risks, farmers often resort to sowing seeds at excessively high rates, which reduces the cost-effectiveness of the technology. However, even with increased seeding rates, unreliable rainfall patterns often lead to inconsistent germination and poor crop establishment (Farooq *et al.*, 2011). Broadcasted seeds struggle to capture rainwater effectively, delaying germination and root development until sufficient rainfall occurs.

In contrast, mechanical row or line seeding, such as using a multi-purpose (MP) seeder, offers a more effective solution. This method ensures that seeds are planted at the appropriate soil depth and distributed uniformly, promoting a stable and even crop stand. By covering the seeds with soil, germinated seedlings can quickly access available soil moisture, while the seed's adhesion to the soil facilitates root proliferation and efficient water uptake, even under dry conditions (Kato and Katsura, 2014). Additionally, row seeding enables more efficient weed management compared to broadcasting, as it allows for better spacing and targeted herbicide application. These advantages make mechanical seeding a superior alternative to dry seeding, addressing key challenges and improving overall crop performance.

Tillage intensity and depth play a critical role in determining soil structure and surface hardness, which directly impact rice establishment in direct seeding systems. Cloddy soils and hard surface layers can hinder seed germination and root development, particularly when seeds are not placed at the optimal depth of 2–3 cm (Kato and Katsura, 2014). Studies have reported that sowing rice seeds at 2 cm depth is most optimum. Another important factor in mechanized DSR is seed rate. While higher seeding rates (e.g., 120 kg/ha) often result in increased tillers and biomass, they do not necessarily translate to higher



grain yields. Studies have shown that yields remain comparable across seeding rates (40 to 120 kg/ha), suggesting that lower seeding rates (40–60 kg/ha) can be used to reduce seed costs without compromising productivity.

3.1. Mechanical seeder used in India

3.1.1. Zero-till drill

The zero-till drill (ZT drill) is a cornerstone of conservation agriculture, designed to minimize soil disturbance during planting. By eliminating or reducing tillage, the ZT drill helps retain soil moisture, suppress weed growth, and prevent soil erosion, contributing to sustainable land management. Equipped with a fertilizer applicator, it enables the simultaneous application of seeds and fertilizers, ensuring precise nutrient placement and improved crop establishment. This technology is particularly beneficial in regions facing water scarcity and soil degradation, as it enhances soil health and reduces the carbon footprint of farming operations.

3.1.2. Lucky seeder

The lucky seeder represents an advanced iteration of the ZT drill, integrating seeding and spraying functionalities into a single machine. This dual-purpose equipment plants rice or wheat seeds and applies herbicides or fertilizers simultaneously, streamlining farming operations and reducing labour costs. Its efficiency in combining multiple tasks makes it a valuable asset for large-scale farming, particularly in areas transitioning from traditional to mechanized agriculture.

3.1.3. Drum seeder

The drum seeder is a manually operated implement designed for the direct sowing of pre-germinated paddy seeds into well-prepared fields. Made from lightweight plastic materials, it can cover 6–8 rows in a single pass, ensuring uniform seed distribution and reducing labour requirements. While it is less

mechanized compared to other seeders, its simplicity and affordability make it an accessible option for smallholder farmers. However, its effectiveness is limited to fields with well-prepared seedbeds, as it requires a smooth and level surface for optimal performance.

3.1.4. Happy seeder

The happy seeder is a cutting-edge ZT drill equipped with a straw chopper and spreader, making it ideal for crop residue management. Happy seeder sows seeds, chops, and spreads the residue of the previous crop as mulch. This not only recycles organic matter but also conserves soil moisture, suppresses weeds, and enhances soil fertility. The happy seeder integrates residue management, seeding, fertilizer application, and mulching into a single operation, significantly reducing the time and labour required for field preparation. Its ability to handle crop residues effectively makes it a game-changer for regions practicing intensive cropping systems, such as rice-wheat rotations.

3.2. Case study

In the Mekong River Delta, Vietnam, the adoption of mechanized direct seeding (mDSR) has led to a significant reduction in seed usage, dropping to 30 kg/ha, a 61–83% decrease compared to traditional broadcast seeding, which typically requires 180 kg/ha. This shift not only reduces input costs but also contributes to a 19–24% reduction in the carbon footprint of rice production. By optimizing seed and fertilizer application, mDSR delivers dual benefits: higher income for farmers and a lower carbon footprint per kilogram of paddy grains compared to conventional broadcast DSR practices (Van Hung *et al.*, 2024). Thus, mDSR is a sustainable and economically viable alternative to traditional broadcast seed. The list of various seed drill available for DSR along with its salient feature summarized in (Table 3).

Table 3: List of seed drill available for DSR and their salient features

Machinery Name	Suitability	Primary Savings (Labour, Cost, Energy)	References
Lucky Seed Drill	Dry DSR	Saves ₹3,000–₹4,500/ha by combining sowing and herbicide application in one trip.	Bhullar <i>et al.</i> , (2024)
Drum Seeder	Wet DSR	Mechanized drum seeder reduces the labour needed by 20% as it eliminates the cost of excessive labour for pulling and transplanting.	Ratnayake <i>et al.</i> , (2013)
Super Seeder	Dry DSR	Needs high-horsepower (more than 55 hp) tractors for operating this seed drill. Thus, the hiring charges for sowing more.	Bishnoi <i>et al.</i> , (2023)
Pneumatic Planter	Wet & Dry	Saves 20% on seed cost via precision metering (20–25 kg/ha rate). The operational cost for the developed Pneumatic Hill Drop Planter equipped with a fertilizer drill was recorded at ₹ 983.74/ha.	Jadhav <i>et al.</i> , (2025)
Precision paddy planter	DSR	A saving of 12.04% in seed rate was observed by sowing with electronic metering-based planter when compared with ground wheel-based mechanical planter. The speed synchronization-based electronic metering mechanism led to a saving of 12.04% in seed use, 16.3% increase in seed placement index, 37% reduction in miss index, 57% reduction in multiple index.	Kumar <i>et al.</i> , (2020)
Inclined Plate Seeder	DSR	It has effective field capacity of 0.66 ha/h with field efficiency having 84.20%. It requires only Rs. 485.74 per ha for direct sowing of paddy whereas sowing by conventional seed-drill requires Rs. 989.73/ha.	Sahu, (2015)
Happy Seeder	DSR	The cost of crop establishment is about half the cost of establishment using conventional practice while maintaining or increasing yield. It can sow seeds even with the straw loads up to about 9 t/ha.	Sidhu <i>et al.</i> , (2007)
Zero Till Drill	DDSR	Maximum field capacity of the machine was at a forward speed of 2.0 kmph is 0.23 ha/h. This machine saves about 300 MJ energy and Rs. 3000/ha spent for weed control.	Mohan <i>et al.</i> , (2022)

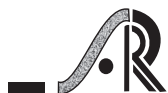
3.3. Challenges in mechanized DSR

Mechanized DSR adoption is often hindered by several operational challenges, including limited seed flow due to seed clogging, inadequate residue-handling capability, and restricted workability across varying soil moisture levels, particularly for smallholder farmers. These issues can lead to uneven seed placement, poor germination, and suboptimal crop establishment, ultimately affecting yield (Vijayakumar *et al.*, 2021). The high cost of mechanical seeders is another significant barrier for smallholder farmers. The initial investment required for purchasing machinery often exceeds the financial capacity of small-scale farmers, limiting their ability to adopt mechanized DSR.

3.4. Strategies to overcome challenges

The development of multi-purpose (MP) seeders has proven to be a game-changer in addressing the challenges of mechanized DSR. These machines not only reduce operating costs per unit but also

enhance operational efficiency. For instance, MP seeders enable uniform seed placement at optimal depths, ensuring better germination and crop establishment. Additionally, they significantly reduce the amount of seeds and labour required compared to traditional broadcasting methods, making them a cost-effective solution for farmers (Kumar and Ladha, 2011). Manufacturing machinery locally is a strategic approach to reducing acquisition costs. It also empowers local communities by enhancing their capacity to provide maintenance and repair services, ensuring the longevity and reliability of the equipment. The integration of fertilizer applicators with MP seeders allows for the simultaneous application of basal fertilizers during seeding, a practice widely adopted in many regions. This not only saves time and labour but also ensures precise nutrient placement, improving fertilizer use efficiency and crop performance. The MP seeder, being a risk-reducing



technology with low acquisition cost, could increase its acceptability among farmers. The MP Seeder is well-calibrated for its delivery of seeds for rice, corn, and green gram, with an option for simultaneous application of fertilizer in corn and green gram.

3.5. Opportunities for wider adoption

Many farmers remain unaware of the availability of suitable machines for DSR operations. Increasing awareness through demonstrations, training programs, and farmer outreach initiatives can bridge this gap and encourage adoption. The success of commercial machinery development lies in meeting market demands at acceptable price points. Designing affordable, farmer-friendly machines that align with operational needs is crucial for widespread adoption. Continued research into optimizing seeding depth, seed rates, and machinery design can further enhance the efficiency of mechanized DSR. Addressing issues such as seed clogging and residue handling will make the technology more robust and adaptable to diverse farming conditions.

3.6. Laser land leveling

Uneven soil surfaces pose significant challenges to crop establishment. They disrupt seed drill operations, leading to poor seed placement and germination, ultimately resulting in suboptimal plant populations, hindered nutrient and water dynamics, and increased weed competition. Furthermore, uneven fields necessitate more power for machinery, driving up energy consumption and production costs while reducing overall productivity. Inefficient land management can also lead to a 10-25% loss of irrigation water, further diminishing crop yields and resource-use efficiency (Kahlowan *et al.*, 2007). While traditional planking methods are used for levelling, they often leave behind dikes and ditches, resulting in inconsistent slopes even with meticulous efforts. Field slopes typically range between 1° to 3° (Jat *et al.*, 2006). In contrast, precision laser land leveling significantly improves rice performance,

especially in non-puddled soils under no-till or permanent bed systems. Laser-leveled fields enhance crop emergence by ensuring proper drainage and preventing waterlogging, promoting uniform seed germination. This technology ensures uniform water distribution and improved crop establishment, leading to even crop growth and minimized waterlogging (Chaudhary and Patel, 2018). Given these benefits, laser land leveling is crucial for the success of DSR, addressing the challenges of uneven fields while enhancing water and nutrient use efficiency, reducing costs, and improving overall productivity.

3.7. Mechanical weeding

Weed management remains one of the most pressing challenges in DSR systems. Unlike traditional transplanted rice, where standing water naturally suppresses weed growth, DSR relies on aerobic soil conditions, which create an environment conducive to weed proliferation (Saravanane *et al.*, 2021). Effective weed control is crucial to ensure optimal crop establishment, growth, and yield. While herbicides are widely used for weed management, their overreliance can lead to herbicide resistance, environmental pollution, and increased production costs. As a sustainable alternative, mechanical weeding using tools such as rotary weeder and cono-weeder offers an effective and cost-efficient solution, minimizing the drawbacks associated with chemical methods. By integrating mechanical weeding into DSR systems, farmers can achieve effective weed control while reducing dependency on herbicides, lowering production costs, and promoting sustainable agricultural practices (Kumar and Ladha, 2011). This approach not only enhances crop performance but also contributes to long-term soil health and environmental conservation.

A 4-row mechanical weeder shows significant promise as a mechanized option for dry DSR. It is particularly effective in moist fields with crops planted in rows and heights not exceeding 15 cm. In many parts of

eastern India, hand-pushed cono-weeders remain widely used despite being labor-intensive and time-consuming. In contrast, a two-row rice power weeder can complete weeding for an acre in just two to three hours, depending on weed density (Vairamuthu *et al.*, 2024). For optimal results, 2-3 manual weeding sessions at appropriate growth stages are typically recommended. The first weeding should be conducted at 20-25 days after sowing (DAS) for dry-seeded rice and 25-30 DAS for wet-seeded rice, followed by a second weeding at 45-50 DAS. Additional weeding sessions may be necessary depending on field-specific conditions, such as weed density and soil moisture levels.

3.7.1. Advantages of mechanical weeding

Mechanized weed control options offer numerous advantages in DSR. By reducing reliance on manual labour and herbicide use, mechanized weed control minimizes the risk of herbicide runoff, soil degradation, and water pollution, aligning with global efforts to promote eco-friendly farming practices. Additionally, mechanical weeding improves soil health by aerating the soil, enhancing its structure, and promoting root growth. It also reduces soil compaction, which improves water infiltration and nutrient availability, benefiting crop performance. This method is particularly effective in controlling herbicide-resistant weeds, offering a viable alternative to herbicides. Furthermore, mechanical weeding significantly reduces labour requirements compared to manual weeding, making it a more efficient and scalable option for large-scale farming operations.

3.7.2. Challenges in mechanical weeding

Despite its benefits, mechanical weeding in DSR is not without challenges. Improper use of mechanical weeders can damage rice seedlings or disrupt soil structure, negatively impacting crop establishment and growth. In fields with severe weed infestations, mechanical weeding alone may prove insufficient, often necessitating supplementary herbicide

applications. The high cost of purchasing mechanical weeders can also be a barrier for smallholder farmers, limiting widespread adoption (Vijayakumar *et al.*, 2021). Operational challenges, such as uneven terrain, crop residues, or high soil moisture levels, can further hinder the effectiveness of mechanical weeders. Additionally, many farmers lack the technical knowledge and skills required to operate these machines efficiently, leading to suboptimal results. Addressing these challenges through innovative design, farmer training, and integrated weed management strategies is essential to fully harness the potential of mechanical weeding in DSR systems.

3.7.3. Solutions to overcome challenges

Innovations in mechanical weeder design, such as adjustable tines and depth control mechanisms, can minimize soil and crop damage while improving weed control efficiency. Combining mechanical weeding with other methods, such as herbicide application or manual weeding, can enhance overall weed control, particularly in fields with heavy infestations (Kumar and Ladha, 2011). Governments and agricultural organizations can provide subsidies or low-interest loans to farmers for purchasing mechanical weeders, making them more accessible. Farmer training programs can equip growers with the skills and knowledge needed to operate mechanical weeders effectively, ensuring optimal results. Addressing field unevenness through precision land leveling can improve the performance of mechanical weeders, enabling them to operate more efficiently. Designing mechanical weeders tailored to local soil types, crop varieties, and farming practices can enhance their effectiveness and adoption.

4. Drone DSR

Drones, or unmanned aerial vehicles (UAVs), equipped with advanced sensors, cameras, and GPS technology, are transforming DSR in several ways, from seed sowing to fertilizer spreading and pesticide spraying. Drone technology is revolutionizing DSR



by addressing key challenges such as uneven seeding, labor-intensive operations, and inefficient weed management. By enhancing precision, efficiency, and sustainability, drones are paving the way for a new era of rice cultivation.

4.1. Drone seeding: Enhancing uniformity and efficiency

One of the most groundbreaking applications of drones in DSR is precision seeding. Traditional broadcasting methods often result in uneven seed distribution and damage to land topography, leading to suboptimal crop establishment and lower yields. Drones, on the other hand, distribute seeds evenly across the field in a fraction of the time, ensuring uniform germination and minimizing seed wastage. The use of spreaders attached to drones facilitates quick and efficient seed and fertilizer distribution, outperforming manual methods in both speed and accuracy (Vijayakumar *et al.*, 2022). However, there is still room for improvement. Current drone seeding methods, while superior to manual broadcasting, lack the precision required for the row placement of seeds. Developing mechanisms for row-specific seed placement could significantly reduce seed rates, optimize crop geometry, and improve overall crop performance. Such advancements would further enhance the efficiency and cost-effectiveness of drone-based seeding in DSR.

4.2. Efficient herbicide application

Weed management is a critical challenge in DSR, where aerobic soil conditions favor weed germination. Traditional herbicide application methods, such as manual knapsack spraying, are labor-intensive, time-consuming, and expose workers to toxic chemicals. Drones offer a transformative solution, enabling precise and efficient herbicide application that minimizes human exposure and ensures better weed control. For instance, the application of

pretilachlor followed by bispyribac sodium via drones significantly reduced weed density and dry weight, resulting in higher grain yields, energy-use efficiency, energy productivity, net returns, and benefit-cost ratios (Paul *et al.*, 2023). Similarly, Avhale *et al.*, (2025) reported that the application of pretilachlor followed by bispyribac sodium using a drone sprayer significantly reduced weed density and weed dry weight compared to the unweeded plot under wet direct-seeded rice. This treatment also resulted in a higher grain yield (5286 kg/ha), net return (Rs. 51631/ha), benefit-cost ratio (2.17), energy-use efficiency (9.53), and energy productivity (0.30 kg/MJ) (Avhale *et al.*, 2025).

However, to maximize the efficiency of drone-based spraying, standard operating protocols (SOP) for spray volume, height, and droplet size need to be established. Recent studies attempted to establish SOP for drone-based herbicide application in DSR. For example, Paul *et al.*, (2024) established the optimum spray volume for herbicide application using drones. Their study revealed that bispyribac-sodium 10% SC applied at a rate of 35 g a.i./ha during the 2-to 3-leaf stage of weeds using a UAV spray system with a spray volume of 30 L/ha demonstrated effective weed control. This is ten times less carrier volume compared to manual methods. Similarly, research by Misra *et al.*, (2025) established the optimum herbicide concentration for drone-based applications. Their study revealed that applying herbicides (triasulfuron 20% + ethoxysulfuron 10%) at 70% of the recommended dose (50.6 g a.i./ha) via drones not only reduced costs by 30% but also improved crop-weed dynamics, yield, WCU (95%), and energy efficiency. 100% RDH (67.5 g a.i./ha) caused phytotoxicity, hindering initial crop growth and resulting in higher weed competition and lower WCE (71-73%). The advantages of using drone in DSR is summarized in (Table 4).

Table 4: Advantage of drone DSR

Operation	Saving of labour, cost, and energy	Reference
Herbicide spray	Cost ratio (2.27 and 2.09), energy-use efficiency (10.86 and 9.55 MJ) and energy productivity (0.81 and 0.71 kg/MJ) were noticed with drone application of pretilachlor fb bispyribac-Na.	Paul <i>et al.</i> , (2023)
Herbicide spray	Drones outperform traditional mist blower methods by ensuring timely herbicide application while significantly reducing labour intensity and physical hardship for farmers.	Abd Ghani <i>et al.</i> , (2024)
	The optimized YOLOv8n-DT model enables drones to use precise “prescription maps” to target actual weed density, increasing identification accuracy while saving 15.28% of herbicides compared to traditional uniform spraying.	Guo <i>et al.</i> , (2024)
	By utilizing a detection model with up to 95% accuracy, the RPAAS method achieves a 45% reduction in herbicide use and minimizes crop injury compared to broadcast spraying, effectively protecting rice yields through site-specific treatment.	Gurjar <i>et al.</i> , (2025)
Direct seeding	Drone seeding at a rate of 40 kg/ha significantly outperformed manual broadcasting, yielding superior growth and higher overall productivity (13%) compared to the traditional manual approach of 60 kg/ha.	Kannan <i>et al.</i> , (2024)

4.3. Benefits and bottlenecks for adoption

The integration of drone technology into DSR offers numerous environmental and economic benefits. From an economic perspective, drones lower production costs by reducing labour and input requirements. The use of drones in DSR significantly reduces the time and labour required for various farming operations. Tasks such as seeding and spraying, which would traditionally take days or even weeks, can now be completed in a matter of hours. This is especially advantageous in regions facing labour shortages, as drones can perform these tasks with minimal human intervention. Although the initial investment in drone technology can be high, the long-term savings and increased yields make it a cost-effective solution for farmers. By optimizing the use of water, fertilizers, and pesticides, drones contribute to more sustainable farming practices.

4.4. Challenges and future prospects

Despite its numerous advantages, the adoption of drone technology in DSR faces several challenges. High initial costs and a lack of technical expertise are significant barriers, particularly in developing countries. Additionally, the absence of SOP for drone operations limits their efficiency and effectiveness. However, the future of drone technology in agriculture is promising. As technology advances and costs decrease, the adoption of drones is expected

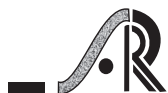
to grow. Governments and private sector players are increasingly investing in research, training, and infrastructure to support the integration of drones into farming practices. The development of drones equipped with artificial intelligence and machine learning capabilities will further enhance their utility, enabling real-time monitoring, data analysis, and decision-making.

5. Drip irrigated DSR

Drip irrigation is a micro-irrigation system that delivers water directly to the root zone of plants through a network of pipes, tubes, and emitters. Unlike traditional flood irrigation, which submerges fields in water, drip irrigation ensures precise water application, maintaining optimal soil moisture levels without waterlogging (Subramanian *et al.*, 2023). This method also opens the door to fertigation and herbigation, the application of fertilizers and herbicides through irrigation water, allowing farmers to deliver nutrients and herbicides at the right time and rate to match crop demand (Ramesh *et al.*, 2024). This precision minimizes nutrient losses, improves nutrient use efficiency, and reduces fertilizer usage by 21-32%, as reported by farmers in various field trials.

5.1. Optimizing drip irrigation for rice: Emitter flow rates and dripline spacing

Drip irrigation systems for rice cultivation require careful calibration of emitter flow rates, dripline



spacing, and irrigation regimes to achieve optimal water distribution and crop performance. By tailoring these parameters to specific soil and climatic conditions, farmers can achieve significant improvements in yield, water productivity, and resource efficiency, paving the way for sustainable and profitable rice farming. Emitter flow rates ranging from 0.6 to 3.5 liters per hour (L/h) have been identified as suitable, depending on factors such as soil infiltration rates, peak crop water requirements, water quality, soil salinity, and water availability. By selecting the appropriate combination of emitter flow rate and spacing, farmers can achieve desired wetting patterns that ensure efficient water use and support healthy crop growth (Rao *et al.*, 2021). In subsurface drip irrigation systems, the installation depth of driplines typically ranges from 5 to 15 cm, depending on soil type, climatic conditions, rotational crops, and farmer preferences. For close-growing crops like rice, an emitter spacing of 30 to 50 cm is recommended, with adjustments made based on soil texture to ensure uniform water distribution (Rao *et al.*, 2021).

Dripline spacing, a critical component of drip irrigation design, is largely determined by soil texture. The width of the wetted strip is influenced primarily by the soil's hydraulic conductivity, while the depth of water penetration depends on both saturated hydraulic conductivity and gravitational forces. As a result, the ideal lateral spacing must be tailored to the specific soil type to maximize irrigation efficiency. For instance, a field trial conducted by Ramesh *et al.*, (2024) in Tamil Nadu, India, addressed the challenges of cultivating rice in sodic soils irrigated with saline water. The study identified TRY (R) 2 as the most suitable rice variety, showcasing superior grain yield, water productivity, panicle development, and tiller efficiency. Notably, a lateral spacing of 90 cm significantly enhanced grain yields compared to 45 cm, offering a practical solution for farmers in similar conditions to boost productivity while conserving water resources.

Further insights into the effectiveness of drip irrigation for rice were provided by Subramanian *et al.*, (2023), who evaluated the impact of different rice varieties and irrigation regimes on growth, productivity, and water-use efficiency. Their field experiment revealed that drip irrigation at 125% of Pan Evaporation (PE) significantly improved growth parameters and grain yields. The KRH 2 hybrid (3,890 kg/ha) and the ADT 45 variety (3,950 kg/ha) achieved the highest yields under this regime. Although the 125% PE treatment resulted in greater total water consumption, its substantial yield advantages make it a viable strategy for water-scarce regions, particularly those with established irrigation infrastructure. Additionally, the spatial analysis indicated that rice rows closer to the drip line consistently produced higher yields, underscoring the importance of precise water application in maximizing crop performance.

5.2. Water saving and higher water productivity

One of the most significant advantages of drip-irrigated rice is its ability to conserve water. Studies have consistently demonstrated substantial water savings compared to conventional flood irrigation. For instance, in Coimbatore, India, drip irrigation improved aerobic rice yields by 29% while saving 50% of irrigation water (Parthasarathi *et al.*, 2018). Similarly, trials in Punjab, India, revealed water savings of 48–53% under sub-surface drip irrigation, with water usage dropping from 7,460–8,740 m³/ha/season under flooded conditions to just 3,864 m³/ha/season (Sidhu *et al.*, 2019). In Islamabad, Pakistan, drip irrigation systems achieved 249% higher water productivity compared to conventional flooding and 197% higher than automatic water delivery systems (AWD) (Akbar *et al.*, 2023). Farmers using drip irrigation required only 779 liters of water to produce one kilogram of paddy, compared to 2,024 liters under traditional methods (Rao *et al.*, 2021).

However, the impact on yield varies depending on location and conditions. In Xinjiang, China, drip

irrigation led to a 31.76–52.19% decrease in grain yields, though water use efficiency (WUE) was significantly higher, measuring 1.52–2.12 times higher than with conventional floods (He *et al.*, 2013). A study at the University of Missouri Marsh Farm in 2005-2006 demonstrated that subsurface drip irrigation for rice reduced water use by 80% compared to traditional flooding but delayed maturity by two weeks. Conversely, in Japan's Kanto Area, drip irrigation with plastic mulch reduced water use by 21–34% while maintaining comparable water productivity despite slightly lower yields (Park *et al.*, 2021). These mixed results highlight the need for further research to optimize drip irrigation practices for different agro-climatic conditions.

Drip irrigation significantly enhances effective precipitation and improves soil health. Unlike traditional flood irrigation, which maintains standing water in rice fields, drip-irrigated DSR ensures that the soil surface remains free of waterlogging at all crop stages. This absence of standing water allows for better utilization of rainfall, increasing effective precipitation. Also, the absence of a puddling operation in DSR promotes higher rates of water infiltration and groundwater recharge. Thus, drip irrigation helps retain soil structure by reducing soil erosion and soil fertility by minimizing nutrient leaching. Indirectly, these benefits create a more resilient farming system while supporting healthier crop growth.

5.3. Energy saving and higher energy productivity

The benefits extend beyond water conservation. Drip irrigation also reduces energy consumption, a critical factor in regions like India, where electricity is costly and often unreliable. By lowering water requirements, drip irrigation saves 1,208.3 electricity units per hectare, representing a 33.8% reduction in energy use compared to flood irrigation. This translates to significant cost savings for farmers, with electricity bills reduced by Rs. 4,834 per hectare (Rao *et al.*, 2021).

5.4. Environmental benefits of drip irrigation in rice

Drip-irrigated rice offers several environmental advantages. Eliminating standing water prevents methane (CH_4) emissions, a potent greenhouse gas (GHG) produced under anaerobic conditions in flooded rice fields. Additionally, fertigation reduces nitrous oxide (N_2O) emissions by synchronizing nitrogen application with crop demand, although DSR with broadcasting of nitrogen fertilizer increases N_2O emission. The absence of waterlogging also minimizes soil erosion and nutrient leaching, enhancing groundwater recharge and reducing runoff.

5.5. Economic benefits of drip irrigation in rice

From an economic perspective, drip irrigation reduces production costs by 22.3% compared to flood irrigation by eliminating field operations such as puddling, nursery raising, transplanting, and pesticide application (Rao *et al.*, 2021). Similarly, Meher *et al.*, (2020) reported that drip irrigation reduced irrigation costs by 2.0 to 5.6 times compared to traditional flood irrigation by lowering overall water consumption. Savings are achieved through reduced labor, fertilizer, and weed control costs, as herbicides can be applied through the drip system (herbigation). Governments in states like Tamil Nadu, Andhra Pradesh, and Telangana have recognized these benefits, offering subsidies of up to Rs. 48,270 per hectare to encourage adoption. However, the high initial cost of drip systems remains a barrier, particularly for small and marginal farmers. Innovative financing mechanisms, such as carbon and water credits, could incentivize wider adoption by increasing farmers income.

5.6. Challenges and Limitations

Despite its potential, drip-irrigated rice faces several challenges. The high initial cost of drip systems and the need for reliable power supply are significant hurdles. Additionally, the lack of rice varieties



specifically bred for aerobic conditions under drip irrigation limits its effectiveness. Farmers also face operational constraints, such as micronutrient deficiencies (iron and zinc), increased susceptibility to blast disease, and pest infestations like root-knot nematodes and termites. Weed management is another critical issue in drip-irrigated rice. The transition from traditional transplanted rice to DSR under drip irrigation creates aerobic soil conditions that are highly conducive to weed germination. This shift not only alters the type of weeds but also intensifies the degree of weed infestation, posing a significant threat to crop productivity. Under drip-irrigated systems, weeds germinate simultaneously with rice seeds, competing aggressively for essential resources such as space, light, water, and nutrients. This competition can severely hinder rice growth and, if left unchecked, lead to substantial yield losses.

Manual weeding, a common practice in traditional rice farming, proves largely ineffective in drip-irrigated DSR. Differentiating rice seedlings from weeds in heavily infested fields is particularly challenging, especially with species like *Echinochloa colonum* and *E. crus-galli*, which bear striking phenotypic similarities to rice seedlings (Subramanian *et al.*, 2021). Moreover, manual weeding is labor-intensive and economically unfeasible, requiring a significant workforce that many farmers cannot afford. To address these challenges, effective weed control in drip-irrigated rice relies on a strategic combination of pre-emergence and early post-emergence herbicides. These herbicides help manage weeds at the earliest stages of growth, preventing them from establishing a competitive advantage over the rice crop. While manual weeding is not a standalone solution, it can complement herbicidal control by removing escaped weeds 25–30 days after sowing. This integrated approach ensures better weed management, safeguarding crop yields and reducing the labour burden on farmers.

5.7. The road ahead

Drip-irrigated rice represents a paradigm shift in rice cultivation, offering a sustainable alternative to traditional flood irrigation. While the technology is still evolving, its potential to conserve water, reduce GHG emissions, and improve resource use efficiency is undeniable. To unlock its full potential, further research is needed to develop suitable weed control measures and rice varieties, optimize irrigation schedules, and address micronutrient deficiencies and pest challenges. Governments and policymakers must also play a role by providing subsidies, technical support, and incentives like carbon credits to make drip irrigation economically viable for farmers. With concerted efforts, drip-irrigated rice could transform the future of rice farming, ensuring food security while safeguarding precious natural resources for generations to come.

6. Vattar DSR and seed priming

In DSR, poor and uneven crop establishment is often linked to field inundation during early crop emergence due to unpredictable heavy monsoon rains. To address this challenge, a technique known as soil mulching, locally referred to as vattar DSR was developed. This method involves planting DSR 2-3 weeks before the onset of the monsoon, leveraging the soil mulch effect to conserve moisture and reduce the need for early irrigation during the first 15 to 21 days (**Figure 2**). This allows for earlier planting and mitigates the risk of inundation. The soil mulching process is a straightforward yet effective management option. It begins with pre-sowing irrigation, followed by shallow tillage to break soil capillaries and prevent moisture loss. Rice sowing is then carried out, with the first irrigation delayed by 2-3 weeks. This technique was extensively evaluated across 10 districts in Eastern Uttar Pradesh and Bihar, covering 1,208 farmers' fields. The results were promising: soil mulching delayed the first irrigation by 15-20 days, saving 2-3 early irrigations, reducing inundation

risks, and suppressing early weed infestation by 50%. Moreover, soil mulch DSR yielded on par with conventional puddled transplanted rice (PTR) and 22% higher (1.1 t/ha) than DSR without soil mulching (dry sowing followed by irrigation). Given these benefits, Bihar Agriculture University has officially endorsed the technology and incorporated it into its state-level agricultural recommendations, marking a significant step toward wider adoption and scalability.

Dhillon *et al.*, (2021) conducted comprehensive field and laboratory trials over two seasons to evaluate the impact of seed priming on the growth and yield of dry DSR. Their findings demonstrated that seed priming techniques significantly enhance germination, crop establishment, growth, and grain yield in DSR systems. Specifically, halopriming (using 2.0% potassium nitrate) and hormopriming (with 50 ppm gibberellic acid, GA3) increased rice yields by 7–11% compared to non-primed seeds (control). Osmopriming (with polyethylene glycol, PEG) also showed promise, delivering a 4% yield increase in one of the study years. The yield improvements from halopriming and hormopriming were attributed to faster and more uniform germination, improved root development, and better yield-related traits. Notably, the duration of priming (12 or 24 hours) had no significant effect on crop emergence, growth, or yield. Additionally, both conventional DSR (sowing in dry soil followed by irrigation) and soil mulch DSR (vattar DSR, sowing in moist soil after pre-sowing irrigation) achieved similar grain yields, although differences were observed in crop emergence, growth patterns, and yield attributes. These results underscore the potential of halopriming with 2.0% potassium nitrate and hormopriming with 50 ppm GA3 as effective strategies to improve crop establishment and productivity in both conventional and soil mulch DSR systems.



Figure 2: Tar-vattar direct seeded rice crop in Punjab

7. Screening suitable herbicides for wet DSR

Poor and uneven crop establishment in DSR can often be attributed to several factors: (i) phytotoxicity caused by pre-emergence (PRE) herbicides when applied under excessively wet soil conditions, often due to unexpected rainfall, (ii) seeds sown deeper than the optimal 2–3 cm depth; and (iii) field inundation caused by unpredictable monsoon rains during the critical early crop emergence stage. To mitigate the risk of herbicide toxicity, on-station trials were conducted at the Patna CSISA Research Platform in 2018 and 2019 to identify herbicides with a low risk of phytotoxicity under wet soil conditions, simulated by 5-cm flooding for 24 hours. The results revealed that herbicides such as oxadiargyl and pretilachlor (with safener) demonstrated a low risk of phytotoxicity under wet (excess moisture) conditions. In contrast, pendimethalin, a commonly used herbicide, caused significant crop damage, reducing crop stand by 45%. Thus, selecting appropriate herbicides could minimize phytotoxicity risks and improve DSR establishment, particularly in regions prone to unpredictable rainfall and waterlogging. The list of suitable pre-emergence, early post-emergence, and post-emergence herbicide for DSR along with its rate and time of application is summarized in (Tables 5 and 6).

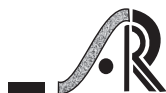


Table 5: Herbicides for Direct seeded rice

Herbicide	Trade Name	Time of application	Commercial formulation	
			Dose/hectare	Dose/acre
Pre emergence (PE)				
Pretilachlor 50% EC	Craze, Prolax, Hifit, Sofit, and Preet Plus	0-3 DAS	1.0 L/ha	400 ml/acre
Pendimethalin 30% EC	Dhanutop	0-3 DAS	2.5 L/ha	1 L/ha
Pyrazosulfuron-ethyl 10% WP	Saathi	0-5 DAS	30 g/ha	12 g/acre
Post emergence (PoE)				
Bispyribac-sodium 10% SC	Nominee Gold, Adora	PoE (15-25 DAS)	250 ml/ha	100 lm/acre
Ethoxysulfuron 15% WG	Sunrice	EPoE (5-10 DAS)	100 g/ha	40 g/acre
Fenoxaprop-p-ethyl 6.9% EC	Rice Star, Whip Super, Legacee	EPoE (10-15 DAS)	1000 ml/ha	400 ml/acre
Oxadiargyl	RAFAZ	PE (14-18 DAS)	1-1.25 L/ha	400-500 ml/acre
2, 4-D ethyl ester	HEERA-44	PE (30-40 DAS)	2.5 L/ha	1 L/acre
Carfentrazone-ethyl 40% DF	Affinity	10-15 DAS	60 g/ha	25 g/acre

Table 6: Mixed Herbicides

Herbicide	Trade Name	Time of application	Dosage (commercial/ha)	
Triafamone 20% and Ethoxysulfuron 10%	Council Activ	Post-emergence (8-12 DAT or DAS)	225 g/ha	90 g/acre
Florpyrauxifen-benzyl Cyhalofop-butyl	Novalact	Post-emergence (15-20 DAT or DAS)	1.25 L/ha	500 ml/acre
Florpyrauxifen-benzyl and penoxsulam active	Novixid	Post-emergence (15-20 DAT or DAS)	1.25 L/ha	500 ml/acre
Pretilachlor and Florpyrauxifen-benzyl	Altessia	Post emergence (5-10 DAT)	800 ml/acre	
Metsulfuron Methyl 10% and Chlorimuron Ethyl 10%	Almix	Post-emergent (20–25 DAS)	20 g/ha	8 g/acre
Chlorimuron + Metsulfuron-methyl	Chlormax	Pre or post emergence	20 g/ha	8 gm/acre
Pretilachlor + Bensulfuron	Bentila, Londax power	Pre-emergence (3 to 5 DAT)	10 kg/ha	4 kg/acre

Conclusion

The modernization of DSR through key technological breakthroughs marks a significant leap forward in sustainable agriculture. Innovations such as drip-irrigated DSR have revolutionized water and nutrient management, ensuring precise delivery while conserving resources. HT rice varieties have simplified weed control, reducing dependency on labour and addressing the persistent challenge of weed resistance. The integration of mechanical solutions ranging from advanced seeders and weeders to laser land leveling has enhanced operational efficiency, improved crop establishment, and optimized resource use. Meanwhile, drone

technology has introduced unprecedented precision in seeding, spraying, and spreading, ushering in an era of smart farming.

Together, these advancements are transforming DSR into a more resilient, productive, and environmentally friendly system. By addressing the limitations of traditional practices, these technologies are not only boosting yields and reducing costs but also promoting sustainable land and water management. As global challenges such as climate change, water scarcity, labour scarcity, and population growth intensify, the adoption of these innovations will be

crucial for ensuring food security and safeguarding the livelihoods of millions of farmers. The future of rice cultivation lies in embracing these technological breakthroughs, paving the way for a more sustainable and prosperous agricultural landscape.

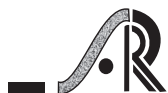
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Studies on Root Traits through High Throughput Phenotyping in Rice (*Oryza Sativa* L.)

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Abstract

The present study was undertaken to characterize 15 rice genotypes for 16 quantitative and root characters under transplanted and direct sown conditions. The *per se* performance revealed that genotypes *viz.*, BPT 3050 and BPT 2766 under transplanted conditions and BPT 3114 and BPT 3050 under direct sown conditions exhibited superior grain yield. For root characters, the genotype BPT 2841 recorded high mean values for root growth angle and BPT 2846 exhibited high values for nodal root length under both transplanted and direct sown conditions. BPT 2846 and BPT 3050 recorded high mean values for root volume under transplanted and direct sown conditions, respectively. The traits namely number of nodal roots, nodal root length, root length density and seminal root length exhibited high heritability along with high genetic advance as per cent of mean under direct sown conditions, which show the preponderance of additive gene action. Under both transplanted and direct sown conditions, total root length had positive and significant relationship with root volume and grain yield, indicated the scope for simultaneous improvement. BPT 5204, BPT 3061, BPT 2766 and BPT 3291 are most divergent genotypes according to PCA biplot analysis under transplanted conditions. Under dry direct sown conditions, BPT 3061, BPT 2766, BPT 3082 and BPT 2841 were identified as diverse genotypes for most of the yield components and root traits.

Keywords: Rice, Direct sown, Root volume, Total root length, Root length density.

Introduction

Rice (*Oryza sativa* L.) is a staple food crop for over 3.5 billion people and an economic driver for many countries in South and Southeast Asia. India ranks first in area (44.6 M ha) and production (150.18 mtons) of rice in the world. In pursuit of boosting rice production, while maintaining economic feasibility within resource constraints, the shift from the traditional puddled-transplanted rice system to direct-seeded rice is gaining significance (Chang *et al.*, 1982 and Haefele *et al.*, 2014). Comparative yields in DSR can be obtained by adopting various cultural practices, selection of suitable cultivars, proper sowing time, optimum seed rate, proper

weed and water management (Gill *et al.*, 2006). The root system is described as the “hidden half”, because it performs a pivotal function in overall crop development as well as in advancement.

Root development and root activities are assumed to have mutual interactions with the shoots. In the last few decades, there has been shoot improvements but neglected the phenotypic variation of root architectural, morphological and anatomical traits. There are five root types in rice root architecture including the embryonic and the post-embryonic roots such as the radicle, the embryonic crown



roots, the post-embryonic crown roots, the large lateral roots, and the small lateral roots (Rebouillat *et al.*, 2009). Genetic improvement for a large and deep root system is considered to be an important strategy for improving the water capture and yield stability of rice varieties (Mambani and Lal, 1983; Yoshida and Hasegawa, 1982). As the area under dry direct sowing is being increased every year, the study of root traits in different rice varieties is essential to identify suitable rice varieties for different types of sowing methods.

Materials and Methods

The experimental material consisted of 15 rice genotypes obtained from Agricultural Research Station, Bapatla. During *rabi* 2023, all the 15 genotypes were sown at the Floriculture Block of Agricultural College Farm on nursery beds raised separately. Twenty-five days old seedlings were transplanted with three replications in 5.0 m² plots in randomized block design (RBD).

Under dry direct seeded condition, planting was done by dibbling the seed in RBD with three replications of 5.0 m² plot size at Northern Block of Agriculture College Farm, Bapatla. Under both the conditions, a spacing of 20 cm and 15 cm was adopted between and within the rows, respectively. In dry direct seeded method, field was kept in moist condition for 3 days after sowing to promote good crop establishment, and then up to maturity stage, field was kept under saturation condition (Bouman *et al.*, 2007 and Shashidhar, 2007). Recommended package of practices were followed for raising the healthy crop. The sampling procedure for root traits was carried out at 60 DAS. Three plant samples per replication per genotype were collected in both the methods and stored at 4°C for one day and analyzed for different root traits by image analysis with the help of digital camera (Canon FOS 70D DSLR Camera). Root images were captured and analyzed for various traits, *viz.*, total root length *i.e.*,

sum of the lengths of all the roots in root system, root volume, root length density, root growth angle, number of nodal roots, seminal root length and nodal root length by using Win RHIZO Pro image analysis system (Tajima and Kato, 2013). An 8-bit grayscale image, after removing debris, was acquired by digital camera (Canon FOS 70D DSLR Camera). The root images were saved in TIFF format; 15 rice root images were collected for the analysis. By using the triangle thresholding algorithm as premeasured using ImageJ, the root images were transformed to binary images (Tajima and Kato, 2011). The morphological data on 5 plants/ replication/ genotype was also collected for nine characters *viz.*, days to 50% flowering, plant height, stem width, ear bearing tillers/ plant, total tillers/ m², panicle length, number of filled grains/ panicle, test weight and grain yield/plot. The mean data was utilized for the estimation of genetic parameters as per Johnson *et al.*, (1955) and Hanson *et al.*, (1956). The simple correlation coefficient was calculated by following Falconer (1964) while principal component analysis was carried out as described by Banfield (1978).

Results and Discussion

The analysis of variance results revealed significant differences among the genotypes for all the characters studied, indicating the existence of sufficient variation among the genotypes under study. The results of the mean performance of genotypes used in the present study revealed that genotypes *viz.*, BPT 3050, BPT 2846 and DRR Dhan 42 recorded superior grain yield per plot than the check variety BPT 5204 under transplanted conditions (**Table 1**), whereas under dry direct sown conditions, BPT 3114, BPT 2295 and BPT 2766 recorded superior grain yield per plot than the check variety BPT 5204 (**Table 2**). Among the genotypes studied, BPT 2766, Binadhan 16 and DRR Dhan 42 had desirable root traits like root growth angle, nodal root length, total root length, root length density,

seminal root length and root volume compared to check variety BPT 5204. When both yield and root traits are considered, BPT 2766, BPT 3114 and BPT 2846 recorded high grain yield and desirable root characteristics under both transplanted and dry direct sown conditions. Under dry direct sown conditions, three genotypes *viz.*, BPT 2846, BPT 2841 and BPT 2295 manifested steep root growth angle suggesting that these genotypes had deeper root system hence, studies may be undertaken to test their tolerance to water stress conditions for their utilization in breeding programmes. DRR Dhan 42, Binadhan 16 and BPT 2858 had longer total root length while Binadhan 16, BPT 2846 and BPT 3291 had high root volume. Hence these genotypes can be recommended for the breeding programmes when aiming for development of above traits. The estimates of phenotypic coefficient of variation for all the characters under study were higher than the estimates of genotypic coefficient of variation. The difference between these two coefficients of variation is less. This close correspondence between two estimates of phenotypic coefficient of variation was also reflected by their high heritability values. Under transplanted condition, minimum phenotypic and genotypic coefficient of variation was observed for days to 50% flowering (9.09 and 8.73%) (**Table 3**) while maximum phenotypic and genotypic coefficient of variation was manifested by root length density (41.78 and 40.62%) indicating the existence of sufficient variation among the genotypes for potential yield improvement through selection. High PCV and GCV were observed for root volume (29.78 and 29.19%), total root length (28.16 and 27.39%) and test weight (24.98 and 24.80%) as well. Similar findings were earlier

reported by Sridhar *et al.*, (2011), Singh *et al.*, (2020) and Devi *et al.*, (2022). Heritability estimates were ranged from 31.54% (total number of tillers per m²) to 98.60% (Test weight). Chandra Bose *et al.*, (2024) also reported high heritability estimates for test weight. Genetic advance as per cent of mean was varied from 6.72% (total number of tillers per m²) to 81.35% (root length density). Under DDSR condition, the genotypic coefficient of variation ranged from 6.51% (total number of tillers per m²) to 38.00% (root length density) (**Table 4**) while PCV varied from 8.89% (total number of tillers per m²) to 40.01% (root length density). Maximum heritability was observed for stem width (95.25%) followed by seminal root length (95.04%) and test weight (92.97%). Genetic advance as per cent of mean manifested highest value for root length density (74.34%) while minimum was recorded by panicle length (7.31%).

Grain yield per plot manifested moderate GCV and PCV coupled with moderate heritability and genetic advance under both transplanted and DDSR conditions indicating that the prevalence of both non-additive and additive gene action in the inheritance of this trait. Under transplanted conditions, test weight, total root length, root length density and root volume exhibited high estimates for all the genetic parameters studied. Similarly, under dry direct sown conditions, test weight, stem width and root length density exhibited high estimates for all the genetic parameters studied suggesting the predominance of additive gene effects. Hence these traits can be improved through simple selection. Similar findings were previously reported by Shashidar *et al.*, (2007), Anandan *et al.*, (2022) and Faysal *et al.*, (2022).

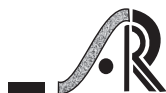


Table 1: Mean performance for yield, yield components and root traits under transplanted condition in rice (*Oryza sativa* L.)

Genotype	DFF	PH (cm)	PL (cm)	EBT/ plant	NT/ m2	NFG/ panicle	TW (g)	SW (mm)	NR	RGA (Degree)	NRL (cm)	TRL (cm)	RLD (cm/cm ³)	SRL (cm)	RV (CC)	GY (kg)/plot
BPT2231	115	95.5	21.7	17	468	192	15.5	3.6	18	38.9	16.8	243.7	0.276	8.4	0.88	3.3
BPT2295	121	101.1	23.0	14	442	207	13.5	4.2	23	43.8	17.5	179.5	0.268	11.3	0.67	3.1
BPT2766	116	102.1	22.2	12	429	248	15.4	7.5	25	46.9	15.4	154.7	0.100	8.2	1.54	3.8
BPT2841	92	114.5	21.4	10	445	251	12.4	5.5	16	37.3	18.6	215.1	0.227	11.6	0.95	3.0
BPT2846	112	100.4	24.0	17	464	251	13.6	4.6	22	55.7	16.7	125.3	0.071	8.4	1.75	3.8
BPT2858	102	118.6	28.6	13	430	329	12.2	3.8	16	30.5	16.3	235.9	0.323	11.7	0.73	2.8
BPT3050	102	98.3	25.6	17	512	177	22.6	3.5	20	47.1	14.5	325.5	0.260	9.5	1.25	4.4
BPT3061	105	130.3	24.1	20	508	226	17.2	6.8	17	46.5	11.2	271.3	0.199	9.3	1.36	3.8
BPT3082	102	96.9	23.5	14	437	272	13.3	5.1	26	36.1	13.7	316.5	0.458	10.6	0.69	3.0
BPT3114	104	121.4	22.4	19	488	173	17.3	4.6	22	39.3	12.9	196.4	0.204	11.9	0.96	3.6
BPT3291	103	99.8	22.2	12	452	211	22.7	4.1	19	49.0	15.3	278.7	0.244	8.5	1.14	3.3
BPT4358	105	102.1	22.8	13	452	224	13.5	5.7	21	50.6	15.6	308.1	0.285	9.6	1.08	3.6
BPT5204	112	87.6	19.4	19	510	181	13.1	4.3	15	41.1	13.5	268.7	0.395	8.8	0.68	3.0
Binadhan 16	75	102.8	22.7	9	415	156	23.5	5.5	25	48.5	14.6	360.8	0.474	12.1	0.76	2.9
DRRDhan 42	78	85.7	24.5	11	398	165	24.3	6.9	24	37.5	16.5	345.4	0.308	6.9	1.12	3.3
MEAN	102.9	104.4	23.2	14.8	457.0	206.8	16.6	5.0	20.6	43.2	15.2	255.0	0.272	9.7	1.03	3.1
Maximum	121	130.3	28.6	20	512	329	24.3	6.9	26	55.7	18.6	360.8	0.474	12.1	1.75	4.4
Minimum	75	85.7	19.4	9	398	156	12.2	3.5	15	30.5	11.2	125.3	0.071	6.9	0.67	2.4
SEm	3.7	3.8	0.6	1.0	10.3	20.7	0.5	0.2	1.8	3.3	0.7	9.4	0.5	0.4	0.2	0.2
CV	6.5	6.4	7.2	7.6	8.0	7.8	5.1	7.7	15.4	13.5	8.2	6.4	11.9	8.3	10.7	16.0
CD	10.8	15.1	1.8	2.9	29.9	60.0	1.4	0.8	5.3	9.7	2.1	27.3	1.5	1.3	0.6	0.8

DFF = Days to 50 per cent Flowering, PH = Plant Height (cm), PL = Panicle Length (cm), EBT/plant = Ear Bearing Tillers per plant, NT/m² = No. of tillers/m², NFG/panicle = No. of Filled grains per panicle, TW = Test weight, GY(kg)/plot = Grain yield (Kg) per plot, SW = Stem width (mm), NR = No. of nodal roots, RGA (Degree) = Root growth angle (Degree), NRL = Nodal root length (cm), TRL = Total root length (cm), RLD = Root length density, SRL = Seminal root length (cm), RV = Root volume.

Table 2: Mean performance of rice genotypes for yield components and root traits under dry direct seeded condition in rice (*Oryza sativa* L.)

Genotype	DFF	PH (cm)	PL (cm)	EBT/ plant	NT/ m ²	NFG/ pancile	TW (g)	SW (mm)	NR	RGA (Degree)	NRL (cm)	TRL (cm)	RLD (cm/cm ³)	SRL (cm)	RV (CC)	GY (Kg)/plot
BPT2231	108	93.2	22.0	15	461	180	15.3	4.3	21	37.3	22.7	321.5	0.171	9.5	1.79	3.0
BPT2295	113	107.5	21.0	13	404	192	14.1	4.6	26	47.4	25.5	325.6	0.282	13.6	1.12	3.8
BPT2766	111	102.0	22.3	12	458	248	14.4	6.1	25	39.4	18.5	288.2	0.189	11.2	1.55	3.2
BPT2841	87	109.2	22.5	12	508	255	11.8	5.7	23	48.6	24.7	342.5	0.271	15.6	1.23	2.8
BPT2846	108	106.5	24.3	11	527	261	14.2	5.6	28	55.4	28.5	306.9	0.155	9.2	1.90	3.4
BPT2858	95	112.9	29.7	13	493	341	12.4	3.2	25	37.5	21.0	410.5	0.308	12.4	1.25	2.7
BPT3050	98	90.5	24.2	13	506	158	19.7	3.8	29	53.0	19.5	420.1	0.456	16.8	0.72	4.1
BPT3061	105	124.4	22.8	14	529	212	15.4	5.6	22	34.2	26.8	387.3	0.284	15.3	1.28	2.9
BPT3082	103	105.4	23.2	16	456	195	13.4	5.4	26	44.1	22.7	350.6	0.241	14.2	1.38	3.2
BPT3114	97	111.9	24.0	15	525	168	15.0	4.2	27	37.7	23.2	360.2	0.216	13.6	1.56	4.2
BPT3291	97	93.3	21.4	14	470	185	21.3	4.8	31	35.2	20.6	309.8	0.397	12.5	0.78	3.1

Genotype	DFF	PH (cm)	PL (cm)	EBT/plant	NT/m ²	NFG/panicle	TW (g)	SW (mm)	NR	RGA (Degree)	NRL (cm)	TRL (cm)	RLD (cm/cm ³)	SRL (cm)	RV (CC)	GY (Kg)/plot
BPT4358	104	95.3	21.3	15	474	204	13.9	4.9	26	52.0	21.4	420.8	0.217	9.8	1.86	3.9
BPT5204	107	94.6	20.0	15	514	153	14.0	4.3	22	46.8	23.7	395.6	0.203	9.6	1.77	2.8
Binadhan 16	81	100.9	19.9	13	469	160	21.9	5.1	35	47.2	26.2	438.4	0.223	13.4	1.93	2.8
DRRDhan 42	82	85.1	19.6	14	448	165	26.6	5.8	32	46.2	23.9	460.5	0.243	11.7	1.77	3.0
MEAN	100.0	102.4	22.5	14	483	195	16.4	4.9	26.7	44.1	23.2	369.2	0.270	12.5	1.46	3.1
Maximum	113	124.4	29.7	16	529	341	26.6	6.1	35	55.4	28.5	460.5	0.456	16.8	1.93	4.2
Minimum	81	85.1	19.6	11	404	153	11.8	3.2	21	34.2	18.5	306.9	0.155	9.2	0.72	2.7
CV (%)	4.1	5.0	8.0	8.2	6.0	6.3	7.1	5.8	9.2	7.8	9.6	5.3	12.4	4.1	6.0	8.1
Sem	2.4	3.2	1.0	0.6	16.8	8.2	0.6	0.0	1.4	2.0	1.2	11.3	0.01	0.3	51.4	0.1
CD	6.9	9.5	2.9	1.9	48.8	23.8	2.0	0.1	4.1	5.8	3.7	32.8	0.05	0.8	0.7	0.4

DFF = Days to 50 per cent Flowering, PH = Plant Height (cm), PL = Panicle Length (cm), EBT/plant = Ear Bearing Tillers per plant, NT/m² = No. of tillers/m², NFG/panicle = No. of Filled grains per panicle, TW = Test weight, GY(kg)/plot = Grain yield (Kg) per plot, SW = Stem width (mm), NR = No. of nodal roots, RGA (Degree) = Root growth angle (Degree), NRL = Nodal root length (cm), TRL = Total root length (cm), RLD = Root length density, SRL = Seminal root length (cm), RV = Root volume.

Table 3: Genetic parameters for yield components and root characters under transplanted and dry direct sown conditions in rice (*Oryza sativa* L.)

S. No	Characters	GCV (%)		PCV (%)		Genetic Advance		Heritability (Broad Sense) (%)		Genetic Advance as % of Mean	
		Trans-planted	Direct sown	Trans-planted	Direct sown	Trans-planted	Direct sown	Trans-planted	Direct sown	Transplanted	Direct sown
1	DFF	8.73	8.80	9.09	9.65	17.18	18.59	92.15	84.70	17.26	18.58
2	PH (cm)	13.53	10.97	14.00	11.61	28.20	9.59	93.34	36.09	26.93	8.63
3	PL (cm)	10.97	7.61	11.13	9.34	2.65	1.67	51.32	28.75	11.77	7.31
4	EBT/Plant	10.14	7.78	11.26	9.35	2.16	1.54	55.72	47.01	15.77	10.99
5	NT/m ²	8.81	6.51	9.35	8.89	30.73	47.57	31.54	53.75	6.72	9.84
6	NFG/panicle	17.57	19.61	18.80	19.72	77.72	22.88	87.31	23.11	33.82	9.52
7	TW (g)	24.80	25.90	24.98	26.87	8.60	8.46	98.60	92.97	50.74	51.46
8	SW (mm)	18.20	26.46	18.67	27.11	1.86	0.78	95.04	95.25	36.55	53.19
9	NR	14.62	14.35	16.26	16.27	4.28	6.05	47.28	67.40	20.70	22.59
10	RGA (degrees)	13.39	14.78	19.04	16.74	8.39	11.87	49.46	77.98	19.40	26.89
11	NRL (cm)	11.70	11.58	14.33	13.32	3.00	3.75	66.69	54.57	19.69	16.10
12	TRL (cm)	27.39	12.41	28.16	14.48	139.86	59.30	94.59	54.36	54.87	17.33
13	RLD (cm/cm ³)	40.62	38.00	41.78	40.01	0.22	0.20	94.53	90.16	81.35	74.34
14	SRL (cm)	16.02	18.32	18.06	18.79	2.86	4.63	78.72	95.04	29.29	36.79
15	RV (cc)	29.19	12.96	29.78	15.51	610.54	203.67	96.10	34.02	58.95	14.37
16	GY (kg) per plot	13.53	11.90	19.22	12.80	0.61	0.33	44.76	38.13	18.65	10.06

PCV-Phenotypic Coefficient of Variation; GCV-Genotypic Coefficient of Variation

DFF = Days to 50 per cent Flowering, PH = Plant Height (cm), PL = Panicle Length (cm), EBT/plant = Ear Bearing Tillers per plant, NT/m² = No. of tillers/m², NFG/panicle = No. of Filled grains per panicle, TW = Test weight, GY(Kg)/plot = Grain yield (Kg) per plot, SW = Stem width (mm), NR = No. of nodal roots, RGA (Degree) = Root growth angle (Degree), NRL = Nodal root length (cm), TRL = Total root length (cm), RLD = Root length density, SRL = Seminal root length (cm), RV = Root volume. P- Phenotypic G-Genotypic

Table 4: Correlation coefficients (Phenotypic and Genotypic) for yield contributing characters and root traits under transplanted and dry direct sown conditions in rice (*Oryza sativa* L.)

	DFF	PH	PL	EBT	NT/m ²	NFG	TW	SW	NR	RGa	NRL	TRL	RLD	SRL	RV	GYP
DFF	G 1.0000	0.2902	0.5703*	0.4136**	0.3137*	-0.1369	-0.4491**	-0.1893	-0.0354	-0.0938	0.1265	0.2827	-0.4106**	0.0016	0.5226**	0.4552**
P	1.0000	0.2675	0.4298**	0.3541*	0.0800	-0.1171	-0.4215**	-0.1729	-0.0030	-0.0928	0.0666	0.0662	-0.3869**	-0.0100	0.2420	0.2669
PH	G 0.2528	1.0000	0.5160*	0.4347**	0.1615	0.3833*	-0.2433	-0.1454	-0.3794*	-0.2798	-0.3997*	0.3300	-0.2292	0.5176**	0.6098**	0.5101**
P	0.0878	1.0000	0.3643**	0.3038*	0.0877	0.3597*	0.2461	-0.1189	-0.2958*	-0.2164	-0.1977	0.1383	0.2180	0.4770**	0.3522*	0.3338*
PL	G 0.1707	0.9205**	1.0000	0.5960**	0.4746**	0.4679**	-0.1726	-0.5435**	-0.0788	0.1352	0.2248	0.5630**	-0.4561**	-0.1554	0.8471**	0.6867**
P	0.1263	0.6329**	1.0000	0.5788**	0.1363	0.3901**	-0.1063	-0.3817**	-0.1323	-0.0115	0.3298*	0.5305**	-0.3387*	-0.0821	0.5316**	0.6442**
EBT	G 0.1674	0.2805	-0.1598	1.0000	0.9502**	0.0279	-0.2553	-0.4772**	-0.4675**	-0.1512	-0.1179	0.8030**	0.0287	-0.1984	0.6714**	0.6982**
P	0.0957	0.1074	0.1150	1.0000	0.1981	-0.0048	-0.1656	-0.3895**	-0.2204	-0.2670	0.0196	0.4286**	-0.0266	-0.1427	0.2714	0.5217**
NT/m ²	G -0.1422	0.1235	0.4827*	-0.1487	1.0000	-0.3076	-0.1815	-0.5345**	-0.8239**	0.3046*	-0.4096**	0.4288**	-0.2454	-0.0875	0.3692	0.0956
P	-0.0126	0.0873	0.1657	-0.1039	1.0000	-0.1446	-0.1123	-0.2443	-0.2959*	0.1309	-0.2446	0.0511	-0.1530	0.0011	0.0352	0.0945
NFG	G -0.4181*	0.8780**	0.6722**	-0.4983*	0.0032	1.0000	0.0511	-0.1957	-0.3076*	-0.1830	0.5018*	0.6541**	-0.2616	-0.0820	0.7863**	0.5514**
P	-0.1959	0.5790**	0.5876**	-0.1455	0.0976	1.0000	0.0407	-0.1796	-0.2954*	0.0374	0.4272**	0.3649*	-0.2694	-0.0358	0.5052**	0.4037**
TW	G -0.5855**	-0.2101	-0.1674	0.0927	-0.2970	0.3359*	1.0000	0.1192	0.3528	0.2912	0.0590	0.2997	0.1215	-0.2738	0.1782	0.1619
P	-0.5419**	-0.1279	-0.0991	0.0606	-0.2426	0.1333	1.0000	0.1184	0.2416	0.2088	0.0497	0.1596	0.1187	-0.2420	0.0959	0.1420
SW	G 0.0098	-0.5356**	-0.5677**	0.1438	0.0743	-0.6284**	-0.1448	1.0000	0.4203**	0.1969	-0.5913**	-0.5432**	-0.1424	-0.2269	-0.2090	-0.5487**
P	0.0107	-0.3232*	-0.2949*	0.0834	0.0716	-0.2174	-0.1514	1.0000	0.2763	0.1634	-0.3504*	-0.2307	-0.1432	-0.2160	-0.0459	-0.3415*
NR	G -0.6780**	-0.2503	-0.2149	-0.2838	-0.2708	0.6999**	0.8544**	-0.0736	1.0000	0.5034**	0.2864	-0.0976	0.1204	0.0263	-0.3689*	-0.1468
P	-0.4947**	-0.0991	-0.0455	-0.1854	-0.1388	0.1821	0.6454**	-0.0651	1.0000	-0.0040	0.0118	-0.0998	0.1007	-0.1102	-0.1171	-0.1119
RGa	G -0.4049*	-0.5042*	-0.1809	-0.4225*	-0.1018	0.1485	0.3492*	-0.4543*	0.4546**	1.0000	0.0266	-0.2143	-0.4622*	-0.3796*	0.1092	-0.2070
P	-0.2598	-0.2344	-0.0329	-0.3279*	0.0217	0.0899	0.3269*	-0.3832*	0.3404*	1.0000	-0.0203	-0.1795	-0.3433*	-0.2060	0.1464	-0.1739
NRL	G -0.0660	-0.8218**	-0.4614*	-0.1251	0.3150*	-0.7575**	-0.0606	0.4874**	0.0558	0.0766	1.0000	0.0198	-0.0068	-0.3393	0.0791	0.1770
P	-0.1112	-0.2361	-0.2316	-0.2673	0.0881	-0.2506	0.0077	0.3498*	-0.0029	0.1297	1.0000	0.5133**	-0.0330	-0.1214	0.3244*	0.5318**
TRL	G -0.1900	0.6825**	0.3376*	0.6501**	0.2322	0.5016**	0.2168	-0.2585	0.0115	-0.1959	-0.4824**	1.0000	0.3599*	-0.2506	0.6994**	0.8987**
P	-0.0610	0.6307**	0.3746*	0.2803	0.1325	0.3438*	0.1755	-0.2329	0.0194	-0.1334	-0.2303	1.0000	0.1555	-0.0752	0.4489**	0.8358**
RLD	G -0.2361	0.5528**	0.5498**	-0.0700	0.1000	0.8323**	0.3829	-0.8854**	0.2966	0.4657**	-0.4793**	0.6001**	1.0000	0.3141	-0.7910**	-0.1723
P	-0.1851	0.3461*	0.2891	0.0110	0.0421	0.3370*	0.3333*	-0.8482**	0.2217	0.3739*	-0.3053*	0.4644**	1.0000	0.2852	-0.4969**	-0.1110
SRL	G -0.3892	0.3060	0.2561	-0.1473	0.1490	0.3662*	0.0788	-0.6746**	0.1097	0.2968*	-0.0517	0.2010	0.6140**	1.0000	-0.4404**	-0.0926
P	-0.3358*	0.2090	0.2072	-0.1606	0.1044	0.1905	0.0643	-0.6408**	0.1130	0.2956*	-0.0090	0.1819	0.5669**	1.0000	-0.3073*	-0.0450
RV	G 0.1140	0.6800**	0.5309*	0.2651	-0.0315	0.6955**	0.1683	0.0809	-0.1756	-0.1212	-0.3954*	0.6196**	0.1381	-0.2259	1.0000	0.9233**
P	-0.0033	0.3908**	0.4241**	0.0879	0.0953	0.3506*	0.1040	0.0306	-0.1135	-0.0821	-0.2479	0.3733*	0.0206	-0.0874	1.0000	0.6257**
GYP	G 0.2953	0.9293**	0.6439**	0.4724**	-0.2843	0.5294*	0.2371	-0.6095*	-0.0051	-0.2090	-0.6735**	0.7113**	0.7196**	0.1407	0.6455**	1.0000
P	0.1707	0.7583**	0.6545**	0.2617	-0.0105	0.5696**	0.1669	-0.3754*	-0.0349	-0.0878	-0.2681	0.6941**	0.4048**	0.1171	0.5956**	1.0000

* Significant at 5% level ** Significant at 1% level

DFF = Days to 50 per cent Flowering, PH = Plant Height (cm), PL = Panicle Length (cm), EBT/plot = Ear Bearing Tillers per plant, NT/m² = No. of tillers/m², NFG/panicle = No. of Filled grains per panicle, TW = Test weight, GY(Kg)/plot = Grain yield (Kg) per plot, SW = Stem width (mm), NR = No. of nodal roots, RGA (Degree) = Root growth angle (Degree), NRL = Nodal root length (cm), TRL = Total root length (cm), RLD = Root length density, SRL = Seminal root length (cm), RV = Root volume, P- Phenotypic G-Genotypic

The estimates of phenotypic correlation for all the characters under study were higher than the estimates of genotypic correlation. From the correlation studies it may be concluded that yield contributing characters *viz.*, days to 50 per cent flowering ($rg=0.4552$ and $rp=0.2669$), plant height ($rg=0.5101$ and $rp=0.3338$), panicle length ($rg=0.6867$ and $rp=0.6442$), ear bearing tillers per plant ($rg=0.6982$ and $rp=0.5217$), number of filled grains per panicle ($rg=0.5514$ and $rp=0.4037$), nodal root length ($rg=0.1770$ and $rp=0.5318$), total root length ($rg=0.8987$ and $rp=0.8358$) and root volume ($rg=0.9233$ and $rp=0.6257$) were positively correlated with grain yield per plot under transplanted conditions indicating that the above traits can be considered for improvement of grain yield. Under dry direct sown conditions, characters *viz.*, plant height ($rg=0.9293$ and $rp=0.7583$), ear bearing tillers per plant ($rg=0.4724$ & $rp=0.2617$), panicle length ($rg=0.6439$ and $rp=0.6545$), number of filled grains per panicle ($rg=0.5294$ and $rp=0.5696$), total root length ($rg=0.7113$ and $rp=0.6941$), root length density ($rg=0.7196$ and $rp=0.4048$) and root volume ($rg=0.6455$ and $rp=0.5956$) were positively correlated with grain yield per plot indicating that these traits can be considered for improvement of grain yield. Stem width was negatively correlated with grain yield per plot under both transplanted and dry direct sown conditions. Days to 50 per cent flowering exhibited negative and significant association with test weight ($rg=-0.4491^{**}$ and $rp=-0.4215^{**}$ and $rg=-0.5855^{**}$ and $rp=-0.5419^{**}$) under both transplanted and dry direct sown conditions respectively suggesting that the genotypes with short duration recorded more test weight in this study. Earlier studies by Deepthi *et al.*, (2022), Heera *et al.*, (2023), Farheen *et al.*, (2023) and Satish Chandra *et al.*, (2024) are in accordance with the present results. Positive correlation of grain yield with total root length and root volume were previously reported by Yogameenakshi *et al.*, (2012) and Quadri *et al.*, (2023). Among the root traits, nodal root length, total root length and root volume

were positively correlated with each other and can be improved simultaneously whereas root length density and seminal root length were negatively correlated with each other under transplanted conditions. Under dry direct sown conditions, among the root traits, total root length, root length density and root volume were positively correlated with each other and can be improved simultaneously. Whereas negative and significant association was observed between nodal root length with total root length, root length density and root volume. Under both transplanted and direct sown conditions total root length has positive and significant relationship with root volume and grain yield indicating the scope for simultaneous improvement. Positive and significant relationship of total root length and root volume with grain yield was previously reported by Yogameenakshi *et al.*, (2012), Haider *et al.*, (2012) and Quadri *et al.*, (2023).

From PCA analysis genetic divergence was assessed for yield and root characters in 15 genotypes to identify diverse germplasm by using Principal Component Analysis (PCA). The first principal component explained 50.769 per cent while, the second, third and fourth principal component explained 22.52 per cent, 13.44 per cent and 8.95 per cent variability, respectively among the genotypes for the traits under transplanted conditions (**Figure 1**). The first principal component explained 41.042 per cent while, the second, third and fourth principal component exhibited 28.60 per cent, 12.29 per cent and 8.67 per cent variability, respectively among the germplasm lines for the traits under dry direct sown conditions (**Figure 2**). A perusal of the results revealed that BPT 5204, BPT 2766, BPT 3061 and BPT 3291 are most divergent genotypes according to PCA biplot analysis under transplanted conditions. Hence, hybridization between these diverse genotypes may result in isolation of transgressive segregants with higher grain yield, higher total root length, and more root volume. Under dry direct sown conditions,

BPT 3061, BPT 2766, BPT 3082 and BPT 2841 were identified as diverse genotypes for most of the yield components and root traits. Hence, using these genotypes in hybridization programme may result in the development and selection of genotypes with higher grain yield, and desirable root traits *viz.*, total root length, root volume, nodal root length and thus making the isolated selected genotypes suitable for dry direct sown conditions.

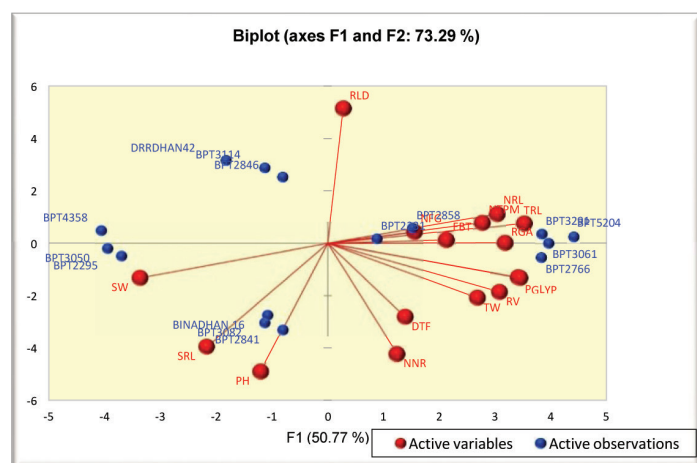


Figure 1: Biplot graph of different traits for first two principal components under transplanted conditions

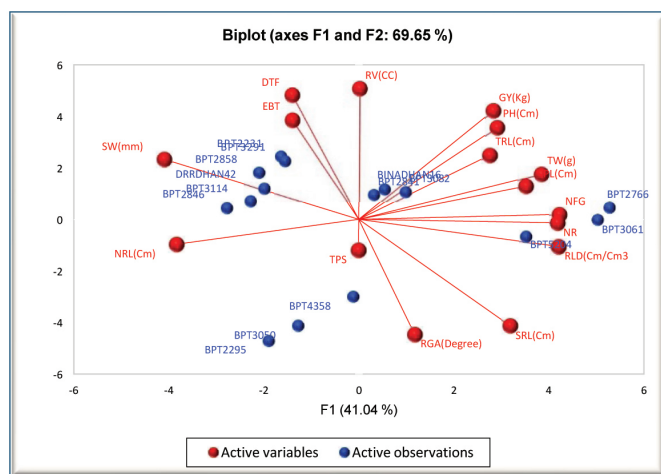


Figure 2: Biplot graph of different traits for first two principal components under dry direct sown conditions

Conclusion

From the present study, it may be concluded that BPT 3050, BPT 3114, BPT 2846 and BPT 2766 recorded high grain yield under both transplanted and dry direct sown conditions. These genotypes also

manifested superior values for yield components and desirable root characters. Hence, all these genotypes may be recommended for dry direct sown conditions. BPT 3050 and BPT 2846 were released varieties and can be popularized under dry direct sown conditions. The other genotypes *viz.*, BPT 3114 and BPT 2766 are advanced breeding lines. These two genotypes may be evaluated under multilocation testing in future for identification of their stability in different locations.

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Zinc and Iron Management in Different Basmati (*Oryza sativa* L.) Varieties under Un-puddled Conditions

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Abstract

A field experiment was carried out at Student's Farm, Khalsa College, Amritsar during *kharif* season, 2023 to study effect of zinc and iron management in different Basmati (*Oryza sativa* L.) varieties under un-puddled conditions. The field experiment was laid out in Split plot design having three varieties *i.e.*, V₁ (Pusa Basmati 1509), V₂ (Pusa Basmati 1847) and V₃ (Punjab Basmati 7) in main plot and four different micronutrient applications *i.e.*, T₁ (control), T₂ (FeSO₄ @ 1%), T₃ (ZnSO₄ @ 25 kg acre⁻¹), T₄ (FeSO₄ @ 1% + ZnSO₄ @ 25 kg acre⁻¹) in sub-plot. The results revealed that the highest plant height (102.2 cm) was recorded in V₂, while leaf area index (3.53), dry matter accumulation (117.1 q ha⁻¹) and number of tillers m⁻² (283) were recorded highest in V₃. Also, the highest yield attributes *i.e.*, effective tillers m⁻² (268), number of filled grains panicle⁻¹ (85.8), grain yield (45.3 q ha⁻¹), straw yield (66 q ha⁻¹) and harvest index (40.7%) were observed under V₃. The highest B:C ratio was found in V₁ (2.74). Among micronutrient application, T₄ recorded highest growth attributes *i.e.*, plant height (108.3 cm), leaf area index (3.5), dry matter accumulation (121 q ha⁻¹) and number of tillers m⁻² (293). Also, highest yield attributes *i.e.*, effective number of tillers m⁻² (270), number of filled grains panicle⁻¹ (87.3), panicle length (26.5cm), 1000 grain weight (23.9), grain yield (45.5q ha⁻¹), straw yield (66 q ha⁻¹) and harvest index (40.7) were observed under T₄. The highest B:C ratio (2.83) was observed in T₂. These findings demonstrate that application of zinc and iron can significantly improve yield of rice under un-puddled conditions.

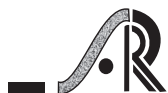
Keywords: Zinc and Iron management, un-puddled, rice, Basmati varieties, micronutrients.

Introduction

Rice (*Oryza sativa* L.) is a major cereal crop and nutritionally staple food consumed by half of the world's population (Barua and Saikia, 2018). It is mostly cultivated by transplanting the seedlings in puddled conditions that involves the creation of anaerobic environment through continuous submergence of rice fields. The various adverse effects associated with this method include poor soil structure, inefficient water use and more methane emission. All

these factors have led to need of cultivation of rice under un-puddled conditions. It involves ploughing and planking of dry soil so that soil become compact and then transplanting of seedlings is done in moist soil conditions. This method can be considered as feasible option to save water and prevent adverse effects of puddling.

The production factors such as selection of a variety plays an important role in enhancing the productivity



of rice. Certain rice varieties are better adapted to certain crop setup methods and farmer management approaches (Adilakshmi *et al.*, 2022). Rice is available in 5000 varieties, of which Basmati rice occupies special status and is known as the 'Queen of Rice'. Punjab Basmati 7, Pusa Basmati 1847 and Pusa Basmati 1509 are semi-dwarf varieties having extra-long grains with excellent cooking and eating quality characters. Punjab Basmati 7 and Pusa Basmati 1847 are resistant to all ten types of bacterial blight pathogens (Anonymous, 2024). Several researchers reported significantly different responses of different genotypes to various management variables and environments with respect to the growth attributes due to inherent characteristics. It is essential to harness the potential of different basmati varieties under unpuddled conditions to evaluate their performance.

As a result of the green revolution in developing countries like India, agricultural produce failed to meet up zinc and iron requirements for human nutrition (Rao *et al.*, 2019). Micronutrient malnutrition has been designated as the most serious challenge to humanity. Also, deficiency of micronutrients is of major concern under unpuddled conditions. Availability of zinc is reduced because of reduced release of zinc from highly insoluble fractions in aerobic conditions (Abdullah, 2015) and iron may become limiting because of oxidation of iron from ferrous to ferric form which are less soluble and not easily available to plants (Yadav *et al.*, 2013). Though number of literature on zinc and iron dynamics in puddled rice conditions are available but to the best of our knowledge, the study on the effect of zinc and iron on growth and production of rice under unpuddled conditions is limited. Keeping this into consideration, the present study entitled, "Zinc and iron management in different Basmati (*Oryza sativa* L.) varieties under unpuddled conditions" was undertaken.

Materials and Methods

The field experiment was carried out during *kharif* season, 2023 at the student's research farm, Khalsa

College, Amritsar [31.63°N latitude and 74.83°E longitude]. The soil of experimental field was sandy loam with soil pH 8.1, low in available nitrogen (195 kg/ha), low in available phosphorus (18 kg/ha), medium in available potassium (263 kg/ha), low in available zinc (0.44 mg/kg) and high in available iron (9.8 mg/kg).

The experiment was laid out in split plot design comprising three varieties V_1 (Pusa Basmati 1509), V_2 (Pusa Basmati 1847) and V_3 (Punjab Basmati 7) in main plot and four micronutrient treatments T_1 (control- no zinc and iron), T_2 (foliar application of FeSO_4 @ 1% at 20 days after transplanting), T_3 (soil application of ZnSO_4 @ 25 kg/acre at transplanting) and T_4 (foliar application of FeSO_4 @ 1% at 20 days after transplanting + soil application of ZnSO_4 @ 25 kg/acre at transplanting) in subplots with three replications.

For sowing, nursery field was ploughed twice with disc harrow and cultivated twice with tractor drawn cultivator followed by heavy planking to make soil compact. The basmati varieties were sown on 15 June and were transplanted on 15 July with spacing of 20 x 15 cm. Light irrigation was applied to the main field before transplanting. Recommended dose of fertilizers (N @ 105 kg/ha and P @ 30 kg/ha) was applied to the crop. Nitrogen was applied through urea in two equal splits at 21 days and 42 days after transplanting. Phosphorus was applied as single super phosphate before transplanting. Whole of ZnSO_4 (21%) @ 25 kg/acre was applied as basal dose and FeSO_4 @ 1% was applied as foliar application @ 20 days after transplanting. Plant height, leaf area index, number of tillers m^{-2} and dry matter accumulation were recorded at harvest by randomly selecting five plants in each experimental unit. Plant height was measured from ground level to the tip of panicle and expressed in centimeters. Dry matter accumulation was recorded by randomly selecting five plants that were sundried for three days and then oven dried at 60°C till constant weight was obtained and data was

expressed as q/ha. Leaf area index was calculated using leaf area meter. Total number of tillers and number of effective tillers m^{-2} were counted from five randomly selected plants and were expressed as tillers m^{-2} and panicles m^{-2} . Five plants were randomly selected from each experimental unit for recording panicle length, number of grains panicle⁻¹. To obtain 1000 grain weight, 1000 grains were counted and weighed on electronic balance. Grain yield was recorded from each plot and expressed as q/ha. The weight of straw from each plot was also recorded three days after harvest for estimation of straw yield, which was expressed as q/ha. Data was subjected to analysis of variance using OP stat. Economics of different treatments were calculated by taking into account cost of inputs and price of outputs in local market and benefit: cost ratio was calculated by dividing net returns with variable cost.

Results and Discussion

Effect of varieties and micronutrient application on growth characters of rice

Plant height, leaf area index, number of tillers and dry matter accumulation were significantly influenced by basmati varieties and micronutrient applications. (Table 1) depicted that among varieties, the highest plant height (104.5 cm) was recorded in V2 (Pusa Basmati 1847) which was statistically at par with V3 (Punjab Basmati 7), however both were significantly higher than V1 (Pusa Basmati 1509). The highest leaf area index (3.5), number of tillers m^{-2} (283) and dry matter accumulation (117.1 q/ha) were recorded in V3 (Pusa Basmati 7) which was statistically at par with V2 (Pusa Basmati 1847), and both were significantly higher than V1 (Pusa Basmati 1509) which recorded lowest values of these parameters. This

might be due to genetic variation in characters of the variety. These results are in conformity with Maurya *et al.*, (2021). Among micronutrient application, T4 (foliar application of FeSO_4 @ 1% at 20 days after transplanting + soil application of ZnSO_4 @ 25 kg/acre at transplanting) recorded highest plant height (108.3 cm), leaf area index (3.5), number of tillers m^{-2} (293) and dry matter accumulation (121.7 q/ha) which was statistically at par with T3 (soil application of ZnSO_4 @ 25 kg/acre at transplanting), however, both the treatments were significantly higher than control which recorded lowest values of all these parameters. Highest growth attributes in T4 might be due to effect of increased photosynthetic process, chlorophyll synthesis, protein synthesis and nitrogen fixation in response to the application of Zn and Fe (Rao *et al.*, 2019).

Effect of varieties and micronutrient application on yield attributing characters of rice

Number of effective tillers, panicle length, number of grains panicle⁻¹ and thousand grain weight were significantly influenced by basmati varieties. (Table 2) depicted that among varieties, the highest number of effective tillers⁻² (268) and the number of grains panicle⁻¹ (85.8) were recorded in V3 (Punjab Basmati 7) which was statistically at par with V2 (Pusa basmati 1847), however, both were significantly higher than V1 (Pusa Basmati 1509). The highest panicle length (25.8 cm) and thousand-grain weight (24.1) were recorded in V2 (Pusa Basmati 1847) which was statistically at par with V1 (Pusa Basmati 1509), both being significantly better than V3 (Punjab Basmati 7). This might be due to genetic makeup of varieties. Tefera *et al.*, (2019) also reported similar results.

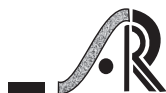


Table 1: Effect of varieties and micronutrient application on plant height, leaf area index, dry matter accumulation and tillers m⁻²

Treatments	Plant height (cm)	Leaf area index	Dry matter accumulation (q/ha)	Tillers m ⁻²
Varieties				
V1 (Pusa Basmati 1509)	93.08	2.80	97.37	255
V2 (Pusa Basmati 1847)	104.5	3.42	111.1	275
V3 (Punjab Basmati 7)	102.2	3.53	117.1	283
C.D.(0.05)	8.95	0.26	12.30	19.6
Micronutrients application				
T1 (Control)	92.88	3.03	96.42	250
T2 (Foliar application of FeSO ₄ @ 1%)	95.33	3.12	101.9	261
T3 (Soil application of ZnSO ₄ @ 25 kg acre ⁻¹)	103.3	3.38	114.6	280
T4 (Foliar application of FeSO ₄ @ 1% + Soil application of ZnSO ₄ @ 25 kg acre ⁻¹)	108.3	3.50	121.7	293
C.D. (0.05)	7.59	0.22	11.17	17.6
Interaction	NS	NS	NS	NS

Table 2: Effect of basmati varieties and micronutrient application on effective number of tillers m⁻², number of filled grains panicle⁻¹, panicle length, 1000 grain weight, grain yield, straw yield, and harvest index

Treatments	Effective number of tillers m ⁻²	Number of filled grains panicle ⁻¹	Panicle length (cm)	1000 grain weight (gm)	Grain yield (q ha ⁻¹)	Straw Yield (q ha ⁻¹)	Harvest Index (%)
Varieties							
V1 (Pusa Basmati 1509)	243	75.1	25.1	23.8	40.11	58.5	40.62
V2 (Pusa Basmati 1847)	259	82.4	25.8	24.1	43.80	63.8	40.65
V3 (Punjab Basmati 7)	268	85.8	23.7	22.4	45.35	66.0	40.74
C.D.(0.05)	15.7	6.74	1.19	1.01	1.99	3.22	NS
Micronutrients application							
T1 (Control)	244	75.2	23.3	23.1	39.03	58.0	40.19
T2 (Foliar application of FeSO ₄ @ 1%)	249	78.1	24.0	23.3	41.35	60.1	40.77
T3 (Soil application of ZnSO ₄ @ 25 kg acre ⁻¹)	264	83.8	25.5	23.5	44.83	65.0	40.84
T4 (Foliar application of FeSO ₄ @ 1% + Soil application of ZnSO ₄ @ 25 kg acre ⁻¹)	270	87.3	26.5	23.9	47.15	68.2	40.88
C.D. (0.05)	12.7	4.8	1.41	NS	2.96	4.91	NS
Interaction	NS	NS	NS	NS	NS	NS	NS

Results revealed that except for thousand grain weight, all other yield attributes were significantly influenced by micronutrient application. The highest values of number of effective tillers, panicle length and number of grains panicle⁻¹ were recorded with T4 (foliar application of FeSO₄ @ 1% at 20 days after transplanting + soil application of ZnSO₄ @ 25 kg/acre at transplanting) which was statistically at par with T3 (soil application of ZnSO₄ @ 25 kg/

acre at transplanting), however, both treatments were significantly higher than control which recorded the lowest values. Highest number of effective tillers might be due to improved metabolic activity with micronutrients that enhanced floral primordia development in many tillers (Janardhan *et al.*, 2019). Higher value of panicle length might be due to increased transportation of photosynthates from source to sink due to application of zinc (Jena *et al.*,

2006). Higher number of filled grains might be due to increased synthesis of carbohydrates and their transport to the site of grain formation (Barua and Saikia, 2018).

Effect of varieties and micronutrient application on grain yield, straw yield and harvest index of rice

Results further depicted that among the varieties, highest grain yield (45.3 q/ha), straw yield (66 q/ha), and harvest index (40.7%) were recorded in V3 (Punjab Basmati 7), which was statistically at par with V2 (Pusa Basmati 1847), and both were significantly higher than V1 (Pusa Basmati 1509), which recorded lowest values. The variation in the yield might be due to the variation in yield components *viz.*, number of panicles, number of filled grains, leaf area index etc. These results were in conformity with Rehman *et al.*, (2011). **(Table 2)** further showed that in the case of micronutrient application, the highest grain yield (47.1 q/ha), straw yield (68.2 q/ha) and harvest index (40.9%) were obtained with T4 (foliar application of FeSO₄ @ 1% at 20 days after transplanting + soil application of ZnSO₄ @ 25 kg/acre at transplanting) which was statistically at par with T3 (soil application of ZnSO₄ @ 25 kg/acre at transplanting), both were significantly higher than T2 (foliar application of FeSO₄ @ 1% at 20 days after transplanting) and T1 (control). Treatment T1 (control) recorded the lowest grain, straw yield and harvest index. This could be because the micronutrient application was not done, which reflected in the soil's extremely low capacity to support growth and yield characteristics. Qureshi *et al.*, (2018) reported similar outcomes of unfortified plots with lower productive parameters in rice. The increased yield due to zinc and iron application was attributed to better performance of crop growth and yield parameters through adequate availability of major and minor micronutrients in the soil, which in turn, favourably influenced physiological processes and buildup of photosynthates (Tabassum *et al.*, 2013).

Effect of varieties and micronutrient application on economic analysis of rice

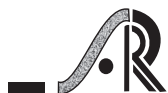
(Table 3) showed that the highest gross returns, net returns and highest B:C ratio were observed under V1 (Pusa Basmati 1509) followed by V3 (Punjab Basmati 7) and V2 (Pusa Basmati 1847). Among the micronutrient applications, the highest gross returns and net returns were observed under T4 (foliar application of FeSO₄ @ 1% at 20 days after transplanting + soil application of ZnSO₄ @ 25 kg/acre at transplanting) and the highest B:C ratio was observed under T2 (foliar application of FeSO₄ @ 1% at 20 days after transplanting).

Table 3: Effect of varieties and micronutrient application on economic analysis of rice

Treatments	Gross returns (Rs ha ⁻¹)	Net returns (Rs ha ⁻¹)	B:C ratio
Varities			
V1 (Pusa Basmati 1509)	149385	109469	2.74
V2 (Pusa Basmati 1847)	135780	96364	2.44
V3 (Punjab Basmati 7)	140585	101669	2.61
Micronutrients application			
T1 (Control)	128799	93883	2.68
T2 (Foliar application of FeSO ₄ @ 1%)	136455	100839	2.83
T3 (Soil application of ZnSO ₄ @ 25 kg acre ⁻¹)	147939	107398	2.60
T4 (Foliar application of FeSO ₄ @ 1% + Soil application of ZnSO ₄ @ 25 kg acre ⁻¹)	155595	114354	2.77

Conclusion

On the basis of the present investigation, it can be concluded that the variety, V₃ (Punjab Basmati 7) and micronutrient treatment, T₄ (combined application of FeSO₄ @ 1% as foliar + ZnSO₄ @ 25 kg/acre as soil application) gives highest yield. But in terms of highest benefit:cost ratio, variety V₁ (Pusa Basmati 1509) and micronutrient treatment T₂ (Foliar application of FeSO₄ @ 1%) are best suited due to dynamic market prices.



Author's contribution

Conceptualization of the research work and designing of experiments by Gurinderjit Kaur, Gurkirat Singh Aulakh; Execution of field/lab experiments data and data collection by Sumeet Kaur and Sumandeep; Analysis of data and interpretation by Sumeet Kaur, Gurinderjit Kaur and Gurkirat Singh Aulakh; Preparation of manuscript by Sumeet Kaur and Sumandeep.

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Enhancing Water Use Efficiency and Yield of Un-puddled Transplanted Basmati Rice (*Oryza sativa* L.) through Green Manuring and Irrigation Scheduling

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Abstract

The declining water table, deteriorating soil health, and low water use efficiency are major challenges to the sustainability of rice-based cropping systems. The study on water-use efficiency and yield of un-puddled transplanted basmati rice (UPTR) (*Oryza sativa* L.) under green manuring and irrigation scheduling was conducted at Khalsa College, Amritsar, during the *kharif* season in 2024. The experiment was arranged in a split-plot design, with three green manuring treatments in the main plot *i.e.*, control (G_0), green manuring with *dhaincha* (G_1), and with cowpea (G_2), and five irrigation schedules in sub-plot, *i.e.*, I_0 : puddled transplanted rice (PTR) + 15 days ponding + alternative wetting and drying (AWD), I_1 (UPTR+ 15 days ponding + AWD), I_2 (UPTR+irrigation at 3mm CPE), I_3 (UPTR+irrigation at 5mm CPE), and I_4 (UPTR+irrigation at 7mm CPE) and replicated thrice. Higher growth and yield parameters and economics were observed in G_1 , followed by G_2 , and the lowest were in G_0 . Among irrigation schedules, I_2 showed the highest growth attributes, grain yield (7570 kg ha^{-1}), biological yield (18680 kg ha^{-1}), and economics, followed by I_1 and I_0 . Wider irrigation intervals (I_3 and I_4) reduced growth and yield attributes. Water productivity was the highest in I_2 and I_1 . Treatments I_0 and I_1 remain at par in grain yield, but water consumption in I_0 was higher, indicating water conservation in I_1 without reduction in yield. Interactions between green manuring and irrigation scheduling show that the combinations of green manures with I_2 at UPTR improve water use efficiency and water productivity.

Keywords: Water use efficiency, UPTR, PTR, CPE and AWD

Introduction

Rice is the staple food for more than half of the world's population. Rice (*Oryza sativa* L.) belongs to the Poaceae family and the Bambusoideae sub-family. Over 90 per cent of the world's rice is produced in Asia. India leads the world with an average annual production of approximately 150 million metric tonnes, followed by China with 145.3 million metric tonnes (USDA, 2025). Mainly, three states produce nearly 36 per cent of India's total rice, 1378.25 lakh tonnes from 478.3 lakh ha area. Telangana (12.24%) followed by Uttar Pradesh (11.60%) and West Bengal (11.38%) (DES, 2025). Punjab ranks fourth with a total production of 214.26 lakh tonnes from an area

of 31.79 lakh ha during 2023-24 (PAU, 2025).

With declining ground water levels, rice sustainability is dwindling (Dhillon and Mangat, 2018). Punjab's 75 per cent of land is under rice cultivation, which requires 140 to 160 cm of irrigation water (Humphreys *et al.*, 2010; Dhanda *et al.*, 2022). PTR method of rice cultivation is very common in Punjab. The ill effects of this method challenge the sustainability of rice through soil physical, chemical, and biological properties. In addition, it also contributes to global warming through methane gas emissions. In contrast, UPTR, direct seeding of rice (DSR), and



system of rice intensification (SRI) have emerged as promising alternative aerobic methods that save irrigation water, improve soil health, increase groundwater recharge, are environmentally friendly, and economically viable (Kaur and Singh, 2017). The soil environment in un-puddled transplanting rice remains similar to that of direct-seeded rice and has the potential for labour saving, reduced water use, reduced methane emissions, resolution of edaphic conflicts, and decreased crop maturity period (Balarajan *et al.*, 2025). In unpuddled transplanting similar to the SRI technique of rice establishment, young-age nursery can be transplanted without mortality (Uphoff, 2024). Further, alternative to ponding of water AWD method of irrigation reduces water consumption while sustaining crop production. Studies show that AWD technique uses less water than the traditional method of continuous flooding (Brar *et al.*, 2018). In north India sufficient turnover period between wheat and basmati rice provides a window for *in situ* green manuring of legume crops. Green manures like *Sesbania*, being leguminous in nature, can add a substantial amount of nitrogen required for rice, as well as adding organic matter to maintain soil fertility and improve the water-holding capacity of soil, and green manures extract nutrients from deeper layers, thereby letting the succeeding crop extract nutrients from the surface layers (Pramanik *et al.*, 2004). Reduction in the use of nitrogen fertilizers and their risks of leaching are additional benefits of green manuring. *Dhaincha*, a leguminous green manuring crop, has the capacity to fix atmospheric nitrogen, reduce bulk density, and increase water-stable aggregates and total pore space by the addition of organic matter (Boparai *et al.*, 1992). Taking the above points into consideration, this investigation was carried out to identify an appropriate combination of irrigation scheduling with crop establishment method and green manuring practice for the development of a sustainable and resource-efficient rice production system.

Materials and Methods

The experimental study was carried out during the *kharif* season in 2024 at Khalsa College, Amritsar, Punjab, which is located at a latitude of 31.63° N, longitude 77.87° E, and 234 m above sea level. The maximum temperature of 40.81°C was recorded during the 29th standard meteorological week of July, and the minimum temperature of 18.57°C was recorded during the 43rd standard meteorological week of October, 2024. The total rainfall during the crop season was recorded as 563.3 mm. The soil in the experimental field has a sandy loam texture, pH 8.2, electrical conductivity 0.29 mhos cm⁻², organic carbon 0.36% (low), available nitrogen 192 kg ha⁻¹ (low), phosphorus 17 kg ha⁻¹ (medium), and potassium 265 kg ha⁻¹ (medium).

A split-plot design was used for the experiment, with three replications. The experiment comprises three green manuring treatments: G₀ (Control), G₁ (*Dhaincha*) and G₂ (Cowpea) in the main plot, and five irrigation schedules: I₀ (PTR+ 15 days ponding + AWD), I₁ (UPTR+ 15 days ponding + AWD), I₂ (UPTR+ irri. at 3mm CPE), I₃ (UPTR+ Irr. at 5mm CPE), and I₄ (UPTR+ IRR. at 7mm CPE) in subplot *kharif* rice Pusa Basmati 1692 (*Oryza sativa* L.), was grown following the package of practices except the treatment selected.

Green manuring crops were sown on 25 May; two irrigations were applied as per requirement and incorporated at 45 days after sowing. Nursery of Pusa Basmati 1692 was sown on the 10th of June after seed treatment. Seedlings of 25 days were uprooted on the 11th of July for transplanting at a spacing of 20×15 cm. In control plots (G₁), the recommended dose of urea (54 kg acre⁻¹) was applied in two equal splits at 21 and 42 days after transplanting. In G₁ and G₂ treatments, 75% of the recommended doses of urea were applied (40.5 kg ha⁻¹). Zinc sulfate heptahydrate (21% Zn) was applied at 25 kg acre⁻¹. Irrigations were applied according to the irrigation treatments. Periodic and final data were recorded and analysed for different indices, *i.e.*

Harvest index: Harvest index was computed using the formula given below;

$$\text{Harvest Index} = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}} \times 100$$

Amount of irrigation water applied from transplanting to harvesting (mm): Irrigation water applied from transplanting to harvest of crop per irrigation (IW) was calculated by multiplying the discharge rate (Q) by the time taken (T) for irrigating the plots and dividing by the area of the plots (A). The total amount of irrigation water during the growing season was calculated by summing the total amount of irrigation water applied during each irrigation in mm. It was calculated in mm. The discharge rate was 8.5 litre/sec, fixed for a particular water source.

$$IW = \left(\frac{Q \times T}{A} \right)$$

Total water input (mm): The total water expense was calculated as the sum of irrigation water applied to the nursery, main field, plus total rainfall received during the crop season. It was expressed in mm.

Water productivity (kg grain/mm): Water productivity was calculated by dividing grain yield (kg) by the amount of total water applied (mm). It is expressed as kg grain/mm of water.

$$\text{Water productivity} = \frac{\text{Grain Yield (kg)}}{\text{Total water input (mm)}}$$

Cost of cultivation (Rs ha⁻¹): Cost of cultivation for each treatment was calculated using the cost of different agronomic practices and inputs used in a particular treatment, respectively.

Gross return (Rs ha⁻¹): To calculate gross return, grain yield was multiplied by the market price.

$$\text{Gross return} = (\text{Grain yield} \times \text{Market price}) + (\text{Straw yield} \times \text{Market price})$$

Net return (Rs ha⁻¹): Net returns of different treatments were calculated by subtracting the total cost of cultivation from the gross return.

$$\text{Net return} = \text{Gross return} - \text{Total cost}$$

B: C Ratio: B:C ratios for different treatments were calculated by dividing the total cost of cultivation by the gross return.

$$\text{B:C ratio} = \text{Gross return} / \text{Total cost}$$

Statistical analysis of observations was carried out using OPSTAT software developed by CCS HAU, Hisar. The critical difference (CD) value at a 5 per cent level of significance (*i.e.*, $p=0.05$) was calculated for comparing the treatments.

Results and Discussion

Yields and harvest index

The data shown in (Table 1) revealed that the highest grain (6710 kg ha⁻¹), straw (10270 kg ha⁻¹), and biological yield (16980 kg ha⁻¹) were recorded under *dhaincha* incorporation (G₁), which was statistically higher than control (G₀) but at par with cowpea incorporation (G₂). This may be due to the beneficial effects of Green manures on nitrogen availability and water-holding capacity. Improved nutrient availability during vegetative and reproductive phases was also observed by Gao *et al.*, (2023). Increased plant height, leaf area index, effective tillers m⁻², number of filled grains per panicle, dry matter accumulation, which contributes directly to grain, straw, and biological yield were also reported by Duhan and Singh, (2002). Similar results were observed with the green manure effect on yield by Irin *et al.*, (2020), Song *et al.*, (2024), and Kumar *et al.*, (2025).

Among irrigation schedules, I₂ produced the highest grain (7570 kg ha⁻¹), straw (11110 kg ha⁻¹), and biological yield (18680 kg ha⁻¹), which was statistically higher than I₃ and I₄. In contrast, it was at par with I₁ and I₀. The higher yield under I₂ was attributed to the greater soil moisture availability, which enhanced nutrient uptake, leaf area, photosynthetic rate, tiller survival, assimilates translocation to grain, and grain filling (Kaur and Sharma, 2022). But UPTR with 5 and 7 mm CPE irrigation (I₃ and I₄) showed the lowest grain yields as delayed irrigation caused water stress. Similar results were reported by Sandhu and Mahal

(2014) and Brar *et al.*, (2021) about the reduction in yield caused by delayed irrigation.

The harvest index (HI) does not significantly vary with green manuring and irrigation scheduling. This was due to similar behaviour in biological and grain development. Kumar *et al.*, (2025) also reported similar findings, stating that green manure enhanced total biological yield without significantly affecting

the partitioning of assimilates between grain and straw. In irrigation scheduling, the highest harvest index (40.5%) was reported under UPTR +irrigation at 3 mm CPE (I_2), which was statistically at par with I_0 and I_1 , which were significantly higher than I_3 and I_4 (un-puddled transplanting with 5 and 7 mm CPE irrigation). Nayak *et al.*, (2020) also reported similar results.

Table 1: Effect of green manuring and irrigation scheduling on grain yield, straw yield, biological yield, harvest index, total water input, and water productivity (kg grain mm⁻¹) of basmati rice

Treatment	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest Index (%)	Total water input (mm)	Water productivity (kg grain mm ⁻¹)
Main plot (Green manuring)						
G ₀ (Control)	5920	9540	15460	38.2	1828	3.24
G ₁ (<i>Dhaincha</i>)	6710	10270	16980	39.5	1750	3.83
G ₂ (Cowpea)	6490	9940	16430	39.5	1760	3.69
C.D.(0.05)	306.1	334	714.8	NS	-	0.16
Sub plot (Irrigation scheduling)						
I ₀ (Puddled + 15 days ponding +AWD)	6890	10880	17770	38.7	1851	3.79
I ₁ (Un-puddled+ 15 days ponding +AWD)	6962	10490	17452	39.9	1830	3.85
I ₂ (At 3mm CPE)	7570	11110	18680	40.5	1870	3.85
I ₃ (At 5mm CPE)	5525	8960	14485	38.1	1720	3.28
I ₄ (At 7mm CPE)	4920	8140	13060	37.6	1625	3.18
C.D. (0.05)	282.7	951	927.5	2.0	-	0.19
Interaction (I×G)	NS	NS	NS	NS	-	0.34
Interaction (G×I)	NS	NS	NS	NS	-	0.32

Irrigation water applied from transplanting to harvest

The data presented in (Table 1) show that the control treatment (1828 mm) had the highest total water input, followed by G₂ (1760 mm), and the lowest in G₁ (1750 mm). This difference is due to high organic matter, which affects the moisture-retaining ability of soil in *dhaincha* and cowpea incorporation. In another study, cowpea required more water input than *dhaincha* due to less plant biomass production (Yin *et al.*, 2025). In case of irrigation scheduling, the highest total water input was recorded in I₃, *i.e.*, 1870

mm, followed by I₀ PTR), *i.e.*, 1851 mm, and I₂ (UPTR with 15 days of ponding in AWD), *i.e.*, 1830 mm, and the lowest in irrigation at 7 mm CPE (1625 mm) I₄. Kaur *et al.*, (2024) also reported similar results. The data presented in (Table 2) show the interaction between green manuring and irrigation scheduling. The combination of green manure and un-puddled transplanting with irrigation at 3 mm CPE recorded the highest total water input, *i.e.*, 1915 mm, and the lowest under *dhaincha* and cowpea incorporation under un-puddled transplanting with irrigation at 7 mm CPE (1600 mm) as per irrigation numbers.

Table 2: Total water input to basmati rice as influenced by the interaction between green manuring and irrigation scheduling

Green manuring × Irrigation scheduling	Total water input (mm)					Mean
	I ₀ (Puddled + 15 days ponding+ AWD)	I ₁ (Unpuddled + 15 days ponding+ AWD)	I ₂ (At 3 mm CPE)	I ₃ (At 5 mm CPE)	I ₄ (At 7 mm CPE)	
G ₀ (Control)	1905	1880	1915	1765	1675	1828
G ₁ (<i>Dhaincha</i>)	1810	1800	1845	1695	1600	1750
G ₂ (Cowpea)	1840	1810	1850	1700	1600	1760
Mean	1851	1830	1870	1720	1625	

Water productivity

The water productivity (WP) significantly varied among the green manuring and irrigation scheduling shown (Table 1). The highest WP was recorded under G₁ (3.83 kg grain mm⁻¹), which was statistically significant from the G₀ (3.24 kg grain mm⁻¹) but at par with cowpea incorporation G₂ (3.69 kg grain mm⁻¹). Green manures enhance the water retention capacity of soil, improve the physical properties of soil due to the addition of organic matter. In irrigation scheduling, the highest WP was observed under I₁

and I₂ (3.85 kg grain mm⁻¹), followed by I₀ (3.79 kg grain mm⁻¹), I₃, and the lowest was in I₄. This trend may be due to higher grain yield in these treatments. Nayak *et al.*, (2016) and Kumari *et al.*, (2018) also reported higher WP under such an irrigation schedule. The data presented in (Table 3) show interactions between green manuring and irrigation scheduling. The highest water productivity was observed under the combination of G₁ and I₂ (4.06 kg grain mm⁻¹) and the lowest under control and I₄ (2.68 kg grain mm⁻¹).

Table 3: Water productivity of basmati rice as influenced by the interaction between different green manuring and irrigation scheduling

Green manuring × Irrigation scheduling	Water productivity (kg grain mm ⁻¹)					Mean
	I ₀ (Puddled + 15 days ponding + AWD)	I ₁ (Unpuddled + 15 days ponding+ AWD)	I ₂ (At 3mm CPE)	I ₃ (At 5 mm CPE)	I ₄ (At 7 mm CPE)	
G ₀ (Control)	3.65	3.69	3.51	2.69	2.68	3.24
G ₁ (<i>Dhaincha</i>)	3.93	4.02	4.06	3.66	3.49	3.83
G ₂ (Cowpea)	3.81	3.83	3.98	3.49	3.37	3.69
Mean	3.79	3.85	3.85	3.28	3.18	
Interaction (I×G)	0.34					
Interaction (G×I)	0.32					

Economic Analysis

The highest gross returns and net returns were observed under G₁, and the highest benefit: cost (B:C) ratio was observed under G₀ (Table 4). Among the irrigation schedules, the highest gross returns, net returns, and

B:C ratio were reported under I₂ followed by I₁, I₀, I₃ and I₄, suggesting that un-puddled transplanting can be a more economically viable and resource-efficient practice without significantly compromising yield.

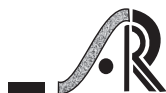


Table 4: Effect of different green manuring and irrigation scheduling on economic analysis of basmati rice

Treatments	Cost of cultivation (Rs ha ⁻¹)	Gross returns (Rs ha ⁻¹)	Net returns (Rs ha ⁻¹)	B:C ratio
Main plots (Green manuring)				
G ₀ (Control)	44,222	207,098	162,876	3.68
G ₁ (<i>Dhaincha</i>)	48,645	226,711	178,065	3.66
G ₂ (Cowpea)	50,895	222,711	171,815	3.38
Sub plots (Irrigation scheduling)				
I ₀ (Puddled + 15 days ponding+ AWD)	51,275	236,888	185,613	3.62
I ₁ (Un-puddled+ 15 days ponding+ AWD)	47,415	238,719	191,303	4.03
I ₂ (At 3mm CPE)	48,540	259,075	210,535	4.34
I ₃ (At 5mm CPE)	46,672	190,310	143,637	3.08
I ₄ (At 7mm CPE)	45,702	169,208	123,505	2.70

Conclusion

Based on the present investigation, it is evident that the growth and yield attributes were higher in G₁(*dhaincha*), which were statistically at par with G₂ (cowpea). In terms of irrigation scheduling, I₂ (3mm CPE) resulted in the best performance across growth, yield parameters and yield. The un-puddled treatment achieved a higher benefit: cost (B: C) ratio than the puddled treatment, indicating that un-puddled transplanting is a more economically viable and resource-efficient practice.

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Soil Quality Index in Rice-Rice Cropping System under Long Term Fertilizer Experiment in Lateritic Soils of Humid Tropics

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Abstract

The Soil Quality Index (SQI) of various nutrient management practices under a rice-rice cropping system was evaluated after 23 years of residual effects in a long-term fertilizer experiment (LTFE) conducted at RARS, Pattambi, Kerala. The LTFE comprised twelve treatments involving different levels of NPK application, imbalanced nutrient combinations, and integrated nutrient management practices. Principal Component Analysis (PCA) was performed using 28 soil indicators encompassing physical, chemical and biological properties. Four principal components with eigenvalues greater than one were retained, together explaining 83.1% of the total variance. The maximum SQI was recorded in treatment T8, which received 100% NPK in combination with farmyard manure (FYM). Overall, SQI values ranged from 1.82 to 3.01. Relative Soil Quality Index (RSQI) values were calculated to classify the nutrient management practices into poor, medium, and high soil quality categories. The results indicated that integrated and balanced fertilizer applications were most effective in sustaining and improving soil quality in laterite soils. Integrated nutrient management treatments (T8, T9, T10, and T11), along with the lime-amended treatment (T4), were categorized under medium soil quality, whereas the remaining treatments fell into the poor soil quality category.

Keywords: LTFE, Soil quality index, principal component analysis, Minimum data set

Introduction

Long-term fertilizer experiments (LTFEs) generate valuable information on the effects of continuous application of fertilizers, using different combinations of organic and inorganic sources, on soil fertility and crop productivity. Such experiments provide a reliable framework for monitoring long-term changes in soil fertility and productivity while safeguarding soil health (Haefele, 2002). In addition, LTFEs offer an effective means to evaluate the sustainability of agricultural management practices. Under the All India Coordinated Research Project on Long-Term Fertilizer Experiments, a field experiment was initiated in 1997 at the Regional Agricultural

Research Station, Pattambi, to study the long-term impact of continuous application of plant nutrients (NPK), applied in organic and inorganic forms and in various combinations, on sustainable productivity in a rice-rice cropping system. Assessment of soil quality in LTFEs thus provides comprehensive insights into the long-term sustainability of nutrient management practices.

The concept of soil quality encompasses both the productive potential of soil and its environmental functions (Parr *et al.*, 1992). It governs essential soil processes such as serving as a medium for plant growth, regulating water movement, recycling

nutrients, and providing habitat for soil biota (Karlen *et al.*, 1997). Soil quality is defined as the capacity of soil to function within ecosystem boundaries so as to sustain biological productivity, maintain environmental quality, and support plant and animal health (Doran and Parkin, 1994). Among the various indicators, soil organic matter is considered a critical determinant of soil quality. Enhancement of soil organic carbon (SOC) stocks through sequestration is a key strategy for improving soil health while simultaneously mitigating climate change. Moreover, greater stabilization of SOC in passive pools with longer residence times contributes to increased carbon sequestration in soils (Samal *et al.*, 2017). In the same long-term rice–rice cropping system on lateritic soils of the humid tropics, integrated nutrient management was found to enhance soil carbon pools and carbon management indices (John *et al.*, 2025). Evidence from recent rice nutrition studies shows that integrated use of organic amendments with recommended fertilizer doses enhances crop productivity and soil health, with enriched organics like Geoxol.com contributing to improved soil quality in rice-based systems (Manasa *et al.*, 2025). Crop productivity was reported to be higher when vermicompost was integrated with chemical fertilizers (Rama Lakshmi *et al.*, 2025).

The soil quality concept is closely linked to the pursuit of agricultural sustainability. Evaluation of soil quality in rice ecosystems is essential for understanding and managing factors that influence crop productivity and long-term sustainability. Soil quality assessment is inherently purpose-specific and site-dependent (Karlen *et al.*, 1994). Although the term soil quality is relatively recent, it is well recognized that soils differ in quality and that soil quality is dynamic, responding to land use and management practices. Soil systems are defined by interacting attributes that operate within functional limits (Karlen *et al.*, 1992). Maintaining soil quality at optimal levels is therefore complex due

to the combined influence of climatic conditions, soil properties, crop management, and human interventions. This complexity is further intensified in rice-based cropping systems (Atanu Mukharjee and Rattan Lal. 2014).

Materials and Methods

The All India Coordinated Research Project on Long-Term Fertilizer Experiments (LTFE) was initiated at the Regional Agricultural Research Station, Pattambi, in 1997 and has been continued with the primary objective of evaluating the long-term effects of continuous application of plant nutrients (NPK), applied in organic and inorganic forms and in various combinations, on sustainable productivity in a rice-rice cropping system.

The long-term fertilizer experiment (LTFE) comprised twelve treatments, namely, T1: 50 per cent NPK (as per KAU POP recommendation), T2: 100 per cent NPK, T3: 150 per cent NPK, T4: 100 per cent NPK + 600 kg ha⁻¹ CaCO₃, T5: 100 per cent NPK, T6: 100 per cent NP, T7: 100 per cent N, T8: 100 per cent NPK + FYM @ 5 t ha⁻¹ to the *virippu* crop only, T9: 50 per cent NPK + FYM @ 5 t ha⁻¹, T10: 100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for *Virippu* crop only), T11 : 50 per cent NPK + *in situ* growing of *Sesbania aculeata* (for *Virippu* crop only) and T12 : Absolute control (No fertilizers or manures). The Package of Practice Recommendation of 90:45:45 kg/ha N, P₂O₅ and K₂O is followed as the 100 per cent Full dose of P fertilizer as Rajphos, ½ dose of N as urea and ½ dose of K as MOP were applied basally. Remaining ½ N and ½ K applied as top dressing at 1 month after basal application. Lime @ 600kg/ha is applied in two splits in T4; 350 kg ha⁻¹ at 2 weeks before transplanting and 250 kg ha⁻¹ as top dressing after one month after transplanting or 10 days before top dressing of fertilizers. In treatments T10 and T11, *dhaincha* (*Sesbania aculeata*) seeds were sown at a rate of 12.5 kg ha⁻¹ and incorporated



into the soil during land preparation. Soil samples were collected after the harvest of the *Kharif* crop in 2020 and analyzed for a range of soil physical, chemical, and biological properties.

Formulation of MDS and SQI

Minimum data set (MDS) for soil quality assessment was established with principal component analysis (PCA) (Dunteman, 1989) performed with R software which is the statistics-based model to create soil quality index (SQI). All measured soil properties were compared in PCA, principal components were selected to get a cumulative proportion of more than 80%. In each PC, the parameter with highest loading and those parameters coming within 10% of the highest loading were selected. The minimum data set (MDS) were finally constituted from the selected parameters by considering the correlation aspects between parameters, ease of measurement, logic and interpretability (Andrews *et al.*, 2002).

After selecting the indicators for the minimum data set (MDS), nonlinear scoring functions were applied to derive scores for each parameter across different treatments. Based on the nature of the indicators, three standard scoring functions were employed: more is better, less is better, and optimum is better. For indicators classified under the more is better category, each observed value was normalized by dividing it by the maximum value recorded in the entire dataset, thereby assigning a score of 1 to the highest observed value. In the case of less is better indicators, the minimum value in the dataset was divided by each observation, ensuring that the lowest value attained a score of 1. For optimum is better indicators, values up to a defined threshold were scored using the more is better approach, while values exceeding the threshold were scored following the less is better function (Mukherjee and Lal, 2014). The resulting normalized scores, ranging from 0 to 1, were then integrated using a weighted additive method, as described by Liebig

et al., (2001), to compute the soil quality index for the different LTFE treatments.

$$SQI = \sum \text{weight} \times \text{individual soil parameter score}$$

The computed soil quality index was compared with the theoretical maximum soil quality index derived from the PCA results, and the relative soil quality index (RSQI) for each treatment was calculated and expressed as a percentage.

Results and Discussion

Principal component analysis (PCA) was the statistical method used to develop the minimum data set for soil quality assessment. PCA was performed on standardized 28 soil attributes. The attributes were bulk density, particle density, porosity, maximum water holding capacity, pH, EC, organic carbon, water soluble carbon, permanganate oxidizable carbon, total N, P, K available N, P, K, Ca, Mg, S, B, Fe, Cu, Mn, Zn, dehydrogenase, urease, acid phosphatase, aryl sulfatase and microbial biomass carbon.

In the PCA conducted for 28 variables, four PCs with Eigen value more than one and a cumulative proportion of variance greater than 80% were selected. The four principal components together accounted for 83.1% of the total variability in the dataset. Principal components explaining 7.1% or more of the total variance were retained for further analysis (**Table 1**). In the PC1 the variables qualified for MDS were microbial biomass carbon, permanganate oxidizable carbon, acid phosphatase, aryl sulfatase, available nitrogen, total nitrogen, and bulk density. In second PC available sulphur was the highly weighed variable. In third PC the highest weighed variable was pH and in fourth PC group porosity was the highly weighed variable.

Suresh *et al.*, (2017) identified soil parameters such as bulk density and available sulphur as key components of the minimum data set (MDS) in a long-term fertilizer experiment with 15 years of cropping history and residual effects. In contrast, Saikia *et*

al., (2019) emphasized the importance of biological indicators, reporting that enzyme activities including β -glucosidase, cellulase, and phenol oxidase were highly sensitive and reliable parameters for evaluating the Soil Quality Index (SQI) in a rice–wheat cropping system.

Table 1: Total variance explained by PCA

	PC1	PC2	PC3	PC4
Eigen value	14.96	3.759	2.531	2.010
Proportion of Variance	0.534	0.134	0.090	0.071
Cumulative Proportion	0.534	0.669	0.759	0.831

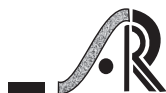
The principal component analysis (PCA) of the soil parameters under twelve nutrient management treatments in the rice–rice cropping system is presented in (**Table 2**). The results showed that the first principal component (PC1), which accounted for 53.4% of the total variance, exhibited strong positive loadings for microbial biomass carbon, followed by permanganate oxidizable carbon, acid phosphatase, aryl sulfatase, available nitrogen, total nitrogen, and bulk density, all falling within 10% of the highest loading value (0.248). The second principal component (PC2), explaining 13.4% of the variance, showed a high positive loading for available sulphur (9.745). Although bulk density also appeared within the 10% loading range in PC2, it was already represented in PC1. The third principal component (PC3), which explained 9.0% of the variance, had a strong positive loading for soil pH (0.520), with no additional variables meeting the 10% criterion. The fourth principal component (PC4), accounting for 7.1% of the variance, was characterized by a high negative loading for porosity (-0.566). As suggested by Andrews *et al.*, (2002), selection among highly correlated variables may also be guided by their practical applicability. Accordingly, microbial biomass carbon, permanganate oxidizable carbon, acid phosphatase, aryl sulfatase, available nitrogen, total nitrogen, and bulk density were selected for the minimum data

set (MDS) from PC1. Available sulphur was chosen from PC2, pH from PC3, and porosity from PC4 as the most influential indicators.

Table 2: Principal component analysis of various soil parameters based on various treatments in LTFE

Parameters	PC1	PC2	PC3	PC4
BD	-0.242	-9.315	0.072	-0.098
PD	-0.099	-3.888	-0.137	0.233
Porosity	0.1058	9.149	-0.055	-0.566
Max.WHC	0.222	-4.018	-0.029	-0.251
pH	0.071	-6.665	0.520	0.001
EC	0.0640	2.392	0.113	0.261
OC	0.027	0.020	-0.109	-0.303
WSC	0.203	-2.017	-0.0150	-0.2113
KMnO ₄ C	0.247	5.951	0.035	0.0495
Avail. N	0.224	-1.648	0.1472	-0.071
P	0.160	-3.469	0.026	-0.117
K	0.161	-3.594	-0.055	0.038
Total N	0.224	-1.191	-0.0348	-0.209
Total P	0.013	-4.562	0.070	0.200
Total K	0.154	-1.547	-0.407	-0.041
Ca	0.188	-2.00	0.355	-0.038
Mg	0.210	1.93	-0.066	0.214
S	0.211	9.745	0.038	0.313
B	0.200	1.894	-0.167	0.068
Fe	0.198	1.196	-0.32	0.154
Cu	0.155	1.495	0.244	-0.182
Zn	0.081	4.998	0.210	0.267
Mn	0.153	2.304	0.183	0.145
DHA	0.204	2.135	0.062	-0.115
Urease	0.219	-1.819	-0.001	-0.051
Phosphatase	0.245	1.074	-0.064	-0.067
Sulfatase	0.234	4.919	0.203	-0.072
MBC	0.248	-5.182	-0.055	-0.055

In our study on a rice–rice cropping system with 23 years of cropping history and residual effects, ten



soil parameters representing physical, chemical, and biological properties-available N, total N, KMnO₄-oxidizable carbon, pH, available S, acid phosphatase, aryl sulfatase, microbial biomass carbon, bulk density, and porosity-were selected for computing the Soil Quality Index (SQI). These parameters were scored as “more is better” (for nutrients and biological indicators), “less is better” (for bulk density), or “optimum is better” (for porosity). The scores were converted to unitless values, weighted using PCA, and summed to calculate the SQI; the results for each LTFE treatment are presented in (Table 3), with the contribution of each parameter shown in (Figure 1).

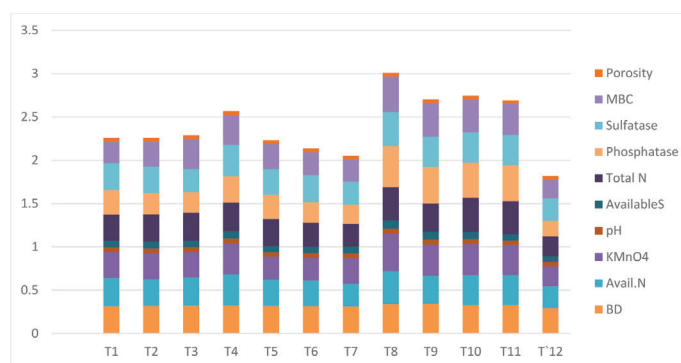


Figure 1: Contribution of each soil attributes in MDS towards SQI as affected by different treatments under LTFE

Table 3: Computed SQI values of different parameters for the treatments in LTFE

Treatments	BD	Avail. N	KMnO ₄ C	pH	S	Total N	Phospha-tase	Sulfatase	MBC	Porosity
T1	0.315	0.327	0.300	0.052	0.079	0.298	0.286	0.309	0.250	0.041
T2	0.317	0.308	0.303	0.053	0.080	0.313	0.250	0.301	0.289	0.043
T3	0.319	0.328	0.296	0.053	0.076	0.321	0.237	0.268	0.348	0.041
T4	0.323	0.362	0.352	0.060	0.085	0.331	0.300	0.365	0.347	0.043
T5	0.317	0.305	0.265	0.053	0.070	0.311	0.279	0.298	0.290	0.041
T6	0.316	0.296	0.260	0.054	0.076	0.278	0.237	0.313	0.264	0.042
T7	0.313	0.261	0.296	0.053	0.080	0.262	0.223	0.265	0.256	0.041
T8	0.340	0.378	0.434	0.055	0.100	0.381	0.476	0.394	0.412	0.040
T9	0.343	0.321	0.364	0.054	0.093	0.324	0.423	0.350	0.388	0.041
T10	0.327	0.347	0.360	0.055	0.085	0.393	0.404	0.354	0.377	0.043
T11	0.327	0.347	0.348	0.052	0.071	0.383	0.413	0.351	0.360	0.039
T12	0.294	0.253	0.225	0.055	0.066	0.229	0.179	0.261	0.218	0.038

The SQI values of BD varied from 0.294 (T₁₂-absolute control) to 0.343 (T₉- 50 per cent NPK+FYM). The SQI of available N ranged from 0.253 to 0.378. The highest value of 0.378 was obtained in T₈ where 100 per cent NPK+FYM were applied and the lowest value (0.253) was in T₁₂ (absolute control). In permanganate oxidizable carbon the SQI varied from 0.225 (absolute control – T₁₂) to 0.434 (T₈- 100 per cent NPK+FYM). SQI of pH ranged from 0.052 in T₁ (50 per cent NPK) and T₁₁(50 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)) to 0.060 in T₄ (100 per cent NPK+lime @ 600 kg ha⁻¹). SQI of available sulphur ranged from 0.066 to 0.100. The highest SQI was observed in T₈ where 100 per cent NPK+FYM applied and lowest in absolute

control (T₁₂). In total N SQI varied from 0.229 (T₁₂- absolute control) to 0.393 (T₁₀- 100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for *Kharif* crop only)). The SQI values of acid phosphatase varied from 0.179 (T₁₂- absolute control) to 0.476 (T₈- 100 per cent NPK+FYM). The aryl sulfatase values were ranged from 0.261 (T₁₂) to 0.394 (T₈). In MBC the SQI varied from 0.218 (T₁₂- absolute control) to 0.412 (T₈-100 per cent NPK+FYM). The SQI values of porosity ranged from 0.038 (absolute control - T₁₂) to 0.043. The highest value of 0.043 were observed in T₂ (100 per cent NPK), T₄ (100 per cent NPK + lime @ 600 kg ha⁻¹) and T₁₀ (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for *Kharif* crop only)).

The Soil Quality Index (SQI) values varied from 1.82 to 3.01 across the treatments. A declining trend in SQI was observed in the order: T8 > T10 > T9 > T11 > T4 > T3 > T2 = T1 > T5 > T6 > T7 > T12. With increase in fertilizer load from 50% NPK to 150% NPK there was an increase in SQI. Thus increasing fertilizer levels helped in maintaining SQI. Sharma *et al.*, (2005) and Suresh *et al.*, (2017) also reported an increasing SQI with increasing level of fertilizers. This increase in SQI with 150% NPK is due to the positive effect of higher dose of fertilizers on certain parameters which came under MDS *i.e.*, increased loading of available nitrogen and total nitrogen which came under MDS. In LTFE treatments, highest SQI was recorded by the treatment with integrated use of NPK and FYM (T₈-0.62). However, the SQI was low (0.37) for the absolute control (T₁₂) due to continuous nutrient removal by crop without restitution. Furthermore, the application of 50% NPK, 100% NPK, 150% NPK, 100% NP, and 100% N alone did not result in a substantial improvement in soil quality, indicating a weaker cumulative influence of the soil parameters identified through PCA. In contrast, the integrated application of the recommended dose of fertilizers in combination with organic manure (100% NPK + FYM) was rated as the most effective treatment, as reflected by the highest SQI values among all treatments. A similar advantage of farmyard manure and in situ green manuring in improving crop productivity and soil organic carbon in this rice–rice system was reported earlier by Thulasi *et al.* (2016). The grain and straw yields exhibited a similar response pattern across treatments, further supporting the superiority of integrated nutrient management practices. Comparable findings were reported by Suresh *et al.*, (2017), who also observed the dominance of integrated nutrient management over other fertilizer management strategies in a long-term fertilizer experiment conducted in Telangana.

The computed RSQI values were used for the categorization of different management practices into

poor, medium and high soil quality groups. Integration of inorganic fertilizers and balanced applications are the best way for restoring and maintaining soil quality in LTFE and these treatments (T₈), (T₉), (T₁₀), (T₁₁), and (T₄) came under medium soil quality category, as presented in (Table 4) and illustrated in (Figure 2). Masto *et al.*, (2007), in a long-term fertilizer experiment conducted at the Indian Agricultural Research Institute, reported that the combined application of NPK fertilizers and organic manures resulted in the highest Soil Quality Index (SQI).

Table 4: Mean RSQI (%) of different treatments of LTFE soil

	RSQI (%)	Soil quality class
T1	46.53	Poor
T2	46.55	Poor
T3	47.19	Poor
T4	52.98	Medium
T5	45.97	Poor
T6	44.04	Poor
T7	42.31	Poor
T8	62.11	Medium
T9	55.69	Medium
T10	56.61	Medium
T11	55.50	Medium
T12	37.49	Poor

Conclusion

In the present study conducted under a rice–rice cropping system with 23 years of continuous cultivation and residual effects, the Soil Quality Index (SQI) values ranged from 1.82 to 3.01. The SQI followed a decreasing trend in the order: T8 > T10 > T9 > T11 > T4 > T3 > T2 = T1 > T5 > T6 > T7 > T12. An increase in SQI was observed with increasing fertilizer levels from 50% NPK to 150% NPK (T1 to T3), indicating a positive response to higher nutrient inputs. Further enhancement in SQI was noted when fertilizer application increased from 50% to 100% NPK in combination with farmyard manure or in situ green manuring, highlighting the role of integrated fertilizer levels in sustaining soil quality.



The relative soil quality index (RSQI) values were used to classify the nutrient management practices into poor, medium, and high soil quality categories. The results demonstrated that integrated and balanced fertilizer applications were more effective in restoring and maintaining soil quality under long-term fertilizer experimentation. Accordingly, the integrated nutrient management treatments (T8, T9, T10, and T11) and the lime-amended treatment (T4) were categorized under the medium soil quality group, while all remaining treatments were classified as poor. Overall, integrated nutrient management practices and lime incorporation contributed to the long-term maintenance of soil quality, whereas the control and fertilizer-only treatments resulted in comparatively lower SQI values.

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Quantification of Chalky Area, Amylose and Amylopectin in Single Rice Grain

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Abstract

Rice grains with chalkiness are considered inferior in cooking quality. Chalky grains contain air spaces in the accumulated starch granules and may vary in amylose content from translucent grains of the same genotype. Further, chalky area percentage (CAP) varies among the genotypes. Hence, this study assessed CAP, amylose and amylopectin contents in individual chalky and translucent grains of seven rice varieties cultivated in wet and dry seasons. Besides, other cooking quality parameters, kernel length after cooking (KLAC), alkali spreading value (ASV), volume expansion ratio (VER) and pasting profiles were assessed in translucent and chalky grains separately. CAP widely varied (5-75%) in the individual grains of varieties. Grains with CAP >75 were more in dry season indicating the influence of environment on chalkiness. In chalky and translucent grains, variation in KLAC and VER were highly significant while variation in ASV was non-significant. Amylose and amylopectin exhibited inverse and direct relationships with CAP, respectively. Compared with translucent grains, the four measured and three derived viscosities showed significant variations in the chalky grains. The cool paste or final viscosity values were lower in the chalky grains. Variation in the cooking quality behaviour of chalky grains is genotype dependent. However, genotypes categorized as VOC may not affect the overall pasting properties or cooking quality of the rice genotype.

Keywords: Rice grain quality, Chalkiness, Amylose, Amylopectin, Chalky area, Single grain

Introduction

Chalkiness is one of the crucial parameters of appearance quality of rice grain. Rice cultivars with more than 20% chalky kernels are in general unacceptable in the world markets. Generally, chalkiness is identified by the presence of partial or complete opaque area inside the endosperm and is influenced by genetic and environment factors (Juliano, 1979). The extent of induced chalkiness varies among the varieties (Yamakawa *et al.*, 2007) and the same variety may contain both chalky and translucent grains.

Mutant male sterile [ms-h (t)] gene (Koh *et al.*, 1999), lack of starch-branching enzyme IIb (BEIIb) gene (Nishi *et al.*, 2001), 1-aminocyclopropane-1-carboxylic acid (ACC) contents and variation

in the activities of the key enzymes involved in starch biosynthesis during grain filling (Jin *et al.*, 2010) are the genetic factors responsible for chalkiness. Whereas environmental factors like sulphur deficiency (Shaeffer *et al.*, 1987), infection by rice blast and sheath blight (Candole *et al.*, 2000), elevated carbon dioxide (Yang *et al.*, 2007), increase in temperature during grain filling period and particularly night time temperatures (Lanning *et al.*, 2011; Tu *et al.*, 2023; Jaldhani *et al.*, 2021), resulting in deterioration of grain quality traits including amylose content, gel consistency and head rice recovery under high-temperature stress. Similarly, rise in irrigation water temperature (Nisha *et al.*, 2025) increases chalkiness.

Chalky grain is filled with loosely packed, round and large compound starch granules while translucent grain contains tightly packed, polyhedral and small single starch granules (Yamakawa *et al.*, 1980, Singh *et al.*, 2006, Fujita *et al.*, 2007).

These reports imply that the accumulation of starch in chalky grain can vary from the translucent grain either in quality, quantity or both. Since starch is the dominant component of the grain change in its quality or quantity can affect the overall grain quality. Though starch contains two linear polysaccharides, amylose (unbranched) and amylopectin (branched), the former was more studied in relation to chalkiness. Considering the variation in chalky size in the cultivars and the possibility of independent inheritance of chalky kernel and chalky area (Zhang *et al.*, 2009), it is essential to reveal the relation between chalky area and starch components in individual grains.

Translucently chalky area in individual grains can be measured manually using a magnifying glass. Though expensive, digital imaging technologies (Yoshioka *et al.*, 2007, Armstrong *et al.*, 2019) can minimize analysis time and human errors as chalky grains transmit less amount of light than translucent grains. They are useful for chalkiness quantification at single grain level in terms of length-width ratio, percentage of grains with chalkiness, area of chalky endosperm and degree of endosperm chalkiness (Wan *et al.*, 2005).

Pasting properties were studied in rice among genotypes (Singh *et al.*, 2006, Champagne *et al.*, 1999, Bao *et al.*, 2002, Bao *et al.*, 1999, Sun *et al.*, 2011, Liu *et al.*, 2009, Devi *et al.*, 2009), lines of Koshihikari × Kasalath mapping population varying in percentage of grains with chalkiness (PGWC) (Zhang *et al.*, 2012), mixture of rice having 0 to 100% chalky grains (Chun *et al.*, 2009), gene edited (Liu *et al.*, 2022), rice cultivated at varying seasonal temperatures (Tu *et al.*, 2023).

Based on this background, rice grain of seven genotypes cultivated in both wet and dry seasons were screened for chalkiness, cooking quality

parameters and pasting properties to explore for any inter-relationship between chalkiness and the quality parameters as well as pasting properties.

Materials and Methods

Seven rice varieties, Aditya, Dhanarasi, Jaya, Nidhi, Suraksha, Swarnadhan and Tulasi, were cultivated during wet season 2015 and dry season 2016 in the experimental fields of ICAR-IIRR, Hyderabad, following standard package of practices. The harvested grain of each sample was collected and dried (14% moisture content) under ambient conditions. The grain was stored at room temperature for three months and then processed as below.

Sample Processing

Each paddy sample was dehusked using Satake TH4 (No. 1012077) and the brown rice was polished using Satake TM05C (No. 554456) miller.

Quality analysis

The milled grain was manually separated into translucent (T) and chalky (C) grain using a trans-illuminator (Armstrong *et al.*, 2019). Each chalky grain was placed on trans-illumination box keeping the germ side of the grain on the left bottom and its image was recorded along with a needle of known length (placed above grain) using Nikon D80 camera at 60.0 mm focal length with 0.016 min exposure time. Later, each image was processed separately with *imageJ* software. Scale for each image was adjusted using the known dimensions of the needle, image was converted to 8-bit, chalky area of the grain was selected by adjusting the threshold value and the selected area was measured using analyse particle tool of the software. Similarly, total area of the grain (same image) was also determined which was considered 100% while calculating the chalky area percentage (CAP) in each grain. Chalky area was estimated in 93 individual chalky grains of the above varieties cultivated in both the seasons.

CAP in single grain = (Chalky area of the grain/Total area of the grain) × 100.

Chalky (having highest CAP) and translucent grains of each sample were separately subjected to alkaline spreading value (ASV) (Little *et al.*, 1958), kernel length after cooking (KLAC) (Juliano, 1980), amylose (AC) and amylopectin (AP) estimation using non-interference equations (Lander *et al.*, 1991, Sanjeeva Rao *et al.*, 2024).

Chalky (having various values of CAP) and translucent grains of each sample were separately powdered (100 mesh) manually in mortar and pestle. Powder (5g) of each sample was separately subjected to rice viscosity analysis (Jayakody *et al.*, 2007) using Physica Smart Starch analyser having MCR 52 and Rheoplus software (Anton Paar).

Statistical analysis

Statistical analysis was performed in R software (version 4.4.2) using *Agricolae* package for ANOVA, *ggplot2* and *reshape2* packages for regression analysis and performance analytics package for correlation analysis.

Results and Discussion

ANOVA analysis indicates that the variation in chalky area % (CAP) in individual grains was significant ($P < 0.5$) among the genotypes and highly significant ($P < 0.001$) with the grain type (Table 1). Variation in individual grain weight was significant for grain type and highly significant among the genotypes as well as Genotype $\times$ Season interaction. Variation in amylose (AC) was significant among the genotypes, significant between genotype $\times$ grain type (G:T) and highly significant between genotype $\times$ season (G:S) interaction. Variation in amylopectin content (AP) was significant among the genotypes, grain type and season. While it was highly significant for G:S and significant for G:T:S.

In dry season, the mean CAP was least in Aditya (40.0%) ranging from 14.0 to 76.1% and highest in Dhanarasi (73.7%) ranging from 55.2 to 91.3% (Table 2). Whereas in wet season, CAP was least in Tulasi (30.7%) ranging from 7.9 to 63.2% and highest

in Dhanarasi (57.1) ranging from 12.4 to 86.7%. Except Aditya and Suraksha, grains possessing CAP above 75% were more in dry season where temperature during grain filling period is usually higher than the wet season. Variation in chalky size in cultivars was observed and opined that there is possibility of independent inheritance of chalky kernel and chalky area (Zhang *et al.*, 2009). The images of rice grain obtained with Cano Scan 9950FV digital image scanner were processed and classified the rice grains based on the position and proportion of chalky area into white-based, white-back, white-back cum based, white-belly, white-core and milky-white rice (Yoshika *et al.*, 2007).

Although variation was observed in individual grain weight of chalky and translucent grains, the mean individual grain weights were statistically same for four (Dhanarasi, Jaya, Suraksha and Swarnadhan) genotypes. In chalky grains, grain weight decreased with the increase in CAP (Figure 1) in all the genotypes in both the seasons. The regression (R^2) was significant with Swarnadhan in both the seasons. While R^2 was significant for Jaya in dry season only.

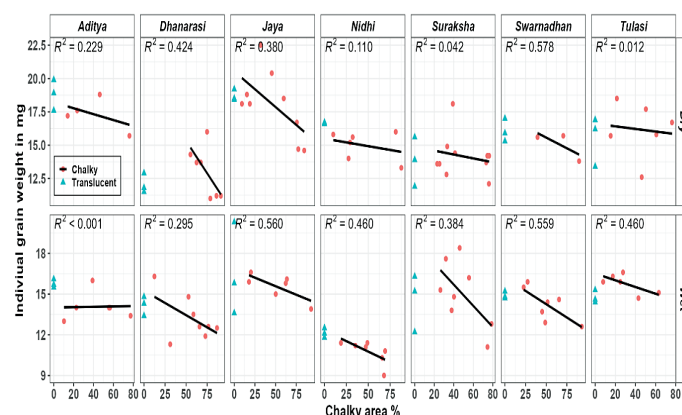


Figure 1: Influence of chalky area % on individual grain weight of rice cultivated in dry and wet seasons. Normal grains in green were not included in regression line

Amylose, Amylopectin and CAP

Considering the variation in chalky area of individual grains within a variety, starch components (AC and AP) were estimated (Sanjeeva Rao *et al.*, 2024)

in individual grains in this study to reveal the influence of chalky area on starch components. Both AC and AP varied in chalky grains in both the seasons (**Table 2**). The mean AC in chalky grains was similar in both the seasons in three genotypes (Jaya, Nidhi and Tulasi), marginally higher in wet season over dry season in two genotypes (Dhanarasi and Swarnadhan) and vice-versa in remaining two genotypes (Aditya and Suraksha). The mean AC was statistically similar in both translucent and chalky grains, except Aditya in wet season and Swarnadhan in dry season. The mean AP in chalky grains was similar in both the seasons in two genotypes (Suraksha and Tulasi), higher in wet season than dry season in three genotypes (Aditya, Jaya and Nidhi) and vice-versa in two genotypes (Dhanarasi and Swarnadhan). The mean AP of translucent grains was statistically dissimilar to that of the mean AP in chalky grains of in two genotypes each in wet (Aditya and Swarnadhan) and dry (Jaya and Swarnadhan) seasons.

Although the mean AC and AP in chalky grains were similar to translucent grains in both the seasons, AC decreased (except Tulasi) and AP increased with the increase in CAP (**Figures 2 and 3**). This indicates that the chalky grains with more CAP contains lesser AC and higher AP in comparison with the translucent grains.

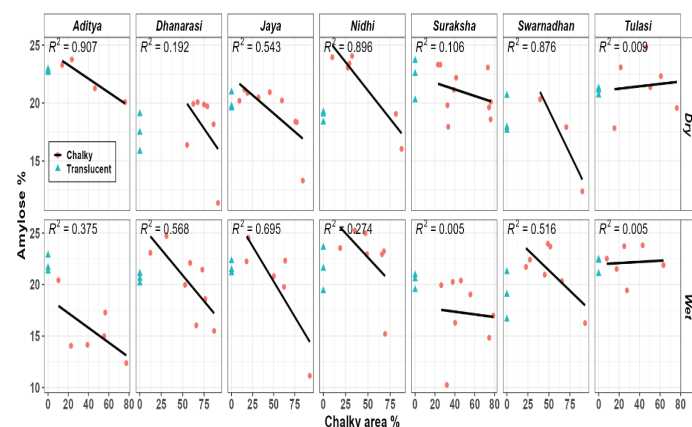


Figure 2: Effect of chalky area % on amylose content of rice grain cultivated in dry and wet seasons. Normal grains in green were not included in regression line

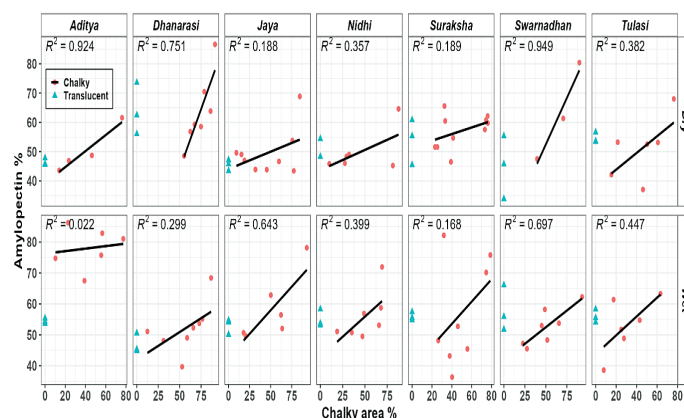
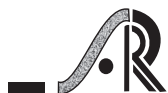


Figure 3: Effect of chalky area % on amylopectin content of rice grain cultivated in dry and wet seasons. Normal grains in green were not included in regression line

In CAP vs AC graph (**Figure 2**), in dry season, the regression value (R^2) was highly significant (> 0.7) in three (Aditya, Nidhi and Swarnadhan) genotypes, significant (> 0.5 and < 0.7) in Jaya and non-significant (< 0.5) in the remaining three (Dhanarasi, Suraksha and Tulasi) genotypes. While in wet season, the R^2 was significant in three (Dhanarasi, Jaya and Swarnadhan) genotypes and non-significant in the remaining four (Aditya, Nidhi, Suraksha and Tulasi) genotypes. This indicates that the chalky grains of Suraksha and Tulasi were more stable in AC in both seasons.

In CAP vs AP graph (**Figure 3**), in dry season, the R^2 value was highly significant in three (Aditya, Dhanarasi and Swarnadhan) genotypes and non-significant in the remaining four (Jaya, Nidhi, Suraksha and Tulasi). While in wet season, almost highly significant in Swarnadhan, significant in Jaya and non-significant in the remaining five (Aditya, Dhanarasi, Nidhi, Suraksha and Tulasi) genotypes. This indicates that the chalky grains of Nidhi, Suraksha and Tulasi were more stable in AP in both the seasons.

Marginal decrease in AC was observed in chalky grains with insignificant correlation (Zhang *et al.*, 2009, Chun *et al.*, 2009, Zhou *et al.*, 2009). The response of amylose content to elevated temperature appears to be genotype dependent. In heat-tolerant QTL introgressed restorers of KMR-3R, Jaldhani *et al.* (2021) observed



both increases and decreases in amylose content under high-temperature stress, indicating differential stability of starch composition among genotypes. Significant low AC (1.7% in Nipponbare to 4.8% in Hatsuboshi) was reported in chalky grains of five varieties ripened at high temperature (Yamakawa *et al.*, 2007). Varied trend in AC was noticed among the six chalky mutants in comparison to the wild Nipponbare wherein AC increased in 2nd, 3rd and 4th mutants, decreased in 1st and 6th mutants and was similar to wild in 5th mutant (Jin *et al.*, 2010).

Thus, it is evident that AC in the chalky grain can vary from translucent grain and the extent of variation depends on CAP of the grain. However, this variation could not appear in earlier reports where amylose content was estimated from the powder obtained from bulk seeds of chalky and translucent grains. Further, means of amylose and amylopectin contents were calculated separately using the values obtained from individual grains for each variety (**Table 2**) to compare the present results with the reported observations. Either negligible or marginal variations were observed in the means of amylose content of both chalky and translucent grains. Amylose content was more in translucent grains of Suraksha in both the seasons as well as Aditya in wet season while it was more in chalky grains of Nidhi in both the seasons. Genetic studies involving bulk seed analysis observed high amylose as incompletely dominant to low whereas single grain analysis revealed high amylose as completely dominant to intermediate or low amylose (Kumar *et al.*, 1987) and thus, emphasized the importance of phenotypic analysis at single grain.

Regarding amylopectin in chalky grains, although quantity was not mentioned, less number of small chains and more number of long chains (Yamakawa *et al.*, 2007) and vice-versa (Chun *et al.*, 2009, Patishdol *et al.*, 2003) were observed.

High temperature stress induced synthesis of α -amylase mRNA followed by the degradation of

starch after the middle stage of grain filling leads to reduced starch content (Yamakawa *et al.*, 2007, Kawakatsu *et al.*, 2009). High-temperature stress is also known to increase grain chalkiness and reduce head rice recovery. Evaluation of heat-tolerant KMR-3R introgression lines under late-sown conditions revealed substantial reductions in head rice recovery, largely attributed to increased chalky grain formation (Jaldhani *et al.*, 2021). In contrast, this study reports increased starch content with the increase in CAP since the extent of increase in amylopectin was more than the degree of decrease in amylose (Liu *et al.*, 2010).

KLAC, VER and ASV in chalky and translucent grains

Even translucent rice grain becomes opaque on cooking and it is difficult to distinguish whether a cooked grain is from chalky grain or translucent grain. Hence, kernel length after cooking (KLAC), alkali spreading value (ASV) and volume expansion ratio (VER) were analysed in milled rice in chalky (highest CAP) and translucent grains of each genotype. ANOVA indicates that the variation in KLAC and VER were highly significant or significant among the genotypes, season, grain type and their interactions (**Table 3**).

Marginal difference (<1 mm) was observed in the KLAC values of translucent and chalky grains of the varieties cultivated in wet season (**Table 4**). Whereas this difference was >1 mm in Suraksha, Swarnadhan and Tulasi cultivated in dry season. In both the seasons, KLAC of translucent grain was marginally higher than chalky grain of Aditya and Dhanrasi. Whereas KLAC of chalky grain was higher in the case of Suraksha and minor variation was noted for Nidhi. In Swarnadhan and Tulasi, KLAC of translucent grain was marginally higher in wet season while KLAC of chalky grain was >1 mm in dry season.

In wet season, VER values were similar in both chalky and translucent grains of Dhanarasi and Tulasi. The values of VER were more in the chalky grains of

Aditya and Jaya and vice-versa in Nidhi, Suraksha and Swarnadhan. In dry season, the VER values were higher in the translucent grains of Aditya, Dhanarasi, Nidhi, Swarnadhan and Tulasi. Whereas the VER values were higher in the chalky grains of Jaya and Suraksha.

ASV is inversely proportional to GT (IRRI, 1976). The requirements and protocol for the conduction of ASV experiment is simple compared to the determination of GT. Difference in ASV between translucent and chalky grains (highest CAP) was either absent or negligible for varieties in both the seasons except for Tulasi cultivated in wet season (**Table 1**). Similarly, insignificant correlation was reported between GT and chalkiness (Zhang *et al.*, 2009) which indicates that GT is unaffected by chalkiness. The 107 glutinous (low amylose) rice noted wide ASV from 2 to 7 (Srinivas *et al.*, 2023) which indicates that decrease in AC due to chalkiness (**Figure 3**) may not necessarily change the ASV.

During cooking, starch granules of rice grain absorb water and swell where their size is manifold higher than the original size of the starch granules and finally solubilise. This irreversible change is gelatinization and this temperature is designated as gelatinization temperature (GT). In addition, separately cooked chalky grains of all genotypes showed undulated texture and were disintegrated with less force whereas the cooked translucent grain had uniform texture and was stable when similar force was applied. Non-uniform distribution of starch granules interspersed by air spaces in chalky grain (Yamakawa *et al.*, 2007, Singh *et al.*, 2006, Fujita *et al.*, 2007) can be related to the undulated texture of cooked chalky grain.

Pasting behaviour of chalky and translucent grain powders

The pasting curve of rice starch popularly known as rapid visco analyser (RVA) profile includes hot-hold-cool hold protocol (Bao *et al.*, 1999, Sun *et al.*, 2011). The paste profile sequentially passes through pasting temperature (PT) as well as pasting viscosity

(PV), peak viscosity (PKV), through viscosity or hot paste viscosity (HPV) and final viscosity or cool paste viscosity (CPV). While breakdown viscosity (BDV=PKV-HPV), setback viscosity (SBV=CPV-PKV) and setback from trough or consistency viscosity (CTV=CPV-HPV) are derived from the above measured viscosities.

ANOVA indicates that variation in PV, PKV, CPV, BDV, SBV and CTV were highly significant with change in genotype (G), season (S), grain type (T) and their interactions (**Table 5**). Variation in HPV was also highly significant in all parameters except T (non-significant). Variation in PT was highly significant for G, S and G:S while significant for GT, S:T and G:S:T. These results emphasize that chalky grains (with all types of CAP) can behave differently during pasting properties in comparison with translucent grains. The pasting viscosities significantly varied among the genotypes (Bao *et al.*, 2002).

The mean values of the above parameters are presented in (**Table 6**) for each genotype in both the seasons in translucent and chalky grains. In wet season, in translucent grains, PT ranged from 70.3 °C (Tulasi) to 77.3 °C (Swarnadhan), PV from 2054 (Dhanarasi) to 6828 (Aditya), PKV from 20160 (Tulasi) to 30610 (Dhanarasi), HPV from 1385 (Dhanarasi) to 3584 (Nidhi), CPV from 1021 (Dhanarasi) to 8506 (Swarnadhan), BDV from 16900 (Swarnadhan) to 29230 (Dhanarasi), SBV from 12760 (Swarnadhan) to 29590 (Dhanarasi) and CTV from -364 (Dhanarasi) to 5033 (Swarnadhan). In chalky grains, 70.9°C (Nidhi) to 78.8°C (Swarnadhan), PV from 428 (Dhanarasi) to 3627 (Swarnadhan), PKV from 22980 (Nidhi) to 32260 (Aditya), HPV from 457 (Aditya) to 3003 (Swarnadhan), CPV from 730 (Aditya) to 15030 (Suraksha), BDV from 21950 (Nidhi) to 31800 (Aditya), SBV from 14180 (Suraksha) to 31530 (Aditya) and CTV from -160 (Nidhi) to 14500 (Suraksha).

In dry season, in translucent grains, PT ranged from 65.3°C (Jaya and Dhanarasi) to 73.6°C (Nidhi), PV

from 150 (Dhanarasi) to 4777 (Nidhi), PKV from 21430 (Nidhi) to 30360 (Tulasi), HPV from 621 (Jaya) to 9278 (Dhanarasi), CPV from 496 (Jaya) to 14110 (Dhanarasi), BDV from 15870 (Nidhi) to 27600 (Jaya), SBV from 12920 (Dhanarasi) to 29370 (Tulasi) and CTV from -1928 (Tulasi) to 4830 (Dhanarasi). In chalky grains, PT ranged from 65.6 °C (Jaya) to 74.7 °C (Dhanarasi), PV from 316 (Dhanarasi) to 5447 (Tulasi), PKV from 20680 (Tulasi) to 32190 (Jaya), HPV from 399 (Jaya) to 14960 (Suraksha), CPV from 488 (Tulasi) to 24420 (Suraksha), BDV from 9825 (Dhanarasi) to 31790 (Jaya), SBV from 2420 (Suraksha) to 31560 (Jaya) and CTV from 74 (Tulasi) to 5908 (Aditya).

Further, PT values were statistically similar for each genotype for both translucent and chalky grains in both the seasons. Most of the PKV values were higher in chalky grain powders. While most of the values of PV, HPV and CPV differed statistically from translucent to chalky grains and were higher in translucent grains. The per cent change of chalky over translucent grain powders (**Figure 4**) both the seasons indicates that chalky grain behaves differently during cooking. The positive value indicates that the respective parameter in chalky grain powder was more than the value noted for translucent grain and vice-versa for negative values. The % change in PT was less than $\pm 5\%$ except Dhanarasi in dry season. Among the viscosities, the % change was least for BDV and highest for CTV as well as CPV. Among the genotypes, highest values of % change in chalky grain were noted for Suraksha (CTV & CPV) and Dhanarasi (CPV).

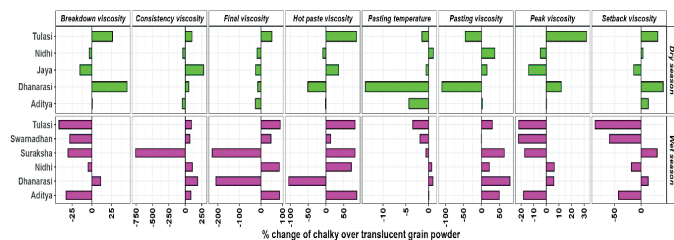


Figure 4: The % change of chalky grain powders over translucent grain powders in pasting profile of rice grain cultivated in dry and wet seasons

In multiple correlation analysis was performed separately for translucent (**Figure 5**) and chalky (**Figure 6**) grains. In translucent grains, KLAC noted significant negative correlation (P 0.1) with CTV only. VER noted significant negative association (P 0.05) with PKV, BDV and SBV. AC noted significant positive correlation (P 0.05) with PV and significant negative correlation (P 0.05) with HPV. AP noted significant positive correlation (P 0.01) with HPV and CPV. The genotypes used in this study contain similar AC and AP contents, however, minor variation in AP content could be responsible for the variation in the pasting properties. In addition, among the measured (PKV, PV, HPV and CPV) viscosities, PKV noted significant negative association (P 0.5) with CPV. While HPV noted highly significant positive association (P 0.001) with CPV.

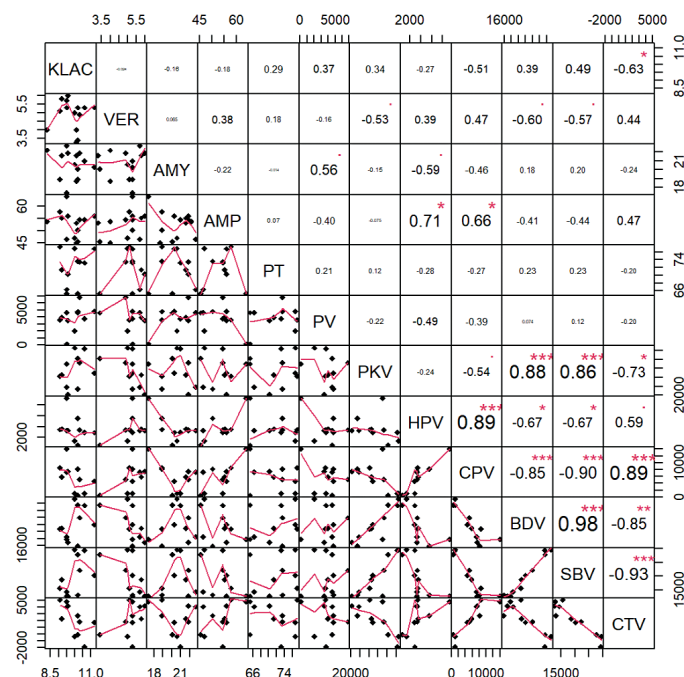


Figure 5: Multiple correlation among cooking quality and pasting parameters in translucent grains.

KLAC (kernel length after cooking), VER (volume expansion ratio), AC (AMY) (amylose %), AP (AMP) (amylopectin %), PT (pasting temperature), PV (pasting viscosity), PKV (peak viscosity), HPV (hot plate viscosity), CPV (cool paste viscosity), BDV (breakdown viscosity), SBV (setback viscosity) and CTV (consistency viscosity) Symbols ***, **, * and dot represent p-values 0, 0.001, 0.01, 0.1 and 0.05 respectively

In multiple correlation analysis of chalky grains, KLAC noted significant positive association (P 0.01) with

CTV and this relationship was opposite to translucent grains. Similarly, VER noted significant positive association (P 0.01) with PKV only. As AC decreased and AP increased with the increase in CAP (**Figures 2 and 3**) in chalky grains in these genotypes, AC noted significant negative association with AP (P 0.01). Although both AC (decreased) and AP (increased) varied among the chalky grains with the increase in CAP, AC alone noted significant negative association (P 0.05) with PKV and it indicates that PKV was more affected by change in AC content. Further, among the measured viscosity parameters, PV noted significant negative association (P 0.01) with HPV and CPV. HPV noted highly significant positive association (P 0.001) with CPV.

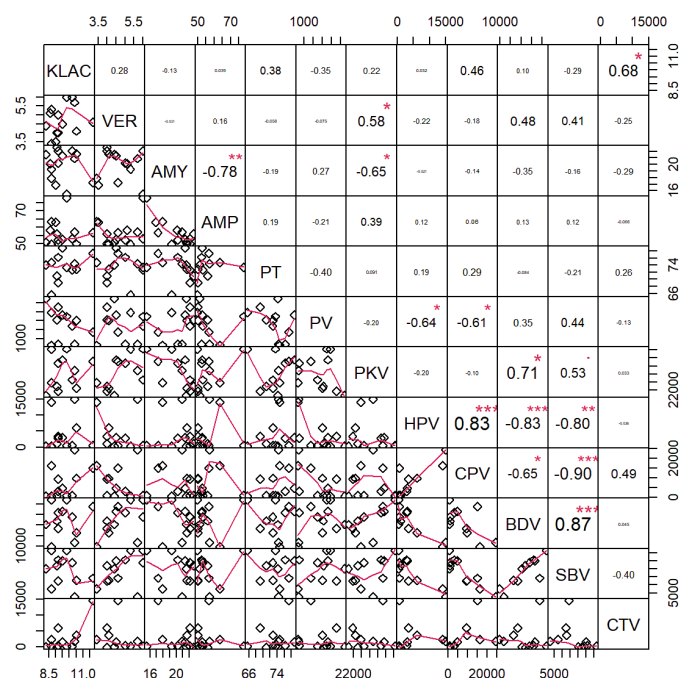


Figure 6: Multiple correlation among cooking quality and pasting parameters in chalky grains.

KLAC (kernel length after cooking), VER (volume expansion ratio), AC (AMY) (amylose %), AP (AMP) (amylopectin %), PT (pasting temperature), PV (pasting viscosity), PKV (peak viscosity), HPV (hot plate viscosity), CPV (cool paste viscosity), BDV (breakdown viscosity), SBV (setback viscosity) and CTV (consistency viscosity). Symbols ***, **, * and . represent p-values 0, 0.001, 0.01, 0.1 and 0.05 respectively

Rice grain with high BDV, PKV and low CTV, CPV, SBV, PT and peak viscosity time were believed to possess soft texture and good eating quality (Liu *et al.*, 2009). The pasting profile properties varied in

rice grains cultivated at lower and higher seasonal temperatures (Tu *et al.*, 2023).

Amylose noted significant negative correlation with PV, HPV, CPV and BDV and the correlation is genotype dependent (Bao *et al.*, 2002). Removal of 1st intron of Wx gene increased AC in the rice grain, however, significant variation was not observed in pasting profiles (Liu *et al.*, 2022). The percentage of grains with chalkiness (PGWC) noted negative association with PKV and BDV in Koshihikari x Kasalath mapping population (Zheng *et al.*, 2012). Variation in pasting profiles were significant from translucent to chalky grains, however, the variation of pasting profiles was non-significant from 5 to 100% increase in the proportion of chalky grain (Chun *et al.*, 2009).

The grain of rice genotypes with similar starch content and composition can vary in pasting properties (Champagna *et al.*, 1999, Bao *et al.*, 2002). The onset of gelatinization and increase in initial viscosity is PT. The maximum viscosity reached during heating is PKV which represents un-gelatinized starch. The swelling of starch granules and pasting is promoted by AP and inhibited by AC (Singh *et al.*, 2006). A higher PKV indicates a greater proportion of un-gelatinized starch and vice versa (Devi *et al.*, 2009). HPV represents the viscosity noted at the end of 5 min of heating at 95°C where breaking of starch granules was noted (Singh *et al.*, 2006). CPV represents the viscosity noted at the end of cooling the gel to 50°C (Bao *et al.*, 1999, Sun *et al.*, 2011). Among the various measured and derived pasting properties, CPV or final viscosity is more relevant to the rice consumer.

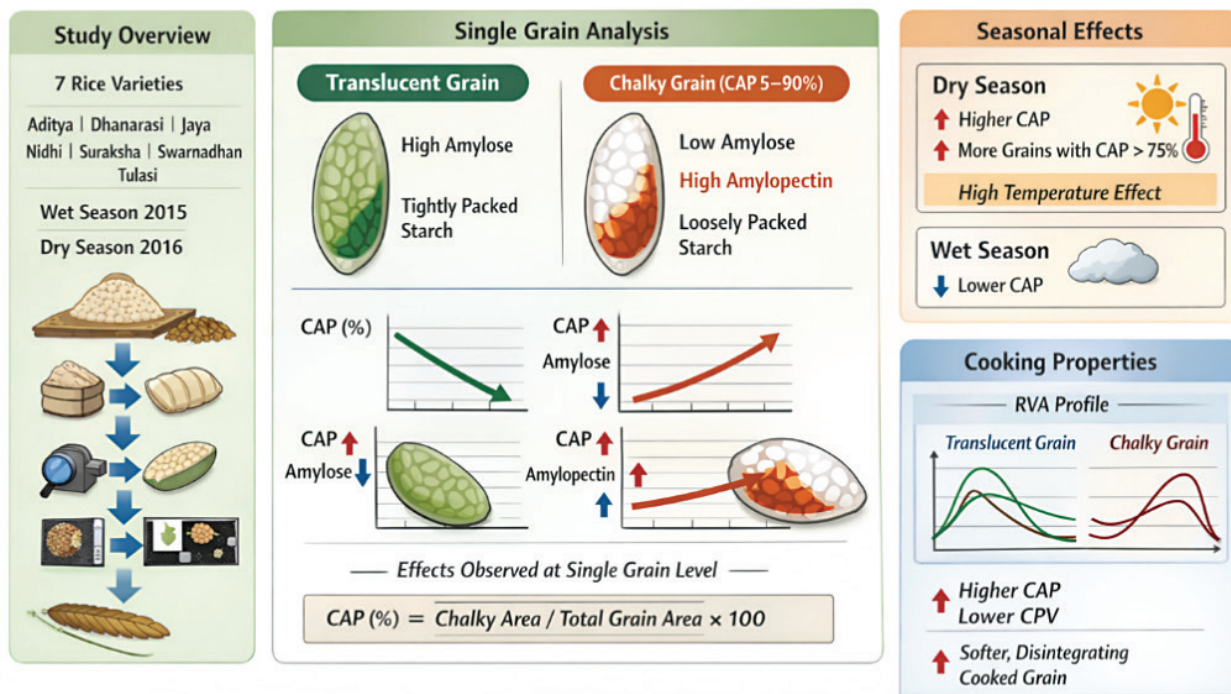
Compared with translucent grains, CPV values were lower in chalky grains. Hence, chalky grains with higher CAP can accumulate lesser AC and more AP with lower CPV. Such cooked grains can behave like low amylose or waxy rice genotypes and can disintegrate with lesser force.

The grain quality of chalkiness is measured manually in a milled rice sample that contains both translucent

and chalky grains. Further, chalkiness is expressed as absent (A), very occasionally chalky (VOC), occasionally chalky (OC) and present (P) if the

number of chalky grains are absent, lesser than 10%, from 11 to 20% and more than 20% in the total sample (Arvind Kumar *et al.*, 2021).

Single-Grain Analysis Reveals Inverse Amylose and Direct Amylopectin Association with Chalky Area in Rice



In conclusion, grains with chalky area percentage (CAP) >75 were more in dry season indicating the influence of environment on chalkiness. Variation in KLAC and VER values was observed in translucent and chalky grains. However, ASV test could not differentiate chalky from translucent grains. Further, amylose content decreased while amylopectin content increased with the increase in CAP. Compared with translucent grains, the four measured and three derived viscosities showed significant variations in the chalky grains. The cool paste or final viscosity values were lower in the chalky grains. The chalky grains with higher CAP can accumulate lesser amylose and more amylopectin and such grains exhibited lower cool paste viscosity. Variation in the cooking quality behaviour of chalky grains is genotype dependent. However, genotypes categorized as VOC may not affect the overall pasting properties or cooking quality of the rice genotype.

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Diversity and Predatory Potential of Coleopteran Species on *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) of Rice

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Abstract

The brown plant hopper, *Nilaparvata lugens* (Stål) is a major insect pest of rice that causes significant losses in yield and grain quality. Coleopteran predators play an important role as biological control agents against rice insect pests. The present study was conducted to investigate the diversity and predatory efficiency of coleopteran species associated with *N. lugens*. Species composition was evaluated using diversity indices such as Shannon-Wiener diversity index (H'), Simpson diversity index (D), Species richness (S) and Species evenness (E). A total of seven predatory coleopteran species were recorded. Among these collected species, *Micraspis discolor* exhibited the highest predatory potential against *N. lugens*. The predatory efficiency of coleopteran species followed the order: *Micraspis discolor* > *Paederus fuscipes* > *Coccinella transversalis* > *Ophionea nigrofasciata* > *Menochilus sexmaculatus* > *Coccinella septempunctata* > *Brumoides suturalis*. Significant H' and D values indicated that the population of coleopteran predators increased with the advancement of crop growth stage. These findings suggest that these natural enemies, particularly coleopteran predators, play a crucial role in suppressing *N. lugens* populations and can contribute to reducing reliance on chemical pesticides in rice ecosystems.

Keywords: Coleoptera, predator, diversity index, species richness, species evenness, pesticides

Introduction

Rice (*Oryza sativa* L.) is one of the most important and oldest cultivated crops in the world that serves as staple food for more than half of the global population. The major rice producing countries are China, India, Pakistan, Southeast Asia, Korea, Japan and other adjacent areas which together contribute about 90 per cent of the global rice production (Kumar, 2022). However, rice cultivation faces several constraints, amongst which insect pests and diseases are responsible for significant annual yield losses (Karthikeyan *et al.*, 2024). The brown plant hopper (BPH), *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae), is one of the most destructive insect pests of rice in Asia. It is a sap-sucking insect that feeds on phloem tissues, causing severe damage through plant desiccation

and ovipositional injury, ultimately leading to a condition known as “hopper burn.” In addition, it acts as a vector of viral diseases such as grassy stunt and ragged stunt (Zulyusri and Anugrah, 2023). *N. lugens* is widely distributed in different parts of the world such as Asia, Australia and Pacific regions including Bangladesh, Burma, Cambodia, China, Hong Kong, Japan, Korea, India, Pakistan, Sri Lanka, Indonesia, Malaysia, Nepal, Philippines, Singapore, Taiwan, Thailand, Vietnam, Caroline Islands, New Guinea and Solomon Islands in Australia and Pacific Islands. The pest is commonly found in irrigated and rainfed rice ecosystems, whereas its occurrence in upland rice is relatively rare (Kingwell-Banham, 2019).

The excessive use of pesticides for pest control in rice has led to the development of pesticide resistance, resurgence of insect pests, and increased cost of production, making such practices unsustainable and economically unviable (Katti, 2013). These challenges have promoted the widespread adoption of Integrated Pest Management (IPM), an ecologically based approach that is compatible with sustainable agricultural systems (Pedigo, 1996). The use of natural enemies, including parasitoids, predators, and pathogens, constitutes a key component of IPM strategies for regulating pest populations in rice ecosystems (Chandra *et al.*, 2017). The rice ecosystem is unique as it comprises both terrestrial and aquatic components, resulting in high ecological complexity and biodiversity (Premila, 2003). Predatory coleopterans are among the most important natural enemies in rice ecosystems and play a crucial role in regulating populations of major insect pests (Tudi *et al.*, 2021). Members of families such as Coccinellidae and Carabidae are effective predators of key rice pests, including plant hoppers, leafhoppers, and other soft-bodied insects, thereby contributing significantly to natural pest suppression (Heong and Hardy, 2009; Horgan *et al.*, 2021). Coleopteran predators are generally polyphagous, highly adaptable, and capable of surviving under diverse environmental conditions, which enhances their effectiveness across different crop growth stages (Symondson *et al.*, 2002). Their high predation rates and active foraging behaviour enable them to efficiently suppress pest populations and maintain ecological stability in rice agroecosystems (Horgan, 2018). In the context of IPM, predatory coleopterans form an essential component of sustainable pest control strategies.

Effective sampling and estimation techniques must be incorporated into biodiversity inventories, especially for hyper-diverse groups of terrestrial creatures like arthropods (Colwell and Coddington, 1994). Accurate identification and enumeration

of individuals to the species level are fundamental for ecological community studies (Gotelli, 2004). A diversity index is a numerical indicator of the number of various types (like species) present in a dataset (a community), and it can also take into account the evolutionary relationships (such as richness, divergence or evenness) among the individuals distributed across those types. In studies involving coleopteran predators, diversity indices serve as important tools for quantifying species composition and ecological relationships within the community. Therefore, the present study was undertaken to investigate the diversity of coleopteran species with the objective of evaluating their predatory potential against *N. lugens* in rice ecosystems. The study aims to generate ecological insights for the effective implementation of IPM strategies.

Materials and Methods

Raising of *N. lugens* population

The present investigation was conducted at the Rice Research Area, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana (30°54'N latitude; 75°48'E longitude and altitude of 247 m above mean sea level) during the *kharif* (wet) crop seasons of 2020, 2021 and 2022. The *N. lugens* population used in the experiment was reared on TN1 plants. Rearing cages were placed in water filled concrete troughs to prevent the entry of natural enemies such as spiders, ants, lizards etc. Thirty days old TN1 plants were used for maintaining the insect culture. The upper ends of the cages were securely tied to prevent the escape of insects. Plants were replaced with fresh ones after complete wilting due to insect feeding. The insect culture was maintained throughout the experimental period to ensure an adequate supply of *N. lugens*. To obtain newly emerged nymphs for experiments, oviposition cages were used, wherein one day old male and female *N. lugens* adults were released for oviposition.



Sampling and collection of coleopteran species

Coleopteran predator species were collected from the paddy crop raised following all recommended agronomic practices of Punjab Agricultural University except for the application of insecticides (Anonymous, 2020). Sampling was carried out from a field of 1500 m² area divided into 60 blocks each measuring 5×5 m from 30 days after transplanting (DAT) until the crop maturity. Collection of predatory beetles was performed using multiple methods. Small beetles were collected by aspirator, whereas large species were collected by sweep net or by manual picking. The collected specimens were handled carefully to avoid injury or mortality and were transferred into small plastic vials for further observations under laboratory conditions.

Functional response to test the effect of prey density on predation

The predatory potential of the collected specimens was evaluated individually in plastic containers (50 cm in diameter and 20 cm in height). In each container, 5, 7 and 10 individuals of 4th-5th instar laboratory reared *N. lugens* nymphs were introduced separately. Small pieces of TN1 paddy plants were placed in each container as food for the nymphs. After 24 hours of starvation, a single beetle was introduced into each container containing a known number of BPH nymphs. A control was maintained at each prey density without beetles. The number of nymphs consumed or killed by each coleopteran species was recorded after 24 hours. The experiment was replicated ten times for each species throughout the cropping season.

Identification of coleopteran specimens

For species identification, the collected beetle specimens were killed and preserved in 90 per cent ethanol. The preserved specimens were critically examined under a stereomicroscope (50× magnification) for identification. Specimens that

could not be identified were preserved separately in 2 mL Eppendorf tubes. Each tube containing a single specimen was properly labelled in duplicate and sent to the National Bureau of Agricultural Insect Resources (Bengaluru) for further identification.

Diversity indices

To estimate the biodiversity of coleopteran species, various diversity indices including Shannon-Wiener diversity index (H'), Simpson diversity index (D), Species richness (S) and Species evenness index (E) were calculated.

The Shannon-Wiener diversity index measures species diversity in a community and is calculated by formula:

$$H' = -\sum p_i \ln(p_i)$$

where, H' is the index of diversity, p_i is the proportion of individuals found in the i^{th} species and $\ln$ is the natural logarithm.

Simpson's Diversity Index takes into account the number of species present, as well as the relative abundance of each species and it is calculated by the formula:

$$D = \frac{1 - \sum n_i(n_i - 1)}{N(N - 1)}$$

where, n is the total number of organisms of a particular species and N is the total number of organisms of all species.

Species evenness index (E) is a measure of the relative abundances of species within a community and is calculated by formula:

$$E = H' / \ln S$$

where, H' = Shannon -Wiener diversity index, $\ln$ = Natural logarithm

Species richness (S) represents total number of species in a community. It is calculated by formula:

$$D = n - 1 / \ln N$$

where, n = number of species recorded, N = the total number of individuals in the sample.

Statistical analysis

One-way Analysis of variance (ANOVA) following post-hoc comparison with Tukey's honestly significant difference (HSD) was used to test the significance of treatments. Statistical analysis was performed using v. 13.0 statistical program (SPSS, 2004).

Results and Discussion

Species recorded

During the three experimental years, seven species belonging to three different families were recorded, all of which showed significant predation against *N. lugens*. Among these, five species belonged to the family Coccinellidae, namely *Micraspis discolor*, *Coccinella transversalis*, *Menochilus sexmaculatus*, *Coccinella septempunctata* and *Brumoides suturalis*. One species each belonged to the families Staphylinidae (*Paederus fuscipes*) and Carabidae (*Ophionea nigrofasciata*). The predominance of coccinellid beetles in the present study highlights their crucial role as natural enemies in rice ecosystems. Coccinellids are widely recognized as efficient generalist predators of soft bodied insect pests, including plant hoppers, thereby contributing significantly to biological control (Hodek *et al.*, 2012; Pervez, 2016). Furthermore, the presence of predator species from different families suggests a complementary and synergistic role in pest suppression. Diverse predator assemblages are known to enhance biological control efficiency by increasing prey capture rates and reducing pest outbreaks (Snyder, 2019).

Predatory potential

The predatory potential of coleopteran species against *N. lugens* varied considerably among species at all prey densities (Table 1, 2 and 3). The overall order of predatory efficiency was recorded as *M. discolor* > *P. fuscipes* > *C. transversalis* > *O. nigrofasciata* > *M. sexmaculatus* > *C. septempunctata* > *B. suturalis*.

The higher predatory performance of *M. discolor* indicates its strong feeding ability and adaptability under rice ecosystem conditions, making it a key natural enemy of *N. lugens*. The relatively higher efficiency of *P. fuscipes* and *C. transversalis* further highlights the important role of both staphylinid and coccinellid beetles in regulating pest populations. The observed variation in predation among species may be attributed to differences in feeding behaviour, searching efficiency, and prey handling capacity. The presence of multiple predator species with varying predatory potential suggests a complementary role in pest suppression, thereby enhancing the stability of biological control in agroecosystems (Landis *et al.*, 2000; Snyder, 2019). However, the comparatively lower predatory potential of *C. septempunctata* and *B. suturalis* may be due to species-specific feeding preferences or lower adaptability to the given conditions. Overall, the findings emphasize the importance of conserving diverse coleopteran predators for sustainable management of *N. lugens* in rice ecosystems (Heong *et al.*, 2015).

Table 1: Prey consumption rates of rice field coleopteran predators of *N. lugens* in the laboratory at 5 prey density (Handling time 24 hours)

Species	Mean number of nymphs consumed per day $\pm$ S.E	Percentage predation (%)
<i>Micraspis discolor</i>	4.1 $\pm$ 0.53 ^a	82
<i>Paederus fuscipes</i>	3.9 $\pm$ 0.53 ^{ab}	78
<i>Coccinella transversalis</i>	3.4 $\pm$ 0.66 ^{bc}	72
<i>Ophionea nigrofasciata</i>	3.2 $\pm$ 0.74 ^d	64
<i>Menochilus sexmaculatus</i>	2.4 $\pm$ 0.48 ^d	48
<i>Coccinella septempunctata</i>	1.9 $\pm$ 0.7 ^{de}	38
<i>Brumoides suturalis</i>	1.5 $\pm$ 0.92 ^e	30

F_{11,119} 19.89, P<0.001

Table 2: Prey consumption rates of rice field coleopteran predators of *N. lugens* in the laboratory at 7 prey density (Handling time 24 hours)

Species	Mean number of nymphs consumed per day $\pm$ S.E	Percentage predation (%)
<i>Micraspis discolor</i>	6.2 $\pm$ 0.97 ^a	88.57
<i>Paederus fuscipes</i>	5.8 $\pm$ 0.74 ^{ab}	82.85
<i>Coccinella transversalis</i>	5.1 $\pm$ 0.94 ^{bc}	72.85
<i>Ophionea nigrofasciata</i>	4.7 $\pm$ 1.1 ^{cd}	67.14
<i>Menochilus sexmaculatus</i>	4 $\pm$ 1.61 ^{de}	57.14
<i>Coccinella septempunctata</i>	3.3 $\pm$ 0.9 ^{ef}	47.14
<i>Brumoides suturalis</i>	2.7 $\pm$ 0.92 ^f	38.57

F_{11,119} 13.25, P<0.001

Table 3: Prey consumption rates of rice field coleopteran predators of *N. lugens* in the laboratory at 10 prey density (Handling time 48 hours)

Species	Mean number of nymphs consumed per day $\pm$ S.E	Percentage predation (%)
<i>Micraspis discolor</i>	8.00 $\pm$ 0.89 ^{ab}	80
<i>Paederus fuscipes</i>	7.60 $\pm$ 1.28 ^{ab}	76
<i>Coccinella transversalis</i>	6.90 $\pm$ 1.22 ^{bc}	69
<i>Ophionea nigrofasciata</i>	6.30 $\pm$ 1.61 ^{bc}	63
<i>Menochilus sexmaculatus</i>	5.30 $\pm$ 2.45 ^{cd}	52
<i>Coccinella septempunctata</i>	4.60 $\pm$ 1.42 ^{de}	46
<i>Brumoides suturalis</i>	3.70 $\pm$ 1.41 ^e	37

F_{11,119} 9.60, P<0.001

Diversity indices

The biodiversity of coleopteran species varied across different prey densities (**Table 4**). The Shannon–Wiener diversity index ranged from 1.89 to 3.83, with the highest value recorded at a prey density of 10 (3.83), indicating greater species diversity at higher prey availability. At lower prey densities of 5 and 7, the diversity index values were comparatively lower (1.89 and 1.91, respectively). Simpson’s diversity index showed only slight variation across prey densities, ranging from 0.151 to 0.157, indicating relatively stable dominance patterns among species. The highest value (0.157) was observed at a prey density of 5, while the lowest (0.151) was recorded at a prey density of 10. Species evenness index values were relatively similar across treatments, ranging from 1.03 to 1.07, suggesting a uniform distribution of individuals among species irrespective of prey

density. The highest evenness (1.07) was observed at prey density 5. Species richness showed variation across prey densities, with the highest value recorded at prey density 7(1.01), followed by prey density 5(0.97), while the lowest richness (0.5) was observed at prey density 10. The higher Shannon-Wiener index at increased prey density suggests that greater prey availability supports a more diverse predator community, likely due to reduced competition and enhanced resource utilization. Similar observations have been reported by Heong *et al.*, 2015 and Snyder, 2019, who emphasized that increased prey abundance promotes predator diversity in agroecosystems. The predator community remained relatively stable across different prey densities, suggesting balanced species distribution and efficient resource utilization (Landis *et al.*, 2000).

Table 4: Diversity indices of spiders at rice phenological stages

Sl No.	Prey density	Shannon-Wiener diversity index (H')	Simpson's Diversity Index (D)	Species evenness index (E)	Species richness (S)
1	5	1.89	0.157	1.07	0.97
2	7	1.91	0.152	1.03	1.01
3	10	3.83	0.151	1.06	0.5

Conclusion

The present study demonstrated that diverse coleopteran predators play a significant role in the biological control of *N. lugens* in rice ecosystems. Among the species evaluated, *M. discolor* exhibited the highest predatory potential, followed by *P. fuscipes* and *C. transversalis*, indicating their effectiveness as key natural enemies. The variation in predatory efficiency among species highlights the importance of predator diversity in ensuring stable and efficient pest suppression. Overall, the findings emphasize that conservation and promotion of native predator fauna can enhance sustainable pest management and reduce reliance on chemical insecticides in rice cultivation.

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Field Efficacy of Bio-pesticides and Botanical Insecticides Against Rice Plant Hoppers

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Abstract

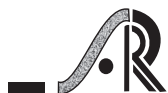
To evaluate the efficacy of bio-pesticides, botanical and chemical treatments for the management of rice sucking insect pests field experiments were conducted during *kharif* 2023 and 2025 crop seasons. The study was laid out in a randomized block design using a susceptible high-yielding variety (PR121), with observations recorded on hopper population, spider abundance and grain yield. Treatments included entomopathogenic fungi (*Lecanicillium saksenae*, *Metarhizium anisopliae*, *Beauveria bassiana*), a botanical insecticide (*azadirachtin*), and a chemical insecticide (*pymetrozine*), along with an untreated control. Pest populations were monitored before spraying and at 7 and 15 days after each application. Results indicated that all treatments significantly reduced hopper populations compared to the control in both seasons. Chess @ 300 g ha⁻¹ consistently recorded the highest reduction in pest density and the maximum grain yield. Among biological treatments, *L. saksenae* (2023) and *B. bassiana* (2025) showed moderate but significant efficacy, while *azadirachtin* provided intermediate control. Biological and botanical treatments maintained relatively stable spider populations, whereas chemical treatment caused a noticeable decline in predator abundance. Grain yield was positively correlated with effective pest suppression, with treated plots producing significantly higher yields than the untreated control. The study demonstrates that although chemical control provides rapid and reliable suppression of sucking pests, bio-pesticides and botanical offer environmentally safer alternatives with better conservation of natural enemies. Integration of bio-pesticides and selective insecticides in an integrated pest management (IPM) framework is recommended for sustainable and eco-friendly rice production.

Keywords: Brown plant hopper, *azadirachtin*, *Lecanicillium saksenae*, *Metarhizium anisopliae*, *Beauveria bassiana*.

Introduction

Rice (*Oryza sativa* L.) is one of the most important staple food crops in the world that serves as the primary source of food for more than half of the global population. Global rice production reached about 800 million tonnes in 2023, with Asian countries contributing nearly 90% of the total production and consumption (FAO, 2025). Despite advances in agronomy, genetics, and crop protection, rice

productivity continues to be constrained by biotic stresses, notably insect pests. Among these, sucking insect pests such as *Nilaparvata lugens* (brown plant hopper), *Sogatella furcifera* (white backed plant hopper), and *Leptocorisa acuta* (rice bug) are particularly damaging, causing significant yield losses and adversely affecting grain quality (Heong and Hardy, 2009; Khush, 2013; Fahad *et al.*, 2015).



Sucking pests cause significant damage to rice plants through direct feeding and oviposition punctures. These insects extract phloem sap from plant tissues, resulting in symptoms such as hopper burn, chlorosis, stunted growth and under severe infestation, plant death. In addition to direct feeding damage, several sucking pests also act as vectors of plant pathogens, particularly viruses, thereby exacerbating yield losses (Cabauatan *et al.*, 2009; Horgan *et al.*, 2015). The complex interactions among pests, host plants and associated pathogens highlight the importance of adopting integrated pest management (IPM) strategies tailored to local agro-ecological conditions (Heong *et al.*, 2015; Bottrell and Schoenly, 2012).

The economic significance of sucking pests in rice production is considerable. In many Asian countries, outbreaks of the brown plant hopper *N. lugens* have caused severe yield losses and have affected millions of hectares of rice cultivation. Historical outbreaks during the 1970s and early 2000s resulted in substantial crop losses and forced changes in varietal deployment and pest management practices (Wu *et al.*, 2020; Iamba and Dono 2021). More recent studies also report periodic resurgence of plant hopper populations associated with intensive rice cultivation and indiscriminate pesticide use (Bottrell and Schoenly, 2012; Horgan, 2024). Overreliance on chemical insecticides has often aggravated pest problems by disrupting natural enemy populations and accelerating the development of insecticide resistance in pest populations (Heong and Schoenly, 2000; Matsumura *et al.*, 2020).

Traditionally, management of sucking insect pests relied heavily on the frequent application of broad-spectrum chemical insecticides. However, overreliance on such chemicals has led to several ecological problems, including pest resurgence, secondary pest outbreaks, environmental contamination and disruption of beneficial arthropod communities. In addition, continuous use of the same

chemical groups has accelerated the development of resistance in pest populations, reducing the long-term effectiveness of many insecticides (Fujii *et al.*, 2020; Horgan *et al.*, 2022). Consequently, modern pest management strategies increasingly emphasize integrated pest management (IPM), which combines cultural practices, host plant resistance, biological control agents, botanicals and selective insecticides in an environmentally sound manner (Isman, 2015; Karthikeyan, 2019; Sparks *et al.*, 2021). Keeping these points in mind the present studies were conducted to evaluate the efficacy of bio-pesticides, botanical against rice plant hoppers under field conditions.

Materials and Methods

Experimental site and crop variety

The field experiments were conducted during *kharif* 2023 and 2025 rice-growing seasons at the Rice Research Farm, Punjab Agricultural University under natural field conditions. A susceptible high-yielding rice variety PR121 was selected for the study to ensure uniform pest infestation and effective evaluation of treatments.

Experimental design and layout

The experiment was laid out in a Randomized Block Design (RBD) with five treatments (2023) and four treatments (2025) with four and five replications, respectively. Each treatment was randomly allocated within each replication. The size of each experimental plot was 45.36 m² and 35.20 m² during *kharif* 2023 and 2025 crop seasons, respectively.

Crop establishment and agronomic practices

Rice seedlings were raised in a nursery and 30-day-old seedlings were transplanted in the field. Transplanting was done at a spacing of 20×15 cm, maintaining two seedlings per hill. All recommended agronomic practices such as irrigation, fertilization, and weed management were followed uniformly for all plots throughout the cropping period, except for pest control measures.

Treatments

During *kharif* 2023, three bio-pesticides were received from Indian Institute of Rice Research, Hyderabad that comprises of a total of five treatments

T₁: *Lecanicillium saksenae* @ 1x10⁷cfu /ml KAU 7714 (20 g talc formulation/L); **T₂:** *Metarhizium anisopliae* @ 1x 10⁸ spores per ml NBAIR Bb 5 (20 g talc formulation/L); **T₃:** *Beauveria bassiana* @ 1x 10⁸ spores per ml NBAIR Bb 5 (20 g talc formulation/L); **T₄:** Chess 50 WG (pymetrozine) @ 300 g/ha, Osheen 20 SG (dinotefuran); **T₅:** Untreated control

Similarly, during *kharif* 2025 a bio-pesticide and a botanical pesticide were received from Indian Institute of Rice Research, Hyderabad that comprises of a total four treatments: **T₁:** *Beauveria bassiana* @ 1x 10⁸ spores per ml NBAIR Bb 5 (20 g talc formulation/L); **T₂:** Chess 50 WG (pymetrozine) @ 300 g/ha, Osheen 20 SG (dinotefuran); **T₃:** *Azadirachtin* 0.005% (Azadin plus) @ 5ml/L; **T₄:** Untreated control

Preparation and application of treatments

The required quantity of each treatment was prepared fresh before the application. *B. bassiana* talc, *L. saksenae* and *M. anisopliae* formulations were mixed in water at the rate of 20 g L⁻¹ and thoroughly stirred to obtain a uniform suspension. Pymetrozine, Dinotefuran and *azadirachtin* were prepared as per the recommended doses under treatments.

Spraying was carried out using a knapsack sprayer fitted with a hollow cone nozzle to ensure uniform coverage and directing the spray towards the base of the plants. Treatments were applied when the pest population reached the economic threshold level. All sprays were conducted during calm weather conditions in the morning hours to minimize drift and ensure maximum efficacy.

Observations on sucking pest population and yield

Observations of plant hoppers on rice were recorded at regular intervals. Pest population was assessed by counting the number of hoppers per hill from

randomly selected 25 hills in each plot. Pre-treatment observations were recorded one day before spraying, while post-treatment observations were taken at 7 and 15 days after each spray. Spider populations were recorded once from ten hills per plot before treatment at the time of the second spray, and again 15 days after the treatments. At maturity, the crop from each plot was harvested separately and grain yield was recorded.

Statistical analysis

The data on pest population and grain yield were subjected to analysis of variance (ANOVA) appropriate for a Randomized Block Design (RBD). Treatment means were compared using the least significant difference test at the 5% probability level to determine significant differences among treatments. Statistical analyses were performed using CPCS1 and SPSS (Version 16.0) software. The corrected per cent reduction of plant hopper population over control after the application of bio-pesticides, botanical and insecticide was calculated using Henderson-Tilton formula (1955).

$$\text{Corrected \% Reduction} = \left[1 - \frac{(\text{Ta} \times \text{Cb})}{(\text{Tb} \times \text{Ca})} \right] \times 100$$

Ta : Number of insects in treated plot after treatment, **Tb** : Number of insects in treated plot before treatment; **Ca** : Number of insects in control plot after treatment, **Cb** : Number of insects in control plot before treatment.

Results and Discussion

The plant hopper population differed significantly among treatments during the *kharif* 2023 cropping season (**Table 1**). Before the first spray, hopper population was uniformly distributed among treatments, ranging from 177.75 to 185.75 hoppers per 25 hills, indicating homogeneity of initial infestation across experimental plots. All treatments significantly reduced hopper populations compared with the untreated control (**Table 1**). Among the



biological treatments, in case of *L. saksenae* plant hopper populations decreased by 49.47% and 58.18% at 7 and 15 days after spray (DAS) after the first spray, respectively. Further reduction of hopper population was also observed following the second spray of *L. saksenae*. *M. anisopliae* also showed considerable efficacy, reducing hopper density by 42.69% and

54.08% after the first spray, likewise the reduction in plant hopper population after the second spray (**Table 1**). Similarly, *B. bassiana* reduced hopper populations by 39.92% and 48.29% after the first spray and similar trend was observed after the application of second spray of *B. bassiana*.

Table 1: Efficacy of bio-pesticides against rice plant hopper during kharif 2023

Treatments	No. of hoppers 25 hills ⁻¹						Spiders no. 10 hills ⁻¹		Yield q ha ⁻¹
	1 st Spray			2 nd Spray			Pre	Post	
	PC	7 DAS	15 DAS	PC	7 DAS	15 DAS			
<i>Lecanicillium saksenae</i> @ 1x10 ⁷ cfu /ml KAU 7714 (20 g talc formulation/L)	177.75	99.25 ^b	90.25 ^b	103.25 ^b	78.50 ^b	73.50 ^b	11.25	10.0 ^b	74.19 ^b
<i>Metarhizium anisopliae</i> @ 1x 10 ⁸ spores per ml NBAIR Bb 5 (20 g talc formulation/L)	185.75	108.25 ^c	104.00 ^c	121.00 ^c	96.50 ^c	92.00 ^c	11.75	10.5 ^{bc}	71.87 ^c
<i>Beauveria bassiana</i> @ 1x 10 ⁸ spores per ml NBAIR Bb 5 (20 g talc formulation/L)	180.75	120.00 ^d	113.50 ^d	152.75 ^d	111.00 ^d	107.00 ^d	11.25	10.0 ^b	68.91 ^d
Chess @ 300 g/ha; Osheen @ 200 g/ha	177.75	46.50 ^a	37.50 ^a	49.75 ^a	22.50 ^a	20.50 ^a	11.00	6.75 ^a	76.37 ^a
Control	180.75	199.75 ^d	219.50 ^e	226.25 ^e	232.50 ^e	248.00 ^e	11.25	14.25 ^d	66.52 ^e
CD (p=0.05)	NS	0.29	0.39	0.36	0.36	0.36	NS	0.19	3.61

*Values with different alphabetic superscripts are significantly different (p<0.05) with respect to different columns

The effectiveness of these entomopathogenic fungi is associated with their infection-based mode of action. Fungal conidia attach to the insect cuticle, germinate and penetrate the host integument through mechanical pressure and enzymatic degradation involving proteases, chitinases and lipases. After entering the hemocoel, the fungi proliferate within the insect body and produce secondary metabolites and toxins that disrupt physiological processes, ultimately causing host mortality. This gradual infection process explains the slower yet sustained suppression compared with chemical insecticides. Among the fungi evaluated against rice plant hoppers, *L. saksenae* exhibited the highest efficacy, followed by *M. anisopliae* and *B. bassiana*. These findings are consistent with earlier studies by Shaikh and Mohite (2015), Shah and Pell (2003), who reported effective rice plant hopper population suppression through fungal pathogenicity mechanisms. In contrast, untreated control plots showed a continuous increase in plant hopper

population throughout the crop season, rising from 180.75 to 248.00, indicating severe infestation under untreated conditions (**Table 1**).

Spider populations were comparatively less affected in biologically treated plots. Treatments involving *Lecanicillium*, *Metarhizium* and *Beauveria* maintained relatively stable spider numbers, with only slight reductions following spraying. However, the chemical treatment resulted in a marked decline in spider population (from 11.00 to 6.75 (10 hills⁻¹)), indicating adverse effects on natural enemies. The control plot exhibited an increase in spider population due to higher prey availability (**Table 1**).

The conservation of spider populations in biologically treated plots highlights the compatibility of entomopathogenic fungi with natural enemies. In contrast, chemical treatment caused a substantial decline in spider density, potentially disrupting ecological balance and increasing the risk of pest resurgence. Conservation of natural enemies is

essential for sustainable pest management in rice ecosystems (Anonymous, 2023).

Grain yield was significantly influenced by different treatments. The highest yield (76.37 q ha^{-1}) was recorded in plots treated with insecticides, followed by *L. saksenae* (74.19 q ha^{-1}) and *B. bassiana* (68.91 q ha^{-1}), whereas the lowest yield (66.53 q ha^{-1}) was observed in the control plot (**Table 1**). Similar relationships between hopper suppression and yield improvement were reported by Pathak and Khan (1994) and also in the reports of All India Co-ordinated Research project on Rice findings in India (Anonymous, 2024).

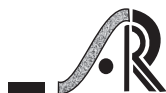
The present investigation revealed a significant reduction in plant hopper population following the application of *B. bassiana*, confirming its effectiveness as a biological control agent under field conditions. After the first spray of *B. bassiana* during *kharif* 2025, hopper density decreased by 34.09% at 7 DAS, indicating an initial suppressive effect, while the continued reduction at 15 DAS demonstrated sustained infection pressure compared with untreated control plots (**Table 2**). Notably, the efficacy of *B. bassiana* was justified in comparison with other treatments, and its performance was markedly superior after the second spray than after a single application. A more pronounced reduction observed after the second spray (51.13% at 7 DAS) further suggests cumulative fungal activity and enhanced secondary transmission within hopper populations. Such delayed mortality is a characteristic feature of fungal bio-pesticides, where infection occurs through spore adhesion, germination, cuticle penetration, and internal proliferation leading to host death. The results obtained in the present study are in agreement with earlier findings that entomopathogenic fungi, particularly *B. bassiana* and *M. anisopliae*, are effective against rice plant hoppers and other homopteran pests. The consistent decline in hopper density observed during the *kharif* 2023 and 2025 crop seasons clearly indicates the progressive pathogenic action of the entomopathogenic fungus.

Several studies have reported that *B. bassiana* and *M. anisopliae* can significantly reduce populations of homopteran pests through pathogenic infection and epizootic spread under favourable environmental conditions (Shahid *et al.*, 2012; Mascarin and Jaronski, 2016). The gradual reduction in hopper density observed during the *kharif* 2023 and 2025 cropping seasons suggests the progressive pathogenic action of the fungus and the potential establishment of fungal inoculums in the field ecosystem.

The effectiveness of *B. bassiana* against plant hoppers has also been attributed to its ability to persist in the environment and infect multiple life stages of the insect host. Studies have indicated that entomopathogenic fungi can act as important components of integrated pest management programs by providing environmentally safe and sustainable alternatives to chemical insecticides (Vega *et al.*, 2012; Lacey *et al.*, 2015). Furthermore, recent research emphasizes the growing importance of microbial bio-pesticides in rice ecosystems, as they reduce chemical pesticide dependency while preserving beneficial arthropods and ecological balance (Mantzoukas and Eliopoulos, 2020; Sparks *et al.*, 2021).

The botanical insecticide Azadirachtin (0.005%) also provided significant suppression of hopper populations. After the first spray, hopper density decreased by 50.47% at 7 DAS, with similar reductions following the second spray. Azadirachtin acts primarily as an insect growth regulator and anti-feedant. It interferes with hormonal regulation by disrupting ecdysone activity, inhibiting molting and metamorphosis, while also acting as a feeding deterrent and oviposition inhibitor (Katti, 2013; Mascarin and Jaronski, 2016).

Supporting evidence from several recent studies indicates that neem-based botanical products exert strong behavioral and physiological effects on sucking insect pests, particularly the brown plant hopper (*N. lugens*). Laboratory and greenhouse experiments



have demonstrated that neem formulations containing azadirachtin significantly influence host orientation, settling behaviour and feeding activity of plant hoppers. Treated rice plants often become less attractive to insects, resulting in delayed probing and reduced feeding duration. Such behavioral modifications ultimately decrease the amount of

phloem sap ingested by the insects (Isman, 2015; Sparks *et al.*, 2021). In contrast, untreated control plots exhibited a continuous increase in hopper population throughout the observation period, rising from 166.6 to 387.2, indicating severe infestation under untreated conditions (**Table 2**).

Table 2: Efficacy of bio-pesticide and botanical against rice plant hopper during *kharif* 2025

Treatments	No. of hoppers 25 hills ⁻¹						Spiders no. 10 hills ⁻¹		Yield q ha ⁻¹
	1 st Spray			2 nd Spray			Pre	Post	
	PC	7 DAS	15 DAS	PC	7 DAS	15 DAS			
<i>Beauveria bassiana</i> @ 1x 10 ⁸ spores per ml NBAIR Bb 5 (20 g talc formulation/L)	161.60 ^a	123.60 ^c	187.60 ^c	204.60 ^c	121.20 ^c	181.60 ^c	11.60	10.20 ^c	54.48 ^c
Chess @ 300 g/ha; Osheen @ 200 g/ha	165.40 ^b	56.60 ^a	98.60 ^a	119.60 ^a	90.80 ^a	106.80 ^a	12.00	9.00 ^b	61.09 ^a
Azadirachtin (0.005%)	172.40 ^d	98.60 ^b	159.60 ^b	177.80 ^b	101.60 ^b	154.00 ^b	11.40	8.20 ^a	57.95 ^b
Control	166.60 ^b	192.40 ^d	225.80 ^d	299.60 ^d	363.20 ^d	387.20 ^d	12.00	14.20 ^d	51.07 ^d
CD (p=0.05)	0.28	0.35	0.44	0.19	0.33	0.40	NS	0.57	0.74

*Values with different alphabetic superscripts are significantly different (p<0.05) with respect to different columns

During the *kharif* 2023 crop season, spider populations were comparatively less affected in plots treated with bio-pesticides and botanical formulations. Similar trends were observed during the *kharif* 2025 crop season, where treatments with *B. bassiana* and azadirachtin maintained relatively stable spider populations with only minor reductions following application. In contrast, the chemical treatment resulted in a noticeable decline in spider abundance (from 12 to 9 individuals per 10 hills), indicating possible adverse effects on beneficial arthropods (**Table 2**). The control plots, however, recorded higher spider populations, which could be attributed to greater prey availability in the absence of pest control interventions. The relatively lower impact of botanical treatments on natural enemies may be attributed to their selective mode of action. Neem-derived compounds are known to exhibit repellent and anti-feedant properties that primarily affect the feeding behaviour of insect pests rather than causing immediate mortality. Experimental

studies have demonstrated that exposure to neem extracts and azadirachtin significantly reduces feeding activity, suppresses growth and interferes with the normal development of brown plant hopper (*N. lugens*) nymphs (Mascarin and Jaronski, 2016; Mantzoukas and Eliopoulos, 2020). Such selective effects make botanical insecticides comparatively safer to beneficial organisms such as spiders and other predatory arthropods. These observations support the principles of ecological pest management, which emphasize the conservation of natural enemies and biodiversity within agroecosystems (Anonymous, 2023).

Yield data revealed that the highest grain yield (61.09 q ha⁻¹) was recorded in plots treated with insecticides, followed by Azadirachtin (57.95 q ha⁻¹) and *B. bassiana* (54.48 q ha⁻¹) as compared to control (51.07 q ha⁻¹). Effective pest suppression therefore translated into improved crop productivity (Pathak and Khan, 1994; Anonymous, 2023). A comparative evaluation of crop performance revealed that

rice yield was significantly higher in *kharif* 2023 compared to *kharif* 2025 crop season. The observed decline in yield and treatment performance during *kharif* 2025 may also be primarily attributed to unfavourable climatic conditions prevailing in Punjab, particularly excessive and uneven monsoon rainfall, cloudy weather conditions during active growth period of the crop. These aberrant weather conditions adversely affected crop growth, development and ultimately also led to reduced productivity (Anonymous, 2025).

The chemical treatments proved to be the most effective treatment for the management of rice plant hopper populations across both the cropping seasons (**Tables 1 and 2**). These consistent reductions across seasons clearly indicate the superior efficacy of insecticides in suppressing hopper populations under field conditions. The effectiveness of Chess and Osheen may be attributed to its active ingredients, pymetrozine and dinotefuran, a selective systemic insecticide specifically targeting sucking insect pests. Unlike conventional neurotoxic insecticides, pymetrozine primarily acts by inhibiting feeding behaviour, while dinotefuran acts on nicotinic acetylcholine receptors in the insect nervous system. Chess interferes with the chordotonal sensory organs of insects, disrupting stylet insertion and preventing sap ingestion, whereas, Osheen causes continuous nerve stimulation, paralysis and finally insect death. As a result, exposed insects cease feeding shortly after treatment and gradually die due to starvation and dehydration rather than immediate toxic effects (Nauen and Denholm, 2005; Anonymous, 2023).

Overall, the results suggest that although chemical control provides rapid and maximum suppression of hopper populations through disruption of insect growth and development, biological control agents offer sustainable alternatives by inducing pathogen-mediated mortality while conserving natural

enemies. Integration of bio-pesticides with need-based chemical applications can therefore contribute to environmentally friendly and sustainable rice production systems.

Conclusion

The field experiments demonstrated that bio-pesticides, botanicals, and insecticide treatments significantly reduced hopper populations and improved rice yield compared with the untreated control. Among the treatments, insecticides provided the highest level of rice plant hopper suppression and resulted in maximum grain yield, although it showed some negative effects on spider populations. Biological agents, particularly *L. saksenae* and *B. bassiana*, along with Azadirachtin, offered moderate but effective control while conserving natural enemies, indicating their ecological compatibility. Overall, the results suggest that integrating bio-pesticides and botanicals with need-based chemical applications can provide an effective and environmentally sustainable strategy for hopper management in rice under Integrated Pest Management (IPM) programmes.

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Conflict of interest

There is no conflict of interest between the authors

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Suitable Fungicides and Bio-Formulation Combination for Management of Sheath Blight Disease in Rice

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Abstract

Field experiments were conducted at M S Swaminathan Rice Research Station, Moncompu, Alappuzha, Kerala, for four consecutive seasons of *Kharif* 2022, *Rabi* 2022-23, *Kharif* 2023 and *Kharif* 2024 with the objective of evaluating the efficiency of commercially available biofertilizer/biocontrol agents and fungicides against rice sheath blight disease. The tested biofertilizer and biocontrol agent combination treatments were *Pseudomonas fluorescens* seed treatment (10 g/kg seed) + PGPR I soil application (1 kg/acre) + PGPR II foliar application (20 g/l), *Pseudomonas fluorescens* seed treatment (10 g/kg seed) + PGPR II foliar spray (20 g/l), and *Pseudomonas fluorescens* seed treatment (10 g/kg seed) + soil application (1 kg/acre) + foliar application (20 g/l). The evaluated fungicides were Hexaconazole 4% + Zineb 68% WP (2.5 g/l), Azoxystrobin 18.2% + Difenconazole 11.4% SC (1 ml/l), Thifluzamide 24% SC (0.8 ml/l), Difenconazole 25% EC (0.5 ml/l), Isoprothiolane 40% EC (1.5 ml/l), Carbendazim 12% + Mancozeb 63% WP (1.5 g/l), Copper Hydroxide 77% WP (2 g/l) and Hexaconazole 5% SC (2 ml/l) (Standard Check fungicide). Among eight fungicides tested, Azoxystrobin 18.2% + Difenconazole 11.4% SC (1 ml/l) was found to be the most promising combination molecule against sheath blight, followed by Thifluzamide 24% SC (0.8 ml/l). The maximum yield was obtained from Difenconazole 25% EC (0.5 ml/l) (6382 kg/ha), and Azoxystrobin 18.2% + Difenconazole 11.4% SC (1 ml/l) (6207 kg/ha), followed by Carbendazim 12% + Mancozeb 63% WP (1.5 g/l) (5837 kg/ha), Thifluzamide 24% SC (0.8 ml/l) (5771 kg/ha) and organic treatment such as *Pseudomonas fluorescens* seed treatment (10 g/kg seed) + PGPR I (1 kg/acre) + PGPR II (20 g/l) with an yield of 5746 kg/ha was also recorded. The control plot recorded the lowest yield of 3697 kg/ha.

Keywords: Rice, Sheath blight, biofertilizer, biocontrol agents, combination fungicide

Introduction

Rice (*Oryza sativa* L.) is a member of the Poaceae family, specifically the genus *Oryza*. It emerged as a wild grass prior to establishing as a crop and is now a staple diet for millions of people worldwide (Prasad *et al.*, 2018). However, rice production worldwide is affected by various biotic and abiotic stresses. Rice sheath blight disease, caused by *Rhizoctonia solani*, is one of the most destructive diseases affecting rice, leading to large scale yield losses especially in the areas such as the U.S.A, Japan, China, and India, where intensive agricultural practices are being followed (Gautam *et al.*, 2003). Under favourable

environmental conditions, sheath blight fungus can reduce yield by up to 50% (Richa *et al.*, 2016). Sclerotia live in the remains of host plants as either mycelia or sclerotia. During the infection process, the sclerotia float to the top of the flooding water in the rice fields and germinate on the rice sheaths to create appressoria or infection cushions. Plants from around 32 families and 188 species can be infected by the pathogen, which has a broad host range (Srinivasachary *et al.*, 2011).

Early symptoms of sheath blight include oval-shaped sheath spots at or just above the water level, often

at the junction of the leaf and sheath. It frequently attacks and kills both leaves and sheaths. In extreme circumstances, sheath blight can infect the panicle, preventing entire grain fill and adhering panicles into a vertical spike. In the current study, various fungicides and bioagents currently in the market were used in field experiments to control sheath blight of rice, taking into account the severity of the illnesses and their economic significance.

Materials and Methods

Field experiments were conducted at MSSwaminathan Rice Research Station, Moncompu, Alappuzha, Kerala for four seasons (*Kharif 2022*, *Rabi 2022-23*, *Kharif 2023* and *Kharif 2024*) with the objective of evaluating the efficiency of commercially available biofertilizer/biocontrol agents and fungicides against rice sheath blight disease. The tested biofertilizer and biocontrol agent combination was *Pseudomonas fluorescens* seed treatment (10 g/kg seed) + PGPR I (soil - 1 kg/acre) + PGPR II (foliar - 20 g/l), *Pseudomonas fluorescens* seed treatment (10 g/kg seed) + PGPR II (foliar - 20 g/l), and *Pseudomonas fluorescens* seed treatment (10 g/kg seed) + soil application (1 kg/acre) + foliar (20 g/l). The KAU biofertilizer PGPR I contain *Azospirillum lipoferum*, *Azotobacter chroococcum*, *Bacillus megaterium* and *Bacillus sporothermodurans*. The biocontrol agent PGPR mix-II contains *Pseudomonas fluorescens* and *Bacillus subtilis*. The evaluated fungicides were Hexaconazole 4% + Zineb 68% WP (2.5 g/l), Azoxystrobin 18.2% + Difenoconazole 11.4% SC (1 ml/l), Thifluzamide 24% SC (0.8 ml/l), Difenoconazole 25% EC (0.5 ml/l), Isoprothiolane 40% EC (1.5 ml/l), Carbendazim 12% + Mancozeb 63% WP (1.5 g/l), Copper Hydroxide 77% WP (2 g/l) and Hexaconazole 5% SC (2 ml/l). The trial was carried out in the direct sown crop of medium duration susceptible variety, Uma. The experiments were laid out in a randomized block design with 3 replications in a 5x2 m plot with 15x15 cm spacing. The NPK fertilizers and all other cultural operations were applied as per Package of

Practices recommendation (90:45:45 kg/ha) by Kerala Agricultural University. The sick plot for sheath blight disease was selected for conducting the experiment. The chemicals were sprayed prophylactically as a single application at the panicle initiation stage, 55 days after transplanting. Three sampling units of 1 sq.m area were fixed in each plot at random. The disease incidence/ severity was recorded before the spray and final observation at fifteen days after spray. Percentage of disease incidence was calculated on 30 plants per sampling unit, by counting the number of infected tillers. Disease incidence was calculated using the following formula (Rajput and Bartaria, 1995; Greer and Webster, 2001)

$$\text{Disease Incidence (\%)} = \frac{\text{Total number of infected plants}}{\left(\frac{\text{Total number of infected plants}}{\text{Total number of plants observed}} \right)} \times 100$$

Degree of severity was graded on a 0-to-9 scale based on the height of the plant portions affected by the disease and it was expressed as a percentage of the total area according to the Standard Evaluation System (SES) for rice (IRRI, 1996).

SES Scale (2014) for sheath blight disease

Grade	Description
0	No infection
1	Vertical spread of the lesions up to 20% of plant height
3	Vertical spread of the lesions up to 21-30% of plant height
5	Vertical spread of the lesions up to 31-45% of plant height
7	Vertical spread of the lesions up to 45-65% of plant height
9	Vertical spread of the lesions up to 66-100% of plant height

PDI was computed according to Wheeler (1969), using the formula

was computed according to Wheeler (1969), using the formula

$$\text{PDI} = \frac{\text{Sum of the scores}}{\text{Number of observations} \times \text{highest number in rating scale}} \times 100$$

Grain yield of each plot was recorded and expressed in kg/ha at 14 per cent moisture. Data on percentages were transformed to arcsine and analysis of variance was performed with transformed values. Significance among mean treatments was determined according to Duncan's multiple range tests (Gomez and Gomez, 1984).

Results and Discussion

The results of field trial at M S Swaminathan Rice Research Station, Moncompu during the seasons *Kharif 2022*, *Rabi 2022-23*, *Kharif 2023*, and *Kharif 2024* revealed that the plots treated with the combination fungicide Azoxystrobin 18.2% + Difenconazole 11.4% SC @ 1ml/l recorded lower sheath blight incidence (14.15%), which was followed by Thifluzamide 24% SC 0.8ml/l with an incidence of 20.66% which are

effective in reduction of sheath blight disease in rice (**Table 1 and Figure 1**). Among the strobilurins, the fungicide Azoxystrobin was widely used due to their effectiveness against sheath blight pathogen (Pramesh *et al.*, 2017). After spraying with Azoxystrobin 11% + Tebuconazole 18.3% in the tillering stage, the disease incidence decreased to 88% in 2020-21 and 81% in 2021-22 (Chitti babu *et al.*, 2024).

Table 1: Evaluation of different fungicides and biofertilizer/biocontrol agent against sheath blight disease incidence (%) of rice during *Kharif 2022*, *Rabi 2022-23*, *Kharif 2023* and *Kharif 2024* (pooled data of four season)

Treat-ments	Fungicides	Dose/l/acre	*Disease Incidence (%)				Mean
			<i>Kharif 2022</i>	<i>Rabi 2022-23</i>	<i>Kharif 2023</i>	<i>Kharif 2024</i>	
1	<i>Pseudomonas fluorescens</i> seed treatment + PGPR I + PGPR II	10 g/kg seed +soil @ 1 kg /acre + 20 g/l	8.53 (16.98)	20.03 (26.58)	32.2 (34.57)	38.18 (38.16)	24.73 (29.82)
2	<i>Pseudomonas fluorescens</i> seed treatment + PGPR II	10 g/kg seed + 20 g/l	12.71 (20.88)	21.479 (27.62)	29.74 (33.04)	27.28 (31.50)	22.8 (28.52)
3	Hexaconazole 4% + Zineb 68% WP	2.5 g	21.09 (27.35)	16.08 (23.66)	14.4 (22.30)	17.14 (24.50)	17.17 (24.50)
4	Azoxystrobin 18.2% + Difenconazole 11.4% SC	1 ml	3.43 (10.63)	11.08 (19.46)	8.82 (20.26)	2.45 (9.10)	6.44 (14.65)
5	Thifluzamide 24% SC	0.8 ml	18.74 (25.62)	22.13 (28.06)	8.93 (17.36)	17.43 (24.65)	20.66 (20.06)
6	Difenconazole 25% EC	0.5 ml	14.62 (22.46)	14.45 (22.38)	20.39 (26.85)	16.34 (23.81)	16.45 (23.97)
7	Isoprothiolane 40% EC	1.5 ml	31.51 (34.14)	29.9 (33.15)	38.3 (38.82)	31.1 (33.90)	13.52 (21.56)
8	Carbendazim 12% + Mancozeb 63% WP	1.5 g	12.68 (20.88)	17.39 (24.65)	31.65 (34.27)	27.61 (31.69)	22.33 (28.18)
9	Copper Hydroxide 77% WP	2 g	41.3 (39.98)	18.64 (25.55)	34.75 (36.15)	34.41 (35.97)	32.85 (35.00)
10	Hexaconazole 5% SC (Standard Check)	2 ml	19.97 (26.49)	5.09 (13.05)	26.12 (30.72)	20.26 (26.78)	17.86 (25.03)
11	<i>Pseudomonas fluorescens</i> Seed +Soil +Foliar (Organic Check)	10 g/kg seed +1 kg/ acre + 20 g	29.73 (33.02)	19.88 (26.42)	23.27 (28.86)	32.23 (34.57)	26.27 (30.85)
12	Control	-	46.34 (42.82)	47.24 (43.39)	49.97 (44.48)	52.17 (46.24)	52.97 (46.27)
	LSD @ 5% (P=0.05)		7.270	8.720	15.186	6.187	7.270
	CV (%)		16.422	20.211	29.731	12.026	18.288

*Mean of three replications. Figures in the parentheses are arc sine transformed values.

The pooled data of the results showed that the prolonged effect on the disease severity was obtained as 6.56% for Azoxystrobin 18.2% + Difenconazole 11.4% SC followed by Thifluzamide 24% SC as 13.23% and Difenconazole 25% EC (16.56%) (**Table 2 and Figure 2**). The fungicide combination

Azoxystrobin 18.2% + Difenconazole 11.4% SC (Strobilurin + Triazole) was more effective against sheath blight than the other individual fungicides reported by Bhuvaneswari *et. al.*, 2012. Current research results have also confirmed the superior efficacy of Azoxystrobin 18.2% + Difenconazole 11.4% SC in reducing the sheath blight severity.

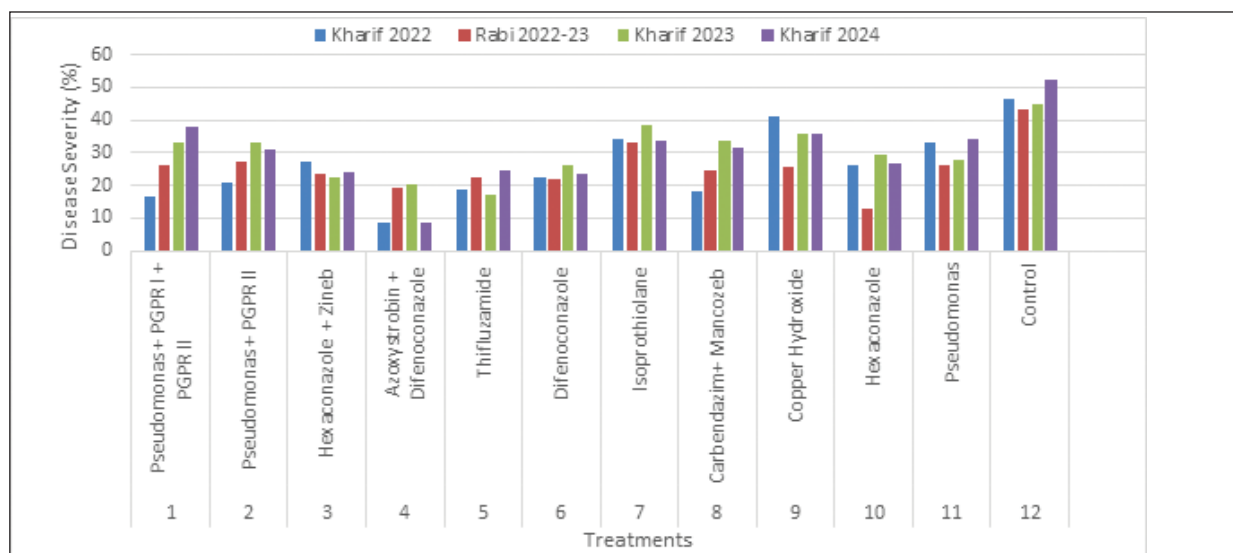


Figure 1: Effectiveness of different fungicides and biofertilizer/biocontrol agent on sheath blight disease incidence (%) of rice during *Kharif 2022*, *Rabi 2022-23*, *Kharif 2023* and *Kharif 2024* (pooled data of four seasons)

Table 2: Evaluation of different fungicides and biofertilizer/biocontrol agent against sheath blight disease severity (%) of rice during *Kharif 2022*, *Rabi 2022-23*, *Kharif 2023* and *Kharif 2024* (pooled data of four seasons)

Treat-ments	Fungicides	Dose/l/acre	*Disease Severity (%)				Mean
			<i>Kharif 2022</i>	<i>Rabi 2022-23</i>	<i>Kharif 2023</i>	<i>Kharif 2024</i>	
1	<i>Pseudomonas fluorescens</i> seed treatment + PGPR I + PGPR II	10 g/kg seed +soil @ 1 kg /acre + 20 g/l	7.03 (15.68)	20.73 (27.06)	29.62 (32.96)	41.78 (40.28)	25.45 (30.26)
2	<i>Pseudomonas fluorescens</i> seed treatment + PGPR II	10 g/kg seed + 20 g/l	9.99 (18.34)	19.25 (26.06)	28.88 (32.52)	32.58 (34.82)	22.67 (28.45)
3	Hexaconazole 4% + Zineb 68% WP	2.5 g	18.51 (25.47)	14.81 (22.63)	15.18 (22.87)	18.88 (25.77)	16.84 (24.20)
4	Azoxystrobin 18.2% + Difenoconazole 11.4% SC	1 ml	3.70 (11.09)	9.99 (17.56)	9.99 (17.56)	2.59 (9.28)	6.56 (14.89)
5	Thiifluzamide 24% SC	0.8 ml	8.88 (18.42)	12.58 (20.79)	8.88 (17.36)	22.59 (28.39)	13.23 (21.30)
6	Difenoconazole 25% EC	0.5 ml	14.81 (22.63)	14.80 (22.06)	19.25 (26.06)	17.40 (24.43)	16.56 (24.04)
7	Isoprothiolane 40% EC	1.5 ml	35.55 (36.63)	32.58 (34.88)	38.82 (39.25)	37.40 (37.52)	36.19 (36.99)
8	Carbendazim 12% + Mancozeb 63% WP	1.5 g	10.74 (19.09)	12.21 (20.44)	39.62 (39.00)	33.69 (35.49)	24.06 (29.40)
9	Copper Hydroxide 77% WP	2 g	39.47 (38.92)	14.07 (22.06)	36.66 (37.29)	42.21 (40.51)	33.32 (35.24)
10	Hexaconazole 5% SC (Standard Check)	2 ml	19.99 (26.49)	4.44 (12.11)	29.25 (32.77)	27.73 (31.76)	20.35 (26.85)
11	<i>Pseudomonas fluorescens</i> Seed +Soil +Foliar (Organic Check)	10 g/kg seed +1 kg/ acre + 20 g	28.51 (32.27)	14.06 (22.06)	26.29 (30.85)	37.77 (37.94)	26.65 (31.11)
12	Control	-	70.36 (57.04)	52.27 (46.26)	59.99 (50.71)	71.10 (57.48)	63.41 (52.71)
	LSD @ 5% (P=0.05)		9.377	17.182	25.541	11.452	11.109
	CV (%)		24.752	54.898	52.779	20.892	30.339

*Mean of three replications. Figures in the parentheses are arc sine transformed values

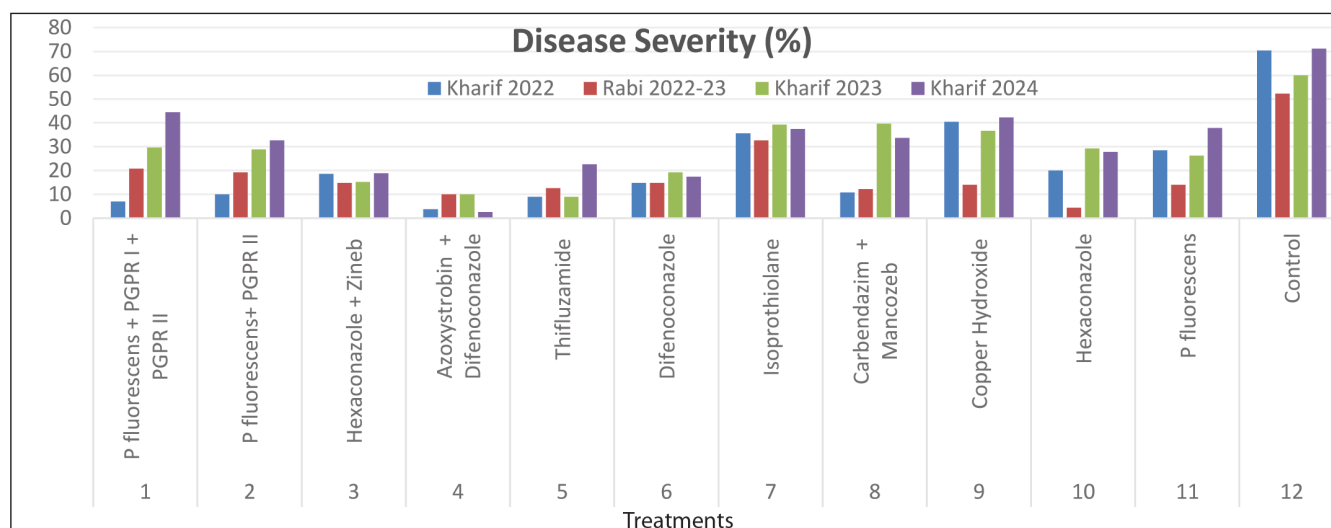


Figure 2: Effectiveness of different fungicides and biofertilizer/biocontrol agent on sheath blight disease severity (%) of rice during Kharif 2022, Rabi 2022-23, Kharif 2023 and Kharif 2024 (pooled data of four seasons)

The results on yield data showed that the systemic fungicides Difenconazole 25% EC and Azoxystrobin 18.2% + Difenconazole 11.4% SC combination fungicide produced highest yield in the study (**Table 3 and Figure 3**). Application of fungicides at various crop stages has been reported to increase yield by reducing disease burden (Pramesh *et al.*, 2017). Previous scientific studies by Bag *et al.*, (2016) also reported that Azoxystrobin 11% +

Tebuconazole 18.3% was effective in reducing the incidence of sheath blight and increasing rice yield. In the study, the highest yield was obtained from Difenconazole 25% EC (6382 kg/ha), Azoxystrobin 18.2% + Difenconazole 11.4% SC (6207 kg/ha), followed by Carbendazim 12% + Mancozeb 63% WP (5837 kg/ha) and Thifluzamide 24% SC (5771 kg/ha).

Table 3: Evaluation of different fungicides and biofertilizer/biocontrol agent on grain yield (kg/ha) of rice during Kharif 2022, Rabi 2022-23, Kharif 2023 and Kharif 2024 (pooled data of four seasons)

Treatments	Fungicides	Dose/l/acre	Grain Yield (kg/ha)				Mean
			Kharif 2022	Rabi 2022-23	Kharif 2023	Kharif 2024	
1	<i>Pseudomonas fluorescens</i> seed treatment + PGPR I + PGPR II	10 g/kg seed +soil @ 1 kg /acre + 20 g/l	5367	5991	6522	5103	5746
2	<i>Pseudomonas fluorescens</i> seed treatment + PGPR II	10 g/kg seed + 20 g/l	5767	5604	6891	4658	5730
3	Hexaconazole 4% + Zineb 68% WP	2.5 g	4883	5776	5667	5604	5483
4	Azoxystrobin 18.2% + Difenconazole 11.4% SC	1 ml	5433	5303	5862	8227	6206
5	Thifluzamide 24% SC	0.8 ml	5000	4687	7963	5432	5771
6	Difenconazole 25% EC	0.5 ml	4850	4529	7763	8385	6382
7	Isoprothiolane 40% EC	1.5 ml	5117	3942	6899	6622	5645
8	Carbendazim 12% + Mancozeb 63% WP	1.5 g	5223	4945	6533	6636	5837
9	Copper Hydroxide 77% WP	2 g	4643	4314	6178	4730	4966
10	Hexaconazole 5% SC (Standard Check)	2 ml	5167	4500	5804	6995	5616
11	<i>Pseudomonas fluorescens</i> Seed +Soil +Foliar (Organic Check)	10 g/kg seed +1 kg/ acre + 20 g/l	3670	5199	4487	6966	5080
12	Control	-	2333	3841	4327	4286	3697
	LSD @ 5% (P=0.05)		1570	NS	1025	NS	1329
	CV (%)		19.366	22.832	9.701	28.918	16.749

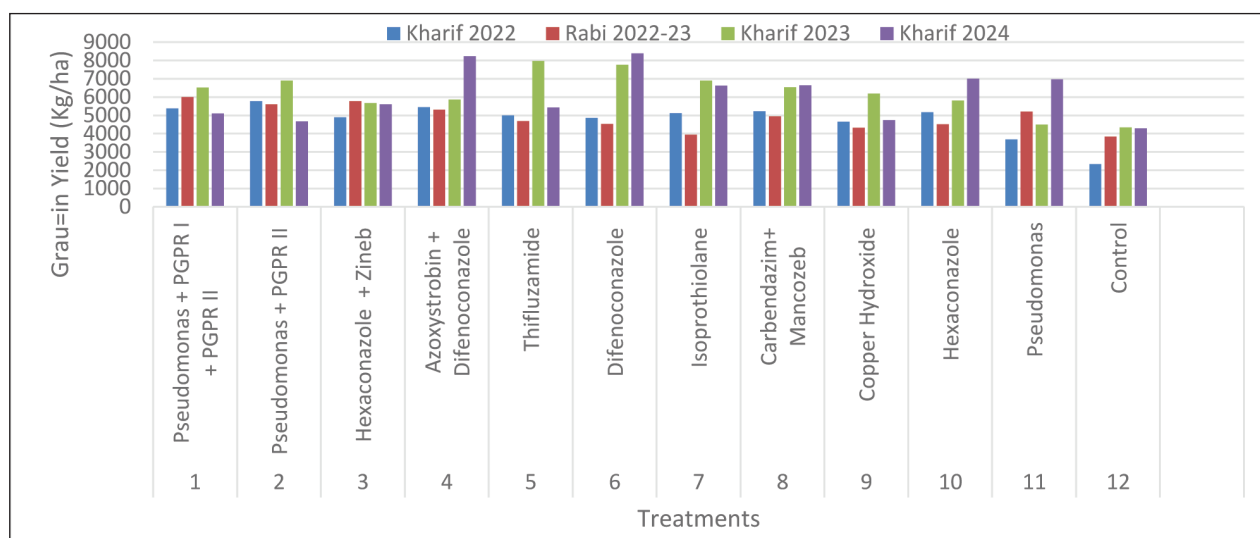


Figure 3: Effectiveness of different fungicides and biofertilizer/biocontrol agent on grain yield(kg/ha) of rice during Kharif 2022, Rabi 2022-23, Kharif 2023 and Kharif 2024 (pooled data of four seasons)

Conclusion

It is concluded that the most successful combination molecule against sheath blight was determined to be the new systemic combination product of Azoxystrobin 18.2% + Difenconazole 11.4% SC@ 1 ml/l, which was followed by Thifluzamide 24% SC@ 0.8 ml/l. Difenconazole 25% EC (6382 kg/ha) produced the highest yield followed by Azoxystrobin 18.2% + Difenconazole 11.4% SC (6207 kg/ha). Carbendazim 12% + Mancozeb 63% WP (5837 kg/ha) and Thifluzamide 24% SC (5771 kg/ha) were next in line, and organic treatments like *Pseudomonas fluorescens* seed treatment (10 g/kg seed) + PGPR I (1 kg/acre) + PGPR II (20 g/l) also produced a yield of 5746 kg/ha found to be efficient in controlling the disease and contributing to productivity.

Acknowledgements

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Next-Generation Fungicides for Sustainable Management of Rice Blast: A Path towards Resilient Paddy Production

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Abstract

Rice blast caused by *Magnaporthe oryzae* is one of the most destructive diseases of rice, leading to heavy yield losses. The present study evaluated the efficacy of Azoxystrobin 16.7% + Tricyclazole 33.3% SC against rice blast under field conditions at three locations in Karnataka during *kharif* 2021-22. The trials were laid out in a randomized block design with ten treatments. Pooled results revealed that Azoxystrobin + Tricyclazole at 750 ml/ha recorded the lowest disease severity (10.57 PDI) with 71.25% reduction over control and the highest grain yield (36.90 q/ha) with a 65.25% increase over control. The same treatment also provided the highest net returns (₹44,386/ha) and benefit–cost ratio (2.63). The superior efficacy of this mixture is attributed to its dual mode of action, enhancing disease control and delaying resistance. Therefore, Azoxystrobin 16.7% + Tricyclazole 33.3% SC at 750 ml/ha can be recommended as an effective component in integrated management of rice blast.

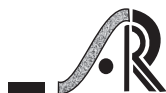
Keywords: Rice blast, *Magnaporthe oryzae*, Azoxystrobin, Tricyclazole, Integrated disease management

Introduction

Rice (*Oryza sativa* L.) is the staple food for more than half of the world's population and contributes significantly to food and nutritional security in Asia, particularly in India. India is the second largest producer of rice after China, with an area of 43.46 million hectares and a production of 119.93 million tons during 2024–25 (DAC&FW 2024). Despite its importance, rice productivity is constrained by several biotic and abiotic stresses. Among the diseases, blast caused by the ascomycetous fungus *Magnaporthe oryzae* (*Pyricularia oryzae*) is considered as the most destructive disease of rice worldwide. It occurs in both tropical and temperate regions and is prevalent in all rice-growing states of India (Sharma *et al.*, 2012). The disease was first reported from China in 1637 and later in India from Thanjavur district of Tamil Nadu in 1919 (Padmanabhan, 1965). Blast affects leaves, nodes

and panicles leading to severe yield losses ranging from 30-50% under endemic conditions and in severe epidemics losses may reach up to 90% (Ou 1985, Nalley *et al.*, 2016). The pathogen survives on infected crop residues, seeds and collateral hosts and its rapid spread is favored by congenial weather conditions such as high relative humidity, prolonged leaf wetness and moderate temperature (Bonman *et al.*, 1992).

Several management strategies have been recommended to mitigate rice blast, including resistant cultivars, fungicides, cultural practices and bio-control agents but the breakdown of varietal resistance, fungicide resistance in pathogen populations and environmental concerns necessitate integrated and sustainable approaches (Skamnioti and Gurr, 2009). Although tricyclazole has long been a standard fungicide, its continuous use has reduced the



sensitivity of *M. oryzae* in many regions (Srivatsava *et al.*, 2017). Various fungicides have been used to control rice diseases, although systemic fungicides such as strobilurin, dithiocarbamate, triazole, and antibiotics have also drawn attention. Single-site fungicides have been shown to be very effective against several rice diseases, but have also been found to promote the development of fungicide resistance in pathogen populations (Deising *et al.*, 2008, Ishii and Hollomon 2015). To address this, newer fungicide combinations such as Azoxystrobin 16.7% + Tricyclazole 33.3% SC with dual modes of action have been introduced, showing promise for improved disease suppression and resistance management (Rajashekhara *et al.*, 2021). Field evaluation of these molecules across locations is essential to establish their efficacy and economic viability and hence the present investigation was undertaken to assess the effectiveness of the Azoxystrobin + Tricyclazole combination compared to other fungicides for managing blast disease of rice under farmers' field conditions.

Materials and Methods

Field experiments were conducted during *kharif* 2021-22 at three locations in Karnataka, the Agricultural Research Station (ARS) Hanagal, Agricultural Research Station (ARS) Mugad, and the Agricultural Extension Education Centre (AEEC) Belagavi. In addition, on-farm demonstrations were carried out during *kharif* 2022-23 at multiple farmer fields across Dharwad, Hanumanamatti, Sirsi, Belagavi and Hangal to validate the efficacy of treatments under real farming conditions. The region falls under the Northern Transitional Zone of Karnataka with average annual rainfall of 850–1100 mm. The trials were laid out in a Randomized Block Design (RBD) with three replications. Ten treatments comprising fungicide mixtures and solo applications were evaluated against an untreated control. HR -12 variety which is susceptible for the blast disease was used for the experiment. The treatment details are presented below

T₁: Azoxystrobin 16.7% + Tricyclazole 33.3% SC @ 500 ml/ha

T₂: Azoxystrobin 16.7% + Tricyclazole 33.3% SC @ 750 ml/ha

T₃: Tricyclazole 75 WP @ 400 g/ha

T₄: Validamycin 3% SL @ 500 ml/ha

T₅: Propiconazole 25 EC @ 500 ml/ha

T₆: Isoprothiolane 40 EC @ 750 ml/ha

T₇: Carbendazim 50 WP @ 500 g/ha

T₈: Azoxystrobin 23 SC @ 500 ml/ha

T₉: Tebuconazole + Trifloxystrobin 75 WG @ 200 g/ha

T₁₀: Untreated control

The fungicides were applied as foliar sprays at the first appearance of blast symptoms and repeated at 15-day intervals for second applications.

The incidence of leaf blast was assessed as per cent disease index (PDI) at 10 days after the final spray using the 0–9 scale proposed by IRRI (1996). Twenty-five of leaves were counted from each treatment to calculate the infection percentage. Grain yield from each plot 5 m X 5 m was recorded at harvest and expressed in kg/ha and later converted into q/ha. The per cent disease index was calculated following the formula suggested by Wheeler (1969).

$$\text{Per cent disease index (PDI)} = \frac{\text{Sum of individual disease ratings}}{\text{No. of leaves observed} \times \text{maximum disease grade}} \times 100$$

Grade	Symptoms
0	No lesions
1	Small lesion on leaf or secondary branches
3	Small roundish to oval lesion (1-2 mm) on leaf or on primary branches/panicle axis
5	Narrow lesion of 1-2 mm breadth and about 3 mm long on leaf, or around the base of uppermost internodes/lower part of panicle axis
7	Broad spindle-shaped lesion with yellow/brown/purple margin on leaf, completely around panicle base, with more than 30% filled grains
9	Complete lesion

The data on disease severity and yield were subjected to Analysis of Variance (ANOVA) using RBD design and treatment means were compared at 5% level of significance (CD at 5%). For economic analysis, pooled data from the three locations were considered to derive average profitability.

Results and Discussion

Pooled analysis across three locations during *kharif* 2021-22 (**Table 1**) revealed that fungicidal treatments significantly reduced blast severity and improved grain yield compared to the untreated control. The combination fungicide Azoxystrobin 16.7%+ Tricyclazole 33.3% SC @ 750 ml/ha was most effective, recording the lowest disease severity (10.57 PDI) with 71.25 per cent reduction over control and the highest grain yield (36.90 q/ha) with a 65.25 per cent increase over control (22.33 q/ha). The 500 ml/ha dose of the same fungicide was statistically comparable with 11.71 PDI (68.63% reduction) and 34.64 q/ha yield (55.13% increase). The enhanced performance of this mixture may be attributed to the complementary action of Tricyclazole, a melanin biosynthesis inhibitor highly specific to blast and Azoxystrobin, a Strobilurin fungicide with broad-spectrum activity targeting fungal respiration. Such dual action provides higher efficacy and delays

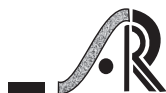
fungicide resistance, which has been emphasized in earlier studies on rice and other crops. The superior performance of this fungicide combination can be attributed to its dual mode of action, ensuring both preventive and curative effects (Kumar *et al.*, 2016; Goswami and Thind, 2018; Hegde *et al.*, 2020 Mishra *et al.*, 2025; Mohiddin *et al.*, 2021, Amoghavarsha *et al.*, 2021, Kumar *et al.*, 2013, Balol *et al.*, 2022 and Magar *et al.*, 2015. Similar results have been reported on other crops such as chickpea (Basamma *et al.*, 2021; Sangeeta *et al.*, 2022), urdbean (Balol *et al.*, 2020), Onion (Shilpakumari *et al.*, 2011), and Mango (Vamshika *et al.*, 2023) efficacy of novel fungicides for the management of False smut of rice (Patil *et al.*, 2024), efficacy of fungicides on rice sheath blight and grain discolouration diseases in rice (Surendran *et al.*, 2023: Yadav *et al.*, 2022) and greengram (Rengima *et al.*, 2025).

Table 1: Management of blast of paddy by Azoxystrobin + Tricyclazole (pooled) 2021-22

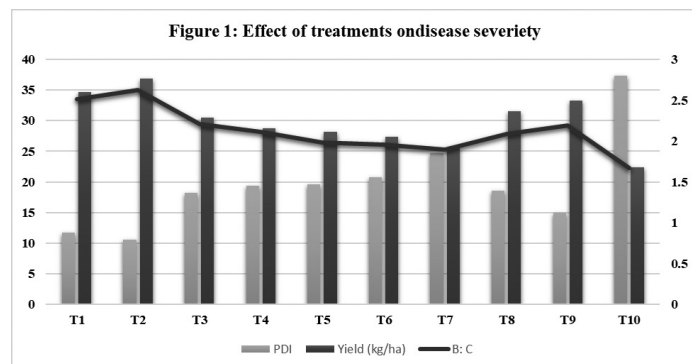
Tr. No	Treatment details	PDI				% Reduction over control	Yield (q/ha)				% increase over control
		Hanagal	Mugad	Belagavi	pooled		Hanagal	Mugad	Belagavi	Pooled	
T ₁	Azoxystrobin 16.7% + Tricyclazole 33.3% SC @ 500 ml/ha	13.54 (21.6)	12.29 (20.54)	9.30 (17.76)	11.71 (20.02)	68.63	37.07	31.61	35.25	34.64	55.13
T ₂	Azoxystrobin 16.7% + Tricyclazole 33.3% SC @ 750 ml/ha	11.35 (19.7)	10.65 (19.05)	9.72 (18.18)	10.57 (18.98)	71.25	38.48	35.41	36.8	36.9	65.25
T ₃	Tricyclazole 75 WP @ 400 g/ha	20.50 (26.94)	19.74 (26.39)	14.28 (22.21)	18.27 (25.32)	51.11	33.13	27.13	31.3	30.52	36.68
T ₄	Validamycin 3% SL @ 500 ml/ha	21.55 (27.67)	20.22 (26.74)	16.45 (23.94)	19.41 (26.15)	47.67	31.37	25.45	29.6	28.81	29.02
T ₅	Propiconazole 25 EC @ 500 ml/ha	22.25 (28.16)	20.49 (26.93)	16.15 (23.71)	19.63 (26.31)	47.23	31.02	24.37	29.3	28.23	26.42
T ₆	Isoprothiolane 40 EC @ 750 ml/ha	22.65 (28.43)	21.67 (27.76)	18.09 (25.18)	20.80 (27.15)	43.75	30.4	22.97	28.6	27.32	22.35
T ₇	Carbendazim 50 WP @ 500 g/ha	27.60 (31.71)	26.6 (31.06)	19.95 (26.54)	24.72 (29.83)	33.66	28.84	22.57	26.55	25.65	14.87
T ₈	Azoxystrobin 23 SC @ 500 ml/ha	19.90 (26.51)	18.85 (25.75)	16.90 (24.29)	18.55 (25.52)	49.59	33.37	29.49	31.6	31.49	41.02
T ₉	Tebuconazole + Trifloxystrobin 75 WG @ 200 g/ha	17.25 (24.55)	16.31 (23.83)	11.43 (19.77)	15.00 (22.8)	59.97	34.67	31.22	33.85	33.25	48.90
T ₁₀	Untreated control	42.20 (40.53)	40.34 (39.45)	29.48 (32.9)	37.31 (37.67)		24.55	18.78	23.65	22.33	
	S Em ±	0.19	0.80	0.28	0.97					0.50	
	CD at 5%	0.56	2.37	0.84	2.88					1.49	

Tricyclazole 400 g/ha, the standard check, showed moderate performance with 18.27 PDI (51.11% reduction) and 30.52 q/ha yield (36.68% increase). The comparatively lower efficacy may be due to reduced

sensitivity of *Magnaporthe oryzae* to tricyclazole, as reported from several rice-growing regions of India (Kumar *et al.*, 2017). Another mixture, Tebuconazole + Trifloxystrobin @ 200 g/ha, also performed well with



15.00 PDI (59.97% reduction) and 33.25 q/ha yield (48.90% increase), supporting its role as a potential alternative in blast management programs (**Figure 1**). Other fungicides such as Validamycin, Propiconazole and Isoprothiolane showed comparatively higher disease levels (19.41-20.80 PDI) and lower yields (27.32-28.81 q/ha), while Carbendazim was least effective (24.72 PDI; 25.65 q/ha yield).



Economic analysis of pooled data (**Table 2**) confirmed the advantage of Azoxystrobin + Tricyclazole. The 750 ml/ha dose resulted in the highest net returns (₹44,386/ha) and benefit-cost ratio (2.63), followed by the 500 ml/ha dose (₹40,402/ha; B:C ratio 2.51). Tricyclazole 400 g/ha also provided favourable returns (₹32,409/ha; B:C ratio 2.21). In contrast, Carbendazim recorded the lowest net returns (₹23,561/ha) and B:C ratio 1.90). These results agree with the findings of (Karthikeyan *et al.*, 2010) and (Reddy *et al.*, 2010) who emphasized the importance of both biological efficacy and economic viability in fungicide evaluation.

Table 2: Economics of management of blast of paddy by Azoxystrobin + Tricyclazole (pooled) 2021-22

	Treatment details	Yield (q/ha)	Gross returns (Rs)	Cost of cultivation (Rs)	Net returns (Rs)	B:C ratio
T ₁	Azoxystrobin 16.7% + Tricyclazole 33.3% SC @ 500 ml/ha	34.64	67201.60	26800.00	40402.00	2.51
T ₂	Azoxystrobin 16.7% + Tricyclazole 33.3% SC @ 750 ml/ha	36.90	71586.00	27200.00	44386.00	2.63
T ₃	Tricyclazole 75 WP @ 400 g/ha	30.52	59208.80	26800.00	32409.00	2.21
T ₄	Validamycin 3% SL @ 500 ml/ha	28.81	55891.40	26500.00	29391.00	2.11
T ₅	Propiconazole 25 EC @ 500 ml/ha	28.23	54766.20	27600.00	27166.00	1.98
T ₆	Isoprothiolane 40 EC @ 750 ml/ha	27.32	53000.80	27000.00	26001.00	1.96
T ₇	Carbendazim 50 WP @ 500 g/ha	25.65	49761.00	26200.00	23561.00	1.90
T ₈	Azoxystrobin 23 SC @ 500 ml/ha	31.49	61090.60	29300.00	31791.00	2.09
T ₉	Tebuconazole + Trifloxystrobin 75 WG @ 200 g/ha	33.25	64505.00	29450.00	35055.00	2.19
T ₁₀	Untreated control	22.33	43320.20	26000.00	17320.00	1.67
	S Em ±	0.50				
	CD at 5%	1.49				

Conclusion

Overall, results clearly establish that Azoxystrobin 16.7% + Tricyclazole 33.3% SC, particularly at 750 ml/ha, offers superior blast management, higher yield and greater profitability compared to single

fungicides. The study demonstrates the effectiveness of tested fungicides in reducing rice blast severity under field conditions. Its consistent performance under experimental trials indicates its potential as a key



**Azoxystrobin 16.7% + Tricyclazole 33.3%
SC @ 750 ml/ha**



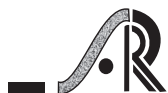
Control

component of Integrated Disease Management (IDM) programs. However, reliance on fungicides alone may lead to resistance buildup. Hence, integration of this

fungicide mixture with resistant varieties, cultural practices and bio-agents is essential for sustainable blast management.

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Molecular Characterization of *Pseudomonas* sp and *Bacillus* sp for Biological Management of Sheath Blight Pathogen in Rice

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Abstract

All the 20 isolates of *Pseudomonas fluorescens* showed positive result in all biochemical characteristics such as KOH test, HCN production, pigment production, gelatin liquefaction, growth at 45 °C and negative results were obtained in gram staining and growth at 4 °C. Among the 20 isolates of *P. fluorescens*, *P.f.* I₁₀ isolate was found to be effective by recording the mycelial growth reduction of 39.56 per cent followed by *P.f.* I₂₀ isolate 30.67 per cent reduction when compared to check (TNAU *P.f.* 1-37.33%). The result revealed that an amplicon of 560 bp. Metabolic compounds such as HCN, Siderophore and Volatiles were analyzed to know their mode of action.

Keywords: Rice, sheath blight, molecular characterization, *Pseudomonas* sp, *Bacillus* sp, and mycelial growth

Introduction

Rice (*Oryza sativa* L.) is one of the widely cultivated important food crop in the world and over half of the world population relies on it for food. It is the chief food for more than 65% of the world's population and is India's pre-eminent crop. Rice provides 20 per cent of the world's dietary supply and is a good source of thiamine, riboflavin, niacin and dietary fiber. In Asia, where 95 per cent of the world's rice is produced and consumed; it contributes 40-80 per cent of the calories of Asian diet (Kanchana *et al.*, 2012). Globally, more than three million people have rice as staple food, and it accounts for 50 to 80 per cent of their daily calorie intake (Delseny *et al.*, 2001). Over the next 20 years, it is expected that demand for rice will grow by 2.5 per cent per year (Hobbs, 2001). In India rice is grown in 43.86 million ha, the production level is 104.80 million tones and the productivity is about 2390 kg/ha (Statistics, 2005). However, in Tamil Nadu rice crop was cultivated about 20 lakh hectare with an annual production of about 75.17 lakh tonnes with a productivity is 3758 kg/hectare during

the year 2015-16 (INDIASTAT). Yadav *et al.*, 2020 found that sheath blight incited by *Rhizoctonia solani* is one of the potentially devastating disease of rice in almost all over the rice growing countries of the world. In India, intensive and extensive cultivation of rice mostly under rice-wheat cropping system have resulted heavy losses to the crop ranging from 5.2 to 70 per cent in yield.

Diseases cause serious constraints to rice cultivation in India. More than 70 diseases caused by fungi, bacteria and viruses have been recorded on rice (Ou, 1985). Among them sheath blight caused by *Rhizoctonia solani* [Teleomorph: *Thanatephorus cucumeris* (Frank) Donk] anastomosis group 1 IA (AG-1 IA) is a serious disease worldwide (Rush and Lee, 1983). The sheath blight disease of rice is prevalent in almost all rice growing countries of the world. Sheath blight is an important soil borne fungal disease (Kuhn) causing upto 40 per cent of yield losses annually. The symptoms of the disease include greenish grey water-

soaked spots develops on the outer most sheath of rice. As the disease progresses spots enlarge, coalesce forming larger lesions with grayish white center surrounded by tan to brown irregular borders or outlines. Sclerotia surviving in the soil are the major source of infection (Damicone and Jackson, 1996). When sclerotia come into contact with a rice plant they germinate and the hyphae produce infection cushions on the exposed leaf sheath. Haustoria grow from the infection cushions, penetrate the host tissue, and typically green gray water-soaked lesions develop (Dodman and Flentje, 1970).

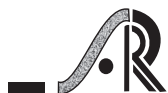
Among the cultivated rice varieties, the level of resistance to rice sheath blight is low. The conventional methods for the fungal diseases control were mainly by using synthetic fungicides. The chemical control using synthetic fungicides is less acceptable due to their increase incidence of development of resistance, lack of specificity towards the target pathogen, adverse effect on environment and beneficial microbes (Mcneil *et al.*, 2010). Fungicide application may not be economically feasible and the time of application appears to be important (Lee and Rush, 1983). Thus, there is a need for alternative disease management that provides effective control without side effects in the environment.

Biological control is proved to be a promising disease management technology against soil borne plant pathogens, when applied either alone or in combination with other management practices Papavizas (1965) directed towards the irrigation of cultural practices with chemical control (Damicone *et al.*, 1996). Cook and Baker (1983) defined biological control as “the reduction of inoculum or disease producing activity of the pathogen accomplished by use of beneficial bacteria as biological control agents to suppress plant disease and also eco-friendly alternative to the chemical fungicides. Biological control is the best solution for long term sustainability and effective management of soil borne diseases

which can minimize the disease (Avila *et al.*, 2013).

A diverse group of biocontrol agents such as bacteria, fungi and viruses exist in nature. Among them bacterial antagonists are considered ideal candidates because of their rapid growth, ease of handling and aggressive colonizing character. Bacterial antagonists, *Pseudomonas* and *Bacillus* in particular, are good candidates for biological control.

Bacilli are gram positive endospore producing bacteria that are tolerant to heat and desiccation; a very good feature required for field application. They have an antagonistic character against many soil borne fungi such as *R. solani*. The fluorescent *Pseudomonads* are gram negative rods and have simple nutrition requirements; are excellent colonizers which widely prevalent in rice rhizosphere. They have been successfully used for biological control of several sclerotium producing fungi such as *Sclerotium rolfsii* (Laha *et al.*, 1996), *R. solani* (Rabindran and Vidhyasekaran, 1996) and *Macrophomina phaseolina* (Meena *et al.*, 2001). Bacterium applied (prior to pathogen inoculation) against several rice pathogens to the seed and rice plants can reduce disease severity by 20- 42% in a greenhouse and the field. Such seed bacterization of rice plants can enhance plant height, number of tillers and grain yield by 3 to 160 per cent. With this above said background, the following objectives were formulated to manage the sheath blight disease of rice effectively by biological method. 1. Isolation of the causal organism of rice sheath blight (*Rhizoctonia solani*) and proving the pathogenicity, 2. Isolation of bacterial antagonists from the rhizosphere region of rice plants and its characterization, 3. Testing the efficacy of bacterial antagonists against *R. solani* under *in vitro* conditions, 4. Testing the efficacy of bacterial antagonists against *R. solani* under field conditions. and 5. Studying the mode of action of antagonists against *R. solani*.



Materials and Methods

Molecular characterization of *Pseudomonas fluorescens*

Genomic DNA extraction

Two *Pseudomonas fluorescens* isolates were grown in Kings B broth for 72 h. The 1.5 ml of culture was centrifuged at 13000 rpm for 5 min. The pellet was suspended with 200µl of 0.1M HCl added with 200µl of lysis solution. Again the sample was added with 700µl of Phenol: Chlorophorm: Isoamyl alcohol (25 :24 :1) and centrifuged at 13000 rpm for 10 min. The aqueous layer was transferred to a new tube. DNA was precipitated by adding equal volume of ice cold ethanol and incubated at -20°C at overnight. Then the pellet was air dried and added with 100µl of TE buffer (10 mM of Tris HCl with pH 8.0, one mM of EDTA with pH 8.0) and treated with in five µl of RNase A (10mg/ml) at 37°C for one hour. The isolated total DNA was tested by electrophoresis in 0.8 per cent agarose gel.

PCR amplification of 16S rRNA from *Pseudomonas fluorescens*

The 16s rRNA region of *Pseudomonas fluorescens* isolates was amplified using primers pairs ITS 1F- 5' CTTGGTCATTAGAGGAAGTAA 3' and ITS 2R 2- 5' TGTGTTCTTCATCGATG -3' as per the protocol of Singh *et al.*, (2008) with the reaction conditions as follows. The PCR was carried out with a master cycler gradient (Eppendorf, Germany) programmed for pre-heating at 92°C at 5min followed by denaturation at 92°C at 4 min, annealing at 28°C at 1 min and extension at 72°C at 2 min for 25 cycles with the final extension at 72°C at 10 min and final hold at 4°C. The PCR products were separated by electrophoresis in the 1.2 per cent agarose gel stained with Ethidium bromide and visualized under UV light and documented using alpha imager (Alpha Innotech, California, USA). The 100 bp DNA ladder was used to measure the size of PCR products (Bangalore Genei, Pvt. Ltd.) was used.

Biochemical characterization of *Bacillus* sp.

The following biochemical tests were carried out for the characterization of *Bacillus* sp.

Staining reaction

Bacterial smear was prepared with 24 hrs old culture on microscopic slide, air dried and heat fixed. The slide was flooded with crystal violet for 60 seconds and then washed with tap water. Then it was flooded with Grams iodine mordant for 60 seconds and washed with tap water. Decolorized with 90% alcohol and washed again with tap water. Thus, the smear was counterstained with safranin for 45 seconds, washed with tap water, blot dried and observed under microscope (Gegersen, 1978).

Starch hydrolysis

Bacterial cultures were streaked on Petri dish containing Peptone sucrose agar incorporated with 0.2 per cent starch and incubated for 5 days. Lugol's iodine solution was flooded on the bacterial culture and observed for the development of clear zone around the bacterial growth which indicated the positive reaction (Dowson, 1957).

Catalase test

The bacterial cultures were grown on nutrient broth and incubated at 37°C for 24 hrs. Then added with 1ml of 3 per cent hydrogen peroxide. Examined immediately and after 5 min for the evaluation of bubbles which indicates a positive test (Aneja, 1993).

Citrate utilization test

Bacterial cultures were steaked on the Petri dish containing Simmons citrate agar medium and incubated at 28±2°C. The colour change in the medium around the bacterial cultures from green to blue colour indicates the utilization of citrate.

Molecular characterization of *Bacillus* sp.

Genomic DNA extraction

Two *Bacillus* sp. isolates were grown in the nutrient broth. About 25 ml of actively grown broth culture

was centrifuged at 6000 rpm for 5 min. The pellet obtained from centrifuged sample was suspended with 1ml of TE buffer and 0.5 ml of 1- Butanol. The emulsion was centrifuged at 6000 rpm for 5 min at 4°C. The pellet obtained was resuspended with 2 ml of TE buffer to remove the trace amount of ethanol and centrifuged at 6000 rpm at 4°C for 5 min. Again, the sample was resuspended in 1ml of TE buffer added with 100 µl (10 mg/ml) freshly prepared lysozyme and incubated at room temperature for 5 min. The sample was mixed with 200 µl of 5 mM NaCl; 150 µl of CTAB (10X stock) again incubated for 10 min. The cell wall lysate was deproteinised with 1ml of Phenol: Chloroform (1:1) and centrifuged at 6000 rpm for 4 °C. The aqueous layer was transferred to a new tube. DNA was precipitated by adding equal volume of ice cold isopropanol and incubated at -20 °C at overnight. DNA was collected by centrifugation at 10000 rpm for 15 min at 4 °C. The pellet was added with 300µl of ice cold ethanol and centrifuged at 15000 rpm at 4 °C. The supernatant was discarded and the pellet was dried at room temperature. The dried pellet was dissolved in 50 µl of TE buffer (10 mM of Tris HCl with pH 8.0, one mM of EDTA with pH 8.0) and treated in five µl of RNase A (10 mg/ml) at 37 °C for one hour. The isolated total DNA was tested by electrophoresis in 0.8 per cent agarose gel.

PCR amplification of 16S rRNA from *Bacillus* sp.

The 16s rRNA region of *Bacillus* sp. isolates was amplified using primers pairs BCF1-5' CGGGAGGCAGCAGTAGGGAT-3' and BCR2-5' CTCCCCAGGCGGAGTGCTTAAT-3' as per the protocol of Singh *et al.*, (2008) with the reaction conditions as follows. The PCR was carried out with a master cycler gradient (Eppendorf, Germany) programmed for pre-heating at 95°C at 5 min followed by denaturation at 94°C at 1 min, annealing at 55°C at 1 min and extension at 72°C at 1 min for 25 cycles with the final extension at 72°C at 5 min and final hold at 4°C. The PCR products were separated by electrophoresis in the 1.2 per cent agarose gel stained

with Ethidium bromide and visualized under UV light and documented using alpha imager (Alpha Innotech, California, USA). The 100 bp DNA ladder was used to measure the size of PCR products (Bangalore Genei, Pvt. Ltd., Bangalore) was used.

In vitro screening of *Pseudomonas fluorescens* isolates against *R. solani*

Twenty *Pseudomonas fluorescens* isolates were screened against the virulent *R. solani* isolate (Rs₂) under *in vitro* by adapting dual culture technique (Dennis and Webster, 1971). Each bacterial isolate was streaked at one side of Petri dish containing PDA at one cm away from the periphery. Nine mm mycelial disc from 5 days old culture of *R. solani* was placed at opposite side of Petri dish at one cm away from the periphery and perpendicular to the bacterial streak. Control plates were maintained without bacterial streak. Three replications were maintained and incubated at room temperature (28±2 °C) for 5 days. After ensuring complete growth of pathogen in the control, Per cent inhibition (PI) over control in each treatment was calculated separately using the following formula (Pandey *et al.*, 2000).

$$PI = \frac{C-T}{C} \times 100$$

C = Average diameter of fungal growth (mm) in control

T = Average diameter of fungal growth (mm) in treatment

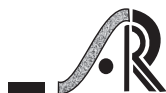
In vitro screening of *Bacillus* sp. isolates against *R. solani*

Twenty *Bacillus* sp. isolates were screened against the virulent *R. solani* isolate (Rs₂) under *in vitro* by adapting dual culture technique Dennis *et al.*, 1971.

Study on mode of action of *Pseudomonas fluorescens* isolates under *in vitro*

Hydrogen cyanide (HCN) production

HCN production of *Pseudomonas fluorescens* isolates was tested qualitatively by following the method of (Schippers *et al.*, 1987). Each bacterial isolate was



streaked separately on Kings' B medium amended with glycine at 4.4g/l. Sterile filter paper saturated with picric acid solution (2.5 g of picric acid, 12.5 g of Na₂CO₃, 1000 ml of distilled water) was placed in the upper lid of the Petri plate. The dishes were sealed with parafilm and incubated at 28°C for 48 h. Change filter paper colour from yellow to light brown, brown or reddish- brown was recorded as weak (+) moderate (++) or strong (+++) reaction HCN production, respectively.

Siderophore production

The 60.5 mg of Chrome Azurol s (CAS) was dissolved in 5 ml of distilled water and mixed with 10 ml of iron solution (1 mM FeCl₃ 6 H₂O in 10 mM HCL). Then added to 72.9 mg of Hexadecyltrimethyl ammonium bromide (HDTMA) in 40 ml of distilled water. The dark blue coloured CAS reagent was then autoclaved for 15 minutes. This reagent was added to Nutrient agar before pouring the plates. The plates were inoculated with active culture of *Pseudomonas fluorescens* and plates are incubated at 48 h. Appearance of an orange zone around the bacterial culture against dark blue background suggest siderophore production (Alla, 1999).

Volatile production of *Pseudomonas fluorescens*

Pseudomonas fluorescens isolates were tested for their volatile production as described by Kazempour, (2004). Nine mm mycelial disc of five days old culture of *R. solani* was placed at the center of Petri plate containing PDA. Each *Pseudomonas fluorescens* isolate was streaked separately in the center of Petri plate containing KB medium. Plate streaked with bacteria was matched face to face over the Petri plate inoculated with fungal disc without any physical contact between them. The plates were sealed to isolate the inside atmosphere and to prevent the loss of volatile formed. Plates were incubated at room temperature for 4 days. Control plate was maintained without bacterial streak. After ensuring complete growth of pathogen in the control, Per cent inhibition (PI) over control by each isolate was calculated using the following formula (Pandey *et al.*, 2000).

$$\text{PI} = \frac{\text{C-T}}{\text{C}} \times 100$$

C = Average diameter of fungal growth (mm) in control

T = Average diameter of fungal growth (mm) in treatment

Volatile production of *Bacillus* sp.

Bacillus sp. isolates were tested for their volatile production as described by Kazempour (2004). Nine mm mycelial disc of five days old culture of *R. solani* was placed at the center of Petri plate containing PDA. Each *Bacillus* sp. isolate was streaked separately in the center of Petri plate containing NA medium.

Results and Discussion

Survey on rice ShB

The maximum severity index of 64 per cent was recorded at TRRI, Aduthurai in Thanjavur district of Tamil Nadu followed by Tiruvayur district with 56% PDI. This might to be due to the high population and virulence of the pathogens, sclerotia present in the soil, continuous cropping of rice, intensive cultivation and the susceptibility of host to pathogen (Sathya *et al.*, 2020).

Biochemical characterization of *Bacillus* sp

The bacterial antagonists were biochemically characterized based on the following diagnostic tests detailed below (Table 1).

Table 1: Biochemical characteristics of *Bacillus* sp.

S. No	Biochemical test	<i>Bacillus</i> sp.	
		B.s.I ₆	TNAU B.s.1
1.	Gram's staining	+	+
2.	Growth at 4 °C	-	-
3.	Growth in NaCl	+	+
4.	Growth at 45 °C	+	+
5.	Catalase test	+	+
6.	Utilization of citrate	+	+
7.	Starch hydrolysis	+	+

+ : Positive, - : Negative

Antifungal activity *Pseudomonas fluorescens*

The antifungal activity of *Pseudomonas fluorescens* isolates against the mycelial growth of *Rhizoctonia solani* (Rs2) under *invitro* conditions are (Table 2).

Table 2: Antifungal activity of *Pseudomonas fluorescens* isolates against the mycelial growth of *Rhizoctonia solani* (Rs₂) under *in vitro* conditions

Sl. No	Treatments	Mycelial growth (cm)*	Per cent reduction over control (%)
1.	<i>Pf.</i> I ₁	6.40	28.88
2.	<i>Pf.</i> I ₂	7.09	21.22
3.	<i>Pf.</i> I ₃	6.30	30.00
4.	<i>Pf.</i> I ₄	7.30	18.88
5.	<i>Pf.</i> I ₅	8.83	1.89
6.	<i>Pf.</i> I ₆	6.42	28.67
7.	<i>Pf.</i> I ₇	6.65	26.11
8.	<i>Pf.</i> I ₈	6.50	27.78
9.	<i>Pf.</i> I ₉	6.63	26.33
10.	<i>Pf.</i> I ₁₀	5.44	39.56
11.	<i>Pf.</i> I ₁₁	7.27	19.22
12.	<i>Pf.</i> I ₁₂	8.93	0.78
13.	<i>Pf.</i> I ₁₃	6.54	27.33
14.	<i>Pf.</i> I ₁₄	6.42	28.67
15.	<i>Pf.</i> I ₁₅	7.23	19.67
16.	<i>Pf.</i> I ₁₆	6.93	23
17.	<i>Pf.</i> I ₁₇	8.59	4.56
18.	<i>Pf.</i> I ₁₈	8.51	5.44
19.	<i>Pf.</i> I ₁₉	6.43	28.56
20.	<i>Pf.</i> I ₂₀	6.24	30.67
21.	TNAU <i>Pf.</i> 1	5.64	37.33
22.	Control	9	-
SEd		0.35	-
CD (P=0.05)		0.70	-

*Mean of three replications

Effect of *Bacillus* sp. on isolate (Rs₂) under *in vitro* conditions

In the present investigation, isolate *B.s.* I₁₀ was found to reduce the mycelial growth of *R. solani* by 35.89 per cent which was found to be effective when compared to all other isolates over control. Among them, seven strains showed strong mycelial inhibition against the mycelial growth of *R. solani*. Shrestha *et al.*, (2016) screened 29 rice associated bacteria against the growth of *R. solani* under *in vitro* conditions. Among them, 26 rice associated bacteria showed antagonistic activity on the mycelial growth of *R. solani* (Table 3).

Table 3: Antifungal activity of *Bacillus* sp. isolates against the mycelial growth of *Rhizoctonia solani* (Rs₂) under *in vitro* conditions

Sl. No	Isolates	Mycelial growth (cm)*	Per cent reduction over control (%)
1.	<i>B.s.</i> I ₁	6.40	28.88
2.	<i>B.s.</i> I ₂	7.17	20.33
3.	<i>B.s.</i> I ₃	7.00	22.22
4.	<i>B.s.</i> I ₄	8.60	4.44
5.	<i>B.s.</i> I ₅	6.50	27.78
6.	<i>B.s.</i> I ₆	5.77	35.89
7.	<i>B.s.</i> I ₇	6.67	25.89
8.	<i>B.s.</i> I ₈	8.90	1.11
9.	<i>B.s.</i> I ₉	6.76	24.89
10.	<i>B.s.</i> I ₁₀	8.40	6.66
11.	<i>B.s.</i> I ₁₁	8.80	2.22
12.	<i>B.s.</i> I ₁₂	8.83	1.88
13.	<i>B.s.</i> I ₁₃	8.17	9.22
14.	<i>B.s.</i> I ₁₄	8.90	1.11
15.	<i>B.s.</i> I ₁₅	6.97	22.55
16.	<i>B.s.</i> I ₁₆	8.84	1.77
17.	<i>B.s.</i> I ₁₇	8.20	8.88
18.	<i>B.s.</i> I ₁₈	6.20	31.11
19.	<i>B.s.</i> I ₁₉	6.90	23.33
20.	<i>B.s.</i> I ₂₀	8.57	4.77
21.	TNAU <i>B.s.</i> 1	5.53	38.55
22.	Control	9	-
SEd		0.20	-
CD (P=0.05)		0.42	-

*Mean of three replications

Mode of action of bacterial antagonists

HCN production

In the present study, all isolates of *Pseudomonas fluorescens* and *Bacillus* sp. were tested for HCN production. All *Pseudomonas fluorescens* isolates showed positive result for HCN production. Among them *Pf.* I₁₀ showed strong HCN production (colour of the filter paper turns yellow to reddish brown). Suresh *et al.*, (2010) reported that the ten strains of fluorescent *Pseudomonads* produced HCN (Table 4).

Table 4: Siderophore, HCN and volatile compounds production by bacterial antagonists

S. No	<i>Pseudomonas</i> sp. Isolates	Test			<i>Bacillus</i> sp. Isolates	Test		
		Siderophore	HCN	Volatile		Siderophore	HCN	Volatile
1	<i>Pf.</i> I ₁	+	+	+	<i>B.s.</i> I ₁	-	-	+
2	<i>Pf.</i> I ₂	+	+	+	<i>B.s.</i> I ₂	-	-	+
3	<i>Pf.</i> I ₃	+	+	+	<i>B.s.</i> I ₃	-	-	+
4	<i>Pf.</i> I ₄	+	+	+	<i>B.s.</i> I ₄	-	-	+
5	<i>Pf.</i> I ₅	+	+	+	<i>B.s.</i> I ₅	-	-	+
6	<i>Pf.</i> I ₆	+	+	+	<i>B.s.</i> I ₆	-	-	+
7	<i>Pf.</i> I ₇	+	+	+	<i>B.s.</i> I ₇	-	-	+
8	<i>Pf.</i> I ₈	+	+	+	<i>B.s.</i> I ₈	-	-	+
9	<i>Pf.</i> I ₉	+	+	+	<i>B.s.</i> I ₉	-	-	+
10	<i>Pf.</i> I ₁₀	+	+	+	<i>B.s.</i> I ₁₀	-	-	+
11	<i>Pf.</i> I ₁₁	+	+	+	<i>B.s.</i> I ₁₁	-	-	+
12	<i>Pf.</i> I ₁₂	+	+	+	<i>B.s.</i> I ₁₂	-	-	+
13	<i>Pf.</i> I ₁₃	+	+	+	<i>B.s.</i> I ₁₃	-	-	+
14	<i>Pf.</i> I ₁₄	+	+	+	<i>B.s.</i> I ₁₄	-	-	+
15	<i>Pf.</i> I ₁₅	+	+	+	<i>B.s.</i> I ₁₅	-	-	+
16	<i>Pf.</i> I ₁₆	+	+	+	<i>B.s.</i> I ₁₆	-	-	+
17	<i>Pf.</i> I ₁₇	+	+	+	<i>B.s.</i> I ₁₇	-	-	+
18	<i>Pf.</i> I ₁₈	+	+	+	<i>B.s.</i> I ₁₈	-	-	+
19	<i>Pf.</i> I ₁₉	+	+	+	<i>B.s.</i> I ₁₉	-	-	+
20	<i>Pf.</i> I ₂₀	+	+	+	<i>B.s.</i> I ₂₀	-	-	+
21	Control	-	-	-	Control	-	-	+
22	TNAU <i>Pf.</i> 1	+	+	+	TNAU <i>B.s.</i> 1	-	-	+

Siderophore production

In the present study, all the isolates of *Pseudomonas fluorescens* were tested for the production of siderophore. All the *Pseudomonas* isolates showed positive result for HCN production. Among them *Pf*I₁₀ produced fluorescent yellow green pigment indicating the production of siderophore (pseudobactin). All the *Bacillus* isolates showed negative result for siderophore production. Meera and Balabaskar (2012) reported that *Pf*4, *Pf*6, *Pf*8, *Pf*11, *Pf*13, *Pf*20 isolates showed positive reaction on siderophore production. Saravanan *et al.*, (2013) reported that the fluorescent *Pseudomonas* produces siderophore under *in vitro* conditions. Showkat *et al.*, (2012) observed the siderophore production in the rhizosphere isolates of *Pseudomonas fluorescens*.

Effect of volatiles from bacterial antagonists against the growth of *R. solani*

Effect of volatiles from *Pseudomonas fluorescens* against the growth of *R. solani* under *in vitro* conditions

In the present investigation, among all the *Pseudomonas* isolates tested, *Pf.* I₁₀ recorded maximum mycelial growth reduction of 38.88 per cent when compared to all other isolates of *Pseudomonas fluorescens*. Kazempour (2004) reported that the production of volatile from *Pseudomonas fluorescens* isolate B41 effectively reduced the mycelial growth (72.7 per cent) of *R. solani* under *in vitro* conditions and all the isolates showed inhibitory effect on mycelial growth (Table 5).

Table 5: Activity of volatile from *Pseudomonas fluorescens* isolates against the mycelial growth of *Rhizoctonia solani* (Rs₂) under *in vitro* conditions

Sl. No	Isolates	Mycelial growth (cm)*	Per cent reduction over control (%)
1.	<i>P.f.</i> I ₁	8.47	5.88
2.	<i>P.f.</i> I ₂	8.42	6.44
3.	<i>P.f.</i> I ₃	6.50	27.77
4.	<i>P.f.</i> I ₄	8.64	4
5.	<i>P.f.</i> I ₅	8.75	2.77
6.	<i>P.f.</i> I ₆	5.93	34.11
7.	<i>P.f.</i> I ₇	7.10	21.11
8.	<i>P.f.</i> I ₈	7.27	19.22
9.	<i>P.f.</i> I ₉	7.50	16.66
10.	<i>P.f.</i> I ₁₀	5.50	38.88
11.	<i>P.f.</i> I ₁₁	8.62	4.22
12.	<i>P.f.</i> I ₁₂	8.76	2.66
13.	<i>P.f.</i> I ₁₃	8.69	3.44
14.	<i>P.f.</i> I ₁₄	8.27	2.11
15.	<i>P.f.</i> I ₁₅	8.69	3.44
16.	<i>P.f.</i> I ₁₆	8.65	3.88
17.	<i>P.f.</i> I ₁₇	8.78	2.44
18.	<i>P.f.</i> I ₁₈	8.74	2.88
19.	<i>P.f.</i> I ₁₉	7.41	17.66
20.	<i>P.f.</i> I ₂₀	8.7	3.33
21.	TNAU <i>P.f.</i> 1	7.49	16.77
22.	Control	9	0
SEd		0.22	-
CD (P=0.05)		0.44	-

*Mean of three replication

Effect of volatiles from *Bacillus* sp. against the growth of *R. solani*

Though all the isolates of *B. subtilis* showed varying results in mycelial growth inhibition of *R. solani*, *B.s.* I₆ isolate was highly effective in inhibiting the mycelial growth next to the *Bacillus* check isolate (TNAU *B.s.*1) from TNAU. Fiddaman and Rossall (1993) reported that the strain of *Bacillus* produces an antibiotic metabolite which is volatile in nature and antifungal to *R. solani* (Table 6).

Table 6: Activity of volatile from *Bacillus* sp. isolates against the mycelial growth of *Rhizoctonia solani* (Rs₂) under *in vitro* conditions

Sl. No	Isolates	Mycelial growth (cm)*	Per cent reduction over control (%)
1.	<i>B.s.</i> I ₁	7.5	16.66
2.	<i>B.s.</i> I ₂	8.81	2.11
3.	<i>B.s.</i> I ₃	8.60	4.44
4.	<i>B.s.</i> I ₄	8.73	3
5.	<i>B.s.</i> I ₅	7.06	21.55
6.	<i>B.s.</i> I ₆	6.32	29.77
7.	<i>B.s.</i> I ₇	8.54	5.11
8.	<i>B.s.</i> I ₈	8.98	0.22
9.	<i>B.s.</i> I ₉	8.89	1.22
10.	<i>B.s.</i> I ₁₀	8.77	2.55
11.	<i>B.s.</i> I ₁₁	8.51	5.44
12.	<i>B.s.</i> I ₁₂	8.60	4.44
13.	<i>B.s.</i> I ₁₃	6.68	25.77
14.	<i>B.s.</i> I ₁₄	7.87	12.55
15.	<i>B.s.</i> I ₁₅	8.79	2.33
16.	<i>B.s.</i> I ₁₆	8.81	2.11
17.	<i>B.s.</i> I ₁₇	8.69	3.44
18.	<i>B.s.</i> I ₁₈	8.81	2.11
19.	<i>B.s.</i> I ₁₉	8.83	1.88
20.	<i>B.s.</i> I ₂₀	7.41	17.66
21.	TNAU <i>B.s.</i> 1	6.18	31.33
22.	Control	9	0
SEd		0.13	-
CD (P = 0.05)		0.27	-

*Mean of three replications

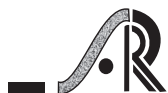
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Bactericides for Combating Rice Bacterial Leaf Blight Disease in Kuttanad

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Abstract

The field experiments were conducted for four successive seasons of *Kharif* 2022, *Rabi* 2022-23, *Kharif* 2023 and *Kharif* 2024 to assess the efficacy of commercially available bactericides against bacterial leaf blight disease of rice at MS Swaminathan Rice Research Station, Moncompu, Alappuzha, Kerala. The experiments were carried out in Randomized Block Design (RBD) with three replications in 10 m² plots using the susceptible variety Uma (MO 16). The bactericides were sprayed as a single application at the time of disease appearance. The evaluated bactericides were Kasugamycin 3 SL @ 2 mL⁻¹, Copper oxychloride 50 WP @ 3 gL⁻¹, Bleaching powder through irrigation water @ 5 kg ha⁻¹, Bordeaux Mixture @ 10 mL⁻¹, Copper hydroxide 77 WP @ 2 gL⁻¹, Kasugamycin 3 SL + Copper oxychloride 50 WP @ 2 mL⁻¹, Streptomycin sulphate 90% + Tetracycline hydrochloride 10 WP @ 0.25 gL⁻¹ + Copper oxychloride 50 WP @ 3 gL⁻¹, Trifloxystrobin 25% + Tebuconazole 50 WG @ 0.4 gL⁻¹, and Streptomycin sulphate 90% + Tetracycline hydrochloride 10 WP @ 0.25 gL⁻¹ (Standard check). The pooled data of four-season station trials revealed that the combination molecule of Streptomycin sulphate 90% + Tetracycline hydrochloride 10 WP @ 0.25 gL⁻¹ + Copper oxychloride 50 WP @ 3 gL⁻¹, reduced rice bacterial blight disease effectively followed by Copper oxychloride 50 WP @ 3 gL⁻¹ and Kasugamycin 3 SL @ 2 mL⁻¹. Kasugamycin 3 SL treated plot recorded highest grain yield of 4461 kg ha⁻¹ and was on par with Streptomycin sulphate 90% + Tetracycline hydrochloride 10 WP + Copper oxychloride 50 WP (4198 kg ha⁻¹).

Keywords: Rice, bacterial leaf blight, bactericides, combination molecule and *Xanthomonas oryzae* pv. *oryzae*

Introduction

Rice (*Oryza sativa* L.) is an important cereal crop cultivated worldwide. According to the FAO, rice is a crucial crop for global food security (Wang *et al.*, 2023). Ever growing population in India is further demanding more rice production and productivity. Under field condition, the productivity of rice is affected by many biotic and abiotic factors.

Bacterial leaf blight (BLB) is one of the major threats to rice production because of its widespread distribution and its destructiveness under favourable conditions. *Xanthomonas oryzae* pv. *oryzae* is the causal organism of bacterial leaf blight, with two distinct phases of infection viz., leaf blight and 'kresek' leaf blight appears as lesions on leaves

while 'kresek' is a systemic infection causing wilting and death of seedlings. According to Singh *et al.*, (2015), BLB is a major disease affecting various cultivars depending on their resistance mechanism and defense response genes. BLB is the most destructive disease which can cause the yield losses up to 70-90% (Yagnasree *et al.*, 2024). The systematic efforts of functionally well-characterized *Pseudomonas* (BRp3 strain) have diverse secondary metabolite production for the control of BLB pathogen (Yasmin *et al.*, 2017). The Kuttanad tract in Kerala is highly for BLB disease due to severe wind and high intermittent rain fall during *kharif* season.



Techniques for management of diseases have been adopted in the past to reduce the yield losses and prevent outbreaks, but the use of chemicals has not proven effective since different pathogenic races have varying levels of susceptibility to sprayed bactericides. Use of a suitable bactericide is the primary requirement for the effective management of the BLB disease. The objective of the present study is evaluation of a set of bactericides available in the market against the growth of bacterial leaf blight pathogen under field condition.

Materials and Methods

The experiments were conducted at the Research Farm of MS Swaminathan Rice Research Station, Moncompu with a group of commercially available bactericides against bacterial blight of rice during *Kharif* 2022, *Rabi* 2022-23, *Kharif* 2023 and *Kharif* 2024. The evaluated bactericides were Kasugamycin 3 SL @ 2 mL⁻¹, Copper oxychloride 50 WP @ 3 gL⁻¹, Bleaching powder through irrigation water @ 5 kg ha⁻¹, Bordeaux Mixture @ 10 mL⁻¹, Copper hydroxide 77 WP @ 2 gL⁻¹, Kasugamycin 3 SL + copper oxychloride 50 WP @ 2 mL⁻¹, Streptomycin sulphate 90% + tetracycline hydrochloride 10 WP @ 0.25 gL⁻¹ + Copper oxychloride 50 WP @ 3 gL⁻¹, Trifloxystrobin 25%+ tebuconazole 50% 75 WG @ 0.4 gL⁻¹, and Streptomycin sulphate 90%+ tetracycline hydrochloride 10 WP @ 0.25 gL⁻¹ (Standard check). The experimental design was Randomized Block Design (RBD) with three replications. For the investigation, seedlings of the cultivar Uma (MO 16) were planted in the field of 5x2 m² size plot with 15x15 cm spacing. NPK fertilizers were applied as per the recommendations (90:45:45 kg ha⁻¹) of Kerala Agricultural University.

The chemicals were sprayed prophylactically at the first emergence of the panicle in a plot. Each plot

had three randomly selected sampling units, each measuring one square meter. Prior to the chemical spraying and fifteen days after spraying, the severity of the disease was observed. According to the SES (Standard Evaluation System) of rice (IRRI, 2014), the degree of severity was recorded as percentage of the total area and graded based on the length and area of the plant leaf sections affected by the disease. Percentage of disease incidence was calculated based on observations from 30 plants per sampling unit, by counting number of plants infected (Shanmukhi Shirisha *et al.*, 2025). Data were transformed to arcsine transformation and analysis of variance was performed with the transformed values. Grain yield was also recorded at fourteen per cent moisture content in grains.

Results and Discussion

The pooled data of the field trials at the Research Station during *Kharif* 2022, *Rabi* 2022-23, *Kharif* 2023 and *Kharif* 2024 (**Table 1** and **Figure 1**) showed that the application of combination molecules of various bactericides in their respective concentration caused a significant reduction (87 to 90%) in the BLB disease than untreated plot (Hani Babu *et al.*, 2025). Among treatments, lowest incidence was recorded (16.54%) with Streptomycin sulphate + Tetracycline hydrochloride @ 0.25 gL⁻¹ + Copper oxychloride 50 WP @ 3 gL⁻¹, followed by Copper oxychloride 50 WP @ 3 gL⁻¹ (20.57%) and Kasugamycin 3 SL @ 2 mL⁻¹ (22.06%). However, these results confirmed the findings of Webster and Sill (1985) who recorded that bactericides, particularly antibiotics such as streptomycin, satisfactorily control several important bacterial diseases of crops.

Table 1: Evaluation of commercially available bactericides against rice bacterial leaf blight disease incidence (%) during Kharif 2022, Rabi 2022-23, Kharif 2023, Kharif 2024

Sl. No.	Bactericides	Quantity / l	Disease Incidence (%)				Mean
			Kharif 2022	Rabi 2022-23	Kharif 2023	Kharif 2024	
1	Kasugamycin 3 SL	2 ml	28.07 (31.82)	12.33 (19.89)	11.33 (22.87)	6.36 (13.66)	14.52 (22.06)
2	Copper oxychloride 50 WP	3 g	12.36 (19.45)	14.48 (22.11)	16.02 (23.21)	9.27 (17.51)	13.03 (20.57)
3	Bleaching powder through irrigation water	2 kg/acre	17.27 (24.46)	21.74 (27.38)	21.80 (27.37)	24.73 (29.42)	21.38 (27.16)
4	Bordeaux Mixture 1%	10 ml	20.14 (26.62)	17.94 (24.54)	22.59 (28.35)	19.99 (27.94)	20.16 (26.86)
5	Copper hydroxide 77 WP	2 g	28.01 (31.83)	12.35 (20.29)	23 (28.49)	24.25 (29.29)	21.90 (27.47)
6	Kasugamycin 3 SL + Copper oxychloride 50 WP	2 ml	14.08 (21.35)	18.58 (25.13)	28.87 (32.34)	30.91 (33.55)	23.11 (28.09)
7	Streptomycin sulphate 90% + tetracycline hydrochloride 10% WP + copper oxychloride 50 WP	0.25 g + 3 g	10.63 (18.53)	6.64 (9.85)	16.97 (23.10)	6.49 (14.67)	10.18 (16.54)
8	Trifloxystrobin 25% + tebuconazole 50% 75 WG	0.4 g	18.25 (24.84)	30.90 (33.70)	37.75 (37.76)	29.59 (32.75)	29.12 (32.26)
9	Streptomycin sulphate 90% + tetracycline hydrochloride 10% WP (Std check)	0.25 g	27.32 (31.16)	12.56 (20.40)	14.39 (24.18)	32.40 (34.61)	21.66 (27.59)
10	Control	-	55.83 (48.35)	48.32 (44.03)	66.12 (54.47)	60.61 (51.16)	57.72 (49.50)
	LSD @ 5% (P=0.05)		8.207	6.404	8.692	7.721	6.837
	CV (%)		20.315	17.843	19.824	18.697	16.947

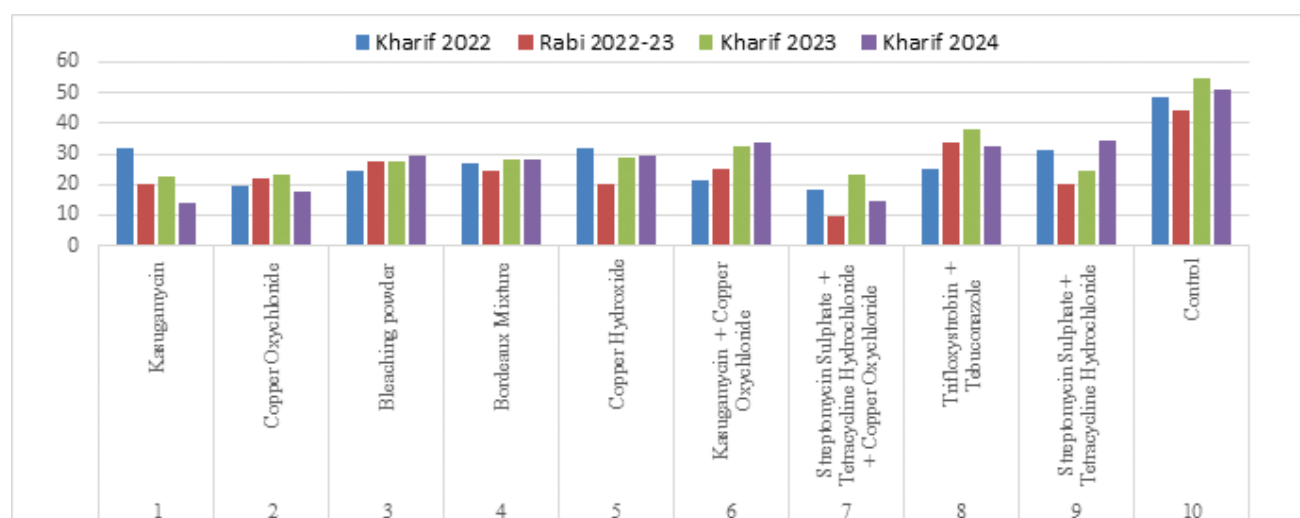


Figure 1: Effectiveness of commercially available bactericides on bacterial leaf blight disease incidence (%) of rice during Kharif 2022, Rabi 2022-23, Kharif 2023, Kharif 2024

The data on disease severity showed that Trifloxystrobin 25% + Tebuconazole 50% 75 WG gave the maximum reduction in disease occurrence (18.53%) followed by bleaching powder through irrigation water (21.47%), Copper oxychloride 50 WP (22.30%) and Streptomycin sulphate 90% + Tetracycline hydrochloride 10% WP + Copper

oxychloride 50 WP (29.67%) (Table 2 and Figure 2). Copper compounds have served as fungicides and also as bactericides (Webster *et al.*, 1985). Khandual *et al.*, (2020) also confirmed that the Streptomycin sulphate 90% + Tetracycline hydrochloride 10% WP exhibited highest inhibitory effect in lowest concentration of 100 ppm.

Table 2: Evaluation of commercially available bactericides against rice bacterial leaf blight disease severity (%) during Kharif 2022, Rabi 2022-23, Kharif 2023, Kharif 2024

Sl. No	Bactericides	Quantity/ l	Disease Severity (%)				Mean
			Kharif 2022	Rabi 2022-23	Kharif 2023	Kharif 2024	
1	Kasugamycin 3 SL	2 ml	31.38 (34.08)	13.05 (21.22)	15.83 (23.42)	36.66 (37.29)	24.23 (29.47)
2	Copper oxychloride 50 WP	3 g	24.16 (29.47)	15.55 (23.26)	10.27 (18.72)	7.77 (16.22)	14.43 (22.30)
3	Bleaching powder through irrigation water	2 kg/acre	11.94 (20.18)	13.88 (21.89)	15.55 (23.26)	12.42 (20.62)	13.44 (21.47)
4	Bordeaux Mixture 1%	10 ml	14.44 (22.30)	20.55 (26.99)	20.83 (27.13)	27.77 (31.82)	20.89 (27.20)
5	Copper hydroxide 77 WP	2 g	18.60 (25.55)	0.00 (0.00)	25.27 (30.20)	18.05 (25.18)	15.48 (23.18)
6	Kasugamycin 3 SL + Copper oxychloride 50 WP	2 ml	29.16 (32.71)	12.22 (20.44)	24.99 (29.93)	31.38 (34.08)	24.43 (29.60)
7	Streptomycin sulphate 90% + tetracycline hydrochloride 10% WP + copper oxychloride 50 WP	0.25 g + 3 g	13.60 (21.64)	19.71 (26.35)	30.55 (33.58)	34.16 (35.79)	24.50 (29.67)
8	Trifloxystrobin 25% + tebuconazole 50% 75 WG	0.4 g	10.27 (18.72)	3.60 (10.04)	19.44 (26.13)	6.93 (15.23)	10.06 (18.53)
9	Streptomycin sulphate 90% + tetracycline hydrochloride 10% WP (Std check)	0.25 g	14.16 (22.14)	33.60 (35.43)	41.11 (39.87)	35.82 (36.75)	31.17 (33.96)
10	Control	-	71.66 (57.86)	55.55 (48.22)	75.27 (60.20)	72.21 (58.18)	68.67 (55.98)
	LSD @ 5% (P=0.05)		12.380	9.473	12.601	12.477	11.515
	CV (%)		35.640	34.775	31.113	30.361	32.086

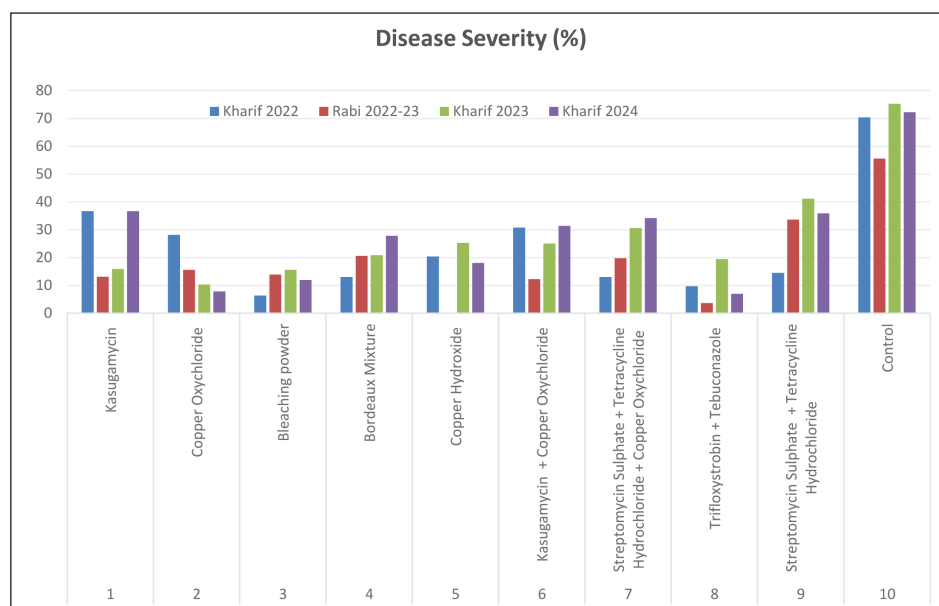


Figure 2: Effectiveness of commercially available bactericides against rice bacterial leaf blight disease severity (%) rice during Kharif 2022, Rabi 2022-23, Kharif 2023, Kharif 2024

Data on grain yield revealed that Kasugamycin 3 SL recorded highest yield (4461 kg ha⁻¹) and was on par with Streptomycin sulphate 90% + Tetracycline hydrochloride 10% WP + Copper oxychloride 50 WP (4198 kg ha⁻¹) (**Table 3** and **Figure 3**). Srinivas *et al.*, (2023) stated that the

grain yield was significantly maximum (6173 kg ha⁻¹) in Streptomycin sulphate 90 SP @ 500 ppm + Tetracycline hydrochloride 10% WP + Copper oxychloride 50 WP @ 1.25% but was statistically on par with Copper oxychloride 50 WP @ 1.25% (5913 kg ha⁻¹). Flare 72 WP (Streptomycin

sulphate) caused 92.23% control of bacterial leaf blight disease and increased the yield up to 3.55% over the control whereas Kasugamycin + copper oxychloride 50 WP gave 87.97% reduction with an increase of 3.01% in yield and Kasugamycin 4 WP gave 86.31% control with yield increase of 2.90% (Muhammad *et al.*, 2019). According to Tandan and Chaliganjewar (2016) Copper oxychloride at 0.25% + Streptomycin sulphate at 0.02% was the most effective chemical for inhibiting bacterial leaf

blight disease. Ahmad *et al.*, (2005) recommended spray of Cupravit or Vitigran Blue (3 g of water), to check further spread of disease. Spraying of copper fungicides alternately with streptomycin (250 ppm) is reported to be effective in controlling the BLB. The present study also observed the combined effect of Streptomycin sulphate + Tetracycline hydrochloride at 0.025% + Copper oxychloride at 0.3% which was found most effective for bacterial leaf blight disease of rice in Kuttanad.

Table 3: Evaluation of commercially available bactericides on grain yield (kg/ha) of rice during Kharif 2022, Rabi 2022-23, Kharif 2023, Kharif 2024

Sl. No	Bactericides	Quantity/ l	Grain Yield (kg/ha)				Mean
			Kharif 2022	Rabi 2022-23	Kharif 2023	Kharif 2024	
1	Kasugamycin 3 SL	2 ml	4862	2512	4974	5493	4461
2	Copper oxychloride 50 WP	3 g	4312	1375	5138	5891	4179
3	Bleaching powder through irrigation water	2 kg/acre	4800	1687	5274	5934	4424
4	Bordeaux Mixture 1%	10 ml	4225	1637	5349	6181	4348
5	Copper hydroxide 77 WP	2 g	4487	1600	4913	6235	4309
6	Kasugamycin 3 SL + Copper oxychloride 50 WP	2 ml	3900	1100	5224	6289	4128
7	Streptomycin sulphate 90% + tetracycline hydrochloride 10% WP + copper oxychloride 50 WP	0.25 g + 3 g	4537	1575	5661	5020	4198
8	Trifloxystrobin 25% + tebuconazole 50% 75 WG	0.4 g	3250	1887	5294	5590	4005
9	Streptomycin sulphate 90% + tetracycline hydrochloride 10% WP (Std check)	0.25 g	3987	1700	4475	5332	3874
10	Control		3100	1625	3106	4109	2985
	LSD @ 5% (P=0.05)		987	NS	1055	NS	710
	CV (%)		16.400	29.656	14.712	21.740	11.953

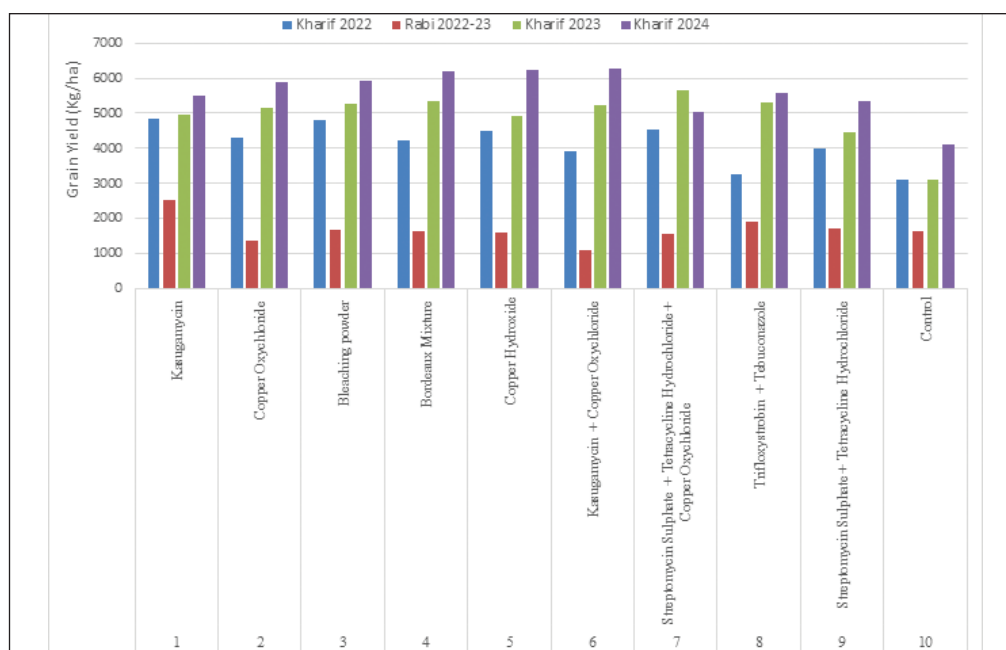


Figure 3: Effectiveness of different bactericides on grain yield (kg/ha) of rice during Kharif 2022, Rabi 2022-23, Kharif 2023 and Kharif 2024



Conclusion

The research to evaluate the efficiency of various bactericides for managing BLB showed that Streptomycin sulphate + tetracycline hydrochloride @ 0.25 gL⁻¹ + copper oxychloride 50 WP @ 3 gL⁻¹, fetched maximum disease control followed by Copper oxychloride 50 WP @ 3 gL⁻¹ and Kasugamycin 3 SL @ 2 mL⁻¹ were the most effective among the tested bactericides. The highest yield was obtained in Kasugamycin 3 SL (4461 kg ha⁻¹) and was on par with combination treatment of Streptomycin sulphate + tetracycline hydrochloride with copper oxychloride 50 WP (4198 kg ha⁻¹) and was found promising to manage rice bacterial leaf blight disease.

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Evaluating Yield Performance and Income Gains from an Advanced Temperate Rice Genotype in the Northwestern Himalayan Agro-Ecosystem

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Abstract

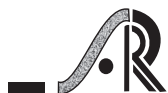
Many factors are responsible for the lower yields at farmers field which need to be identified and replaced by suitable technological interventions. Newly developed high yielding varieties and related package of practice can help bridging the yield gaps between potential and what is obtained by farmers. Keeping this in view, front-line demonstrations were conducted on a new variety (Shalimar rice -4) and crop management during 2019 to 2021. The results indicated that use of obsolete varieties, imbalanced fertilizer application, higher plant population and lack of disease management were factors responsible for low productivity at farmers' field. A positive linear correlation between grain yield and panicles m⁻² (0.3027 and 0.2191), grains panicle⁻¹ (0.6597 and 0.4398) and 1000 grain weight (0.067 and 0.0861) were recorded in Farmer's practice and Improved practice, respectively. Yield was 15.5% higher in improved practice compared to farmers' practice. An extension gap of 9.9 q ha⁻¹ and a technology gap of 6.2 q ha⁻¹ were observed in the study. Net returns were Rs. 129243 ha⁻¹ in farmers practice and Rs.146815 ha⁻¹ in improved practice. An additional income of Rs. 17572 ha⁻¹ and effective gain of Rs. 14812 ha⁻¹ were recorded in the improved practice. Higher benefit: cost ratio (2.9) was also registered in improved practice compared to farmers practice (2.7).

Keywords: Rice, front-line demonstrations, temperate ecology, agroecosystem and yield gap analysis.

Introduction

Despite India having the largest area under rice cultivation globally, its productivity remains considerably lower than the world average (Mubarak *et al.*, 2023a). A significant yield gap persists between the potential yield and the actual yield realized at farmers' fields (Mubarak and Shakoor, 2019). This gap is largely attributed to the continued use of traditional rice cultivars and sub-optimal crop management practices. Bridging this yield gap requires a systematic identification of the underlying constraints and large-scale demonstration of improved technologies under real farming conditions.

In Kashmir Valley, located in the north-western Himalayas, rice is not only the staple food but also a critical source of livelihood and employment for a substantial portion of the population. Therefore, the adoption of improved rice production technologies, including high-yielding varieties and better crop management practices, is directly linked to regional food security and enhancement of farmers' income. In this context, the Mountain Research Center for Field Crops (MRCFC), SKUAST-Kashmir released the variety Shalimar Rice-4 (SR-4) in 2017 through a farmers' participatory breeding programme. This



variety is a disease-resistant with a yield potential of up to 10 t ha⁻¹ under optimal management (Mubarak *et al.*, 2022).

Although improved varieties like SR-4 and recommended crop management practices are available, their adoption at the farmers' level remains limited. Moreover, there is inadequate location-specific information on the performance of these improved technologies under farmers' field conditions in the Kashmir Valley, as well as a lack of systematic assessment of the key factors responsible for low productivity. In view of the above, the present study was conducted during 2019-2021 with the objectives to identify the major factors responsible for low rice productivity at farmers' fields in the Kashmir Valley, to evaluate the performance of improved variety SR-4 and recommended crop management practices, under farmers' participatory conditions and to assess the potential of these interventions in bridging the yield gap and enhancing farmers' productivity and income.

Materials and Methods

A detailed survey of the 13 adopted villages (**Table 1**) located in the lap of Peer Panchal Himalayan Range between 33.62 to 33.70°N latitude and 74.8 to 75.02°E was conducted in year 2018 to ascertain different factors responsible for low yields at farmers' field. The information was collected through face-to-face interaction and questionnaire designed for the purpose. Improved practice, which included Shalimar Rice-4 variety and related crop management was used for the demonstrations at farmers field against the existing farmers' practice, which included traditional variety (Jhelum and K-39) and farmers' crop management. Sixty-four (64) frontline demonstration programmes were sponsored by ICAR. Agricultural Technology Application Research Institute Zone-1 were conducted by Farm Science Center (KVK)-Kulgam in collaboration with Mountain Research Center for Field Crops over an area of 38.8 hectares from 2019 to 2021. Each demonstration occupied one acre

area (0.5 acre under Improved practice and 0.5 acre under Farmers' practice). The details of Farmers practice and Improved practices are mentioned in (**Table 2**). Growth and yield attributes were also recorded during the study. Mean values for plant height and tiller number were recorded from 10 randomly selected plants each from farmers practice and improved practice from each location. Panicle number and number of grains were also recorded from 10 randomly selected plants from each location and then converted to panicle number m⁻² and grains per panicle⁻¹, respectively. Parameters like 1000 grain weight and grain yield were also recorded after sun drying at 14% moisture. For economic assessment, values of both grain and paddy straw were taken into consideration, as paddy straw has economic value in the valley particularly for cattle feeding and apple packing. Additional gains, effective gains, extension gap, technology gap and technology Index were calculated by using formulae given below:

- Additional gains (₹ha⁻¹) = Net returns (₹ha⁻¹) from Improved practice – Net returns (₹ha⁻¹) from farmers' practice
- Effective gains (₹ha⁻¹) = Additional returns (₹ha⁻¹) – additional costs (₹ha⁻¹)
- Extension gap (q ha⁻¹) = Improved practice yield (q ha⁻¹) – farmers' practice yield (q ha⁻¹).
- Technology gap (q ha⁻¹) = Yield in demonstrated technology (q ha⁻¹) – Potential yield (q ha⁻¹).
- Technology Index
$$\text{(\%)} = \frac{\text{Potential yield-Demo yield}}{\text{Potential yield}} \times 100$$

Table 1: List of villages covered under demonstrations

S. No.	Name of Village	S. No.	Name of Village
1	Tarigam	8	Kanipora
2	Sonigam	9	Kujar
3	Yaripora	10	Brazloo
4	Home Shali bough	11	Kaladrangh
5	Frisal	12	Chimegam, Chanpora
6	T N Pora	13	Gnosargam
7	Shurat	-	

Yield and other parameters from paired observations (farmers' practice vs. improved practice within the same fields) were analyzed using Student's paired t-test to assess the significance of differences between the two practices. Prior to analysis, assumptions of normality and homogeneity of variance were examined. Statistical significance was tested at $P \leq 0.05$.

Results and Discussion

A. Factors responsible for low yields

Participatory rural appraisal revealed that low rice productivity in the study area is a consequence of multiple, interrelated agronomic and management constraints rather than a single limiting factor.

A.1 Use of obsolete varieties

A majority of farmers continued to cultivate old rice varieties (Table 2) characterized by low yield potential

and high susceptibility to diseases, particularly blast. Under such conditions, yield stability becomes highly dependent on timely disease management, which is often lacking. Previous studies have documented substantial blast incidence in commonly grown varieties such as Jhelum and K-39 (Mubarak *et al.*, 2014), with disease severity being particularly pronounced in temperate ecosystems like Kashmir (Bhat *et al.*, 2013). The low adoption of plant protection measures, only 8.3% of farmers reported fungicide use, further exacerbates yield losses. This highlights that varietal vulnerability, when combined with weak management, creates a high-risk production system. Therefore, the introduction of disease-resistant varieties can simultaneously reduce production risk, lower dependence on fungicides, and improve environmental and human health outcomes (Mubarak *et al.*, 2023c).

Table 2: Details of farmers practice and improved practice

Input/operation	Farmers practice (Control)	Improved practice
1. Variety	K-39, Jhelum	Shalimar Rice -4
2. Seed rate for one hectare	150-200 kg ha ⁻¹	60 Kg kg ha ⁻¹
3. Seed treatment/ Kg seed	No seed treatment	Pre-treated seed with Carbendazim (1g) + Mancozeb (2g)
4. Seed sowing	1 st May-10 th May	Last week of April to 5 th May
5. Fertilizer dose (N,P ₂ O ₅ ,K ₂ O)	Haphazard, generally with higher dose of nitrogen and no or low potassium in many cases (Range of N & K ₂ O application 100-150 and 0-30 kg ha ⁻¹)	120:60:20
6. Age of seedling at transplanting	35- 43 days	30 days
7. Plants per hill	5-16	2-3
8. Time of fertilizer application	Basal application with two splits of urea. (Only 8% farmers aware about 3 split doses)	½ basal, ¼ at active tillering stage, ¼ at panicle initiation stage
9. Water management	All season flooding	Intermittent irrigation 15 days after transplantation (at saturation)

A.2 Imbalanced nutrient management

Nutrient management practices were skewed towards excessive nitrogen use with inadequate potassium application. The average application rates of 127.32 kg N ha⁻¹ and only 13.97 kg K₂O ha⁻¹ clearly indicate

a significant imbalance. Such disproportionate fertilization not only reduces nutrient use efficiency but also increases susceptibility to lodging and diseases. Balanced fertilization, particularly the integration of potassium and organic manures,



is known to enhance crop resilience and sustain productivity (Mubarak and Singh, 2011; Mubarak and Jhanger, 2023). The observed imbalance, therefore, directly contributes to sub-optimal crop performance and reinforces the need for site-specific nutrient management.

A.3 Inadequate plant protection

Despite the availability of well-established blast management strategies, their adoption was minimal among farmers. Even basic preventive measures such as seed treatment were largely absent. This management gap is critical, given that blast disease is a major yield-limiting factor in the region (Bhat *et al.*, 2013). The convergence of susceptible varieties and poor disease management amplifies yield losses, suggesting that technological interventions must integrate both host resistance and improved agronomic practices rather than addressing them in isolation.

A.4 Other constraining factors

Additional constraints included low mechanization, inefficient water management, excessive plant density and weak institutional linkages between farmers and extension systems. These factors collectively limit the effective adoption of improved technologies and contribute to the persistence of yield gaps.

B. Technological intervention and its impact

Based on the identified constraints, a frontline demonstration programme was implemented to evaluate improved practices, including the adoption of the high-yielding, disease-resistant variety SR-4 along with recommended crop management practices.

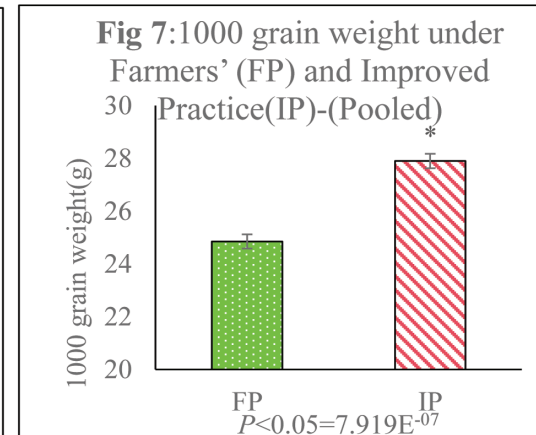
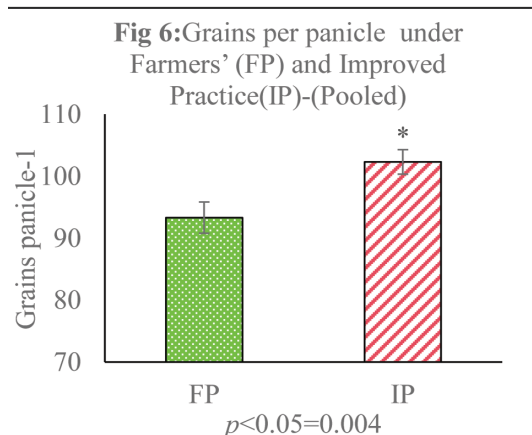
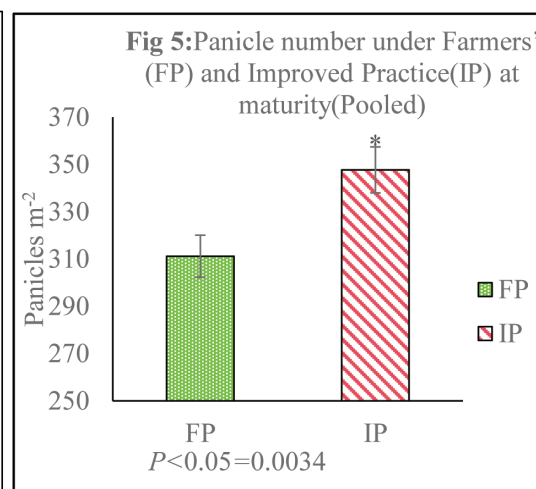
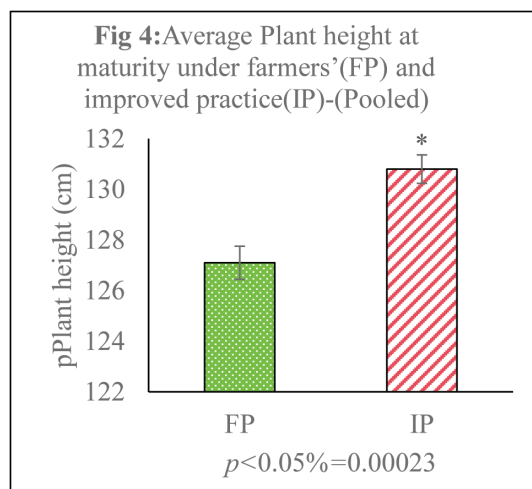
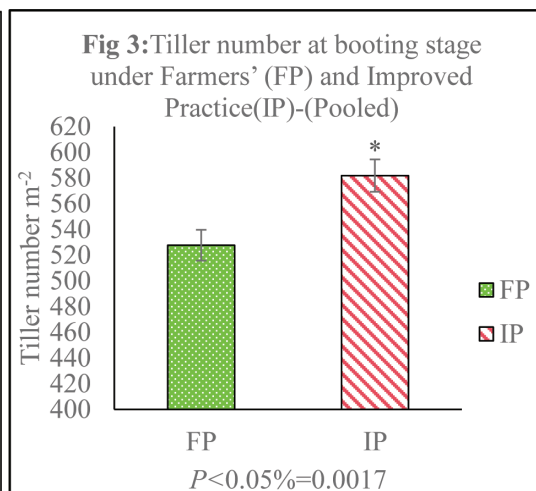
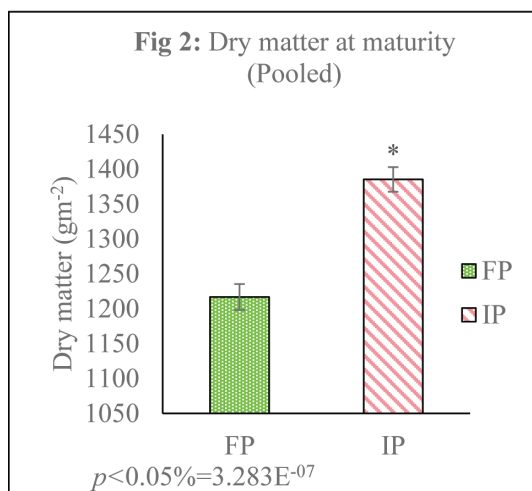
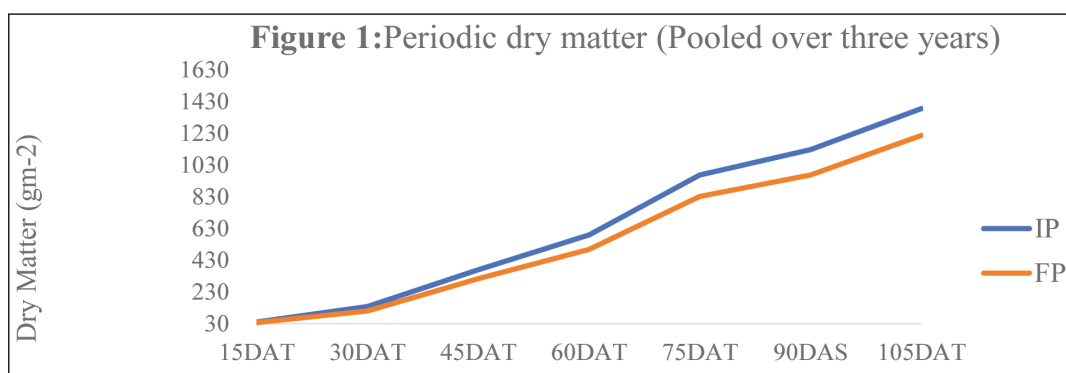
B.1 Impact on crop growth and yield attributes

Improved practices consistently enhanced crop growth parameters compared to farmers' practices. Dry matter accumulation was significantly higher under improved practices at later growth stages, indicating better resource use efficiency and biomass partitioning (Table 3, Figures 1 and 2). Similarly,

tiller density (581 m⁻²) and plant height (130 cm) were significantly higher under improved practices. These improvements can be attributed to the combined effect of superior genetic potential (SR-4) and improved agronomic management. In contrast, lower growth under farmers' practices reflects the compounded effects of varietal limitations, nutrient imbalance, higher plant competition and disease incidence.

The observed trends align with earlier findings under similar agro-ecological conditions (Sheikh *et al.*, 2013; Mubarak and Shakoor, 2019; Mubarak *et al.*, 2023b), reinforcing the role of integrated crop management in enhancing growth dynamics.

Yield attributes followed a similar pattern. Improved practices significantly increased panicle density, grains per panicle and 1000-grain weight (Table 3). The enhancement in these traits is a direct consequence of improved crop growth, highlighting the strong physiological linkage between source and sink (Figures 3-7). Comparable improvements in yield attributes under improved management have also been reported by Najeeb *et al.*, (2018), Mitra *et al.*, (2014), and Singh *et al.*, (2015).



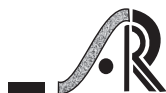


Table 3: Crop growth and yield parameters under farmers' Practice (FP) and Improved Practice (IP)

Parameters	2019	2020		2021		Mean		
	FP	IP	FP	IP	FP	IP	FP	IP
Plant height (cm)	126.4	131.7	128.2	132.9	126.7	130.8	127.1	130.8
Dry matter (gm ⁻²)	1276	1392	1238	1415	1134	1348	1216	1385
Tiller number m ⁻²	563	576	533	612	487	557	527	581
Panilce number m ⁻²	334	356	297	363	302	324	311.2	347.7
Grians panicle ⁻¹	101.4	108.3	92.3	96.7	86.3	102.1	93.3	102.3
1000 grain weight (g)	25.3	28.42	24.69	28.13	24.61	27.18	24.86	27.9

B.2 Impact on Grain Yield

Grain yield was significantly higher under improved practices across all years of study (Table 4; Figures 8-10), clearly demonstrating the effectiveness of the intervention. Yield under improved practices ranged from 73.2 to 74.5 q ha⁻¹ compared to 62.0 to 65.2 q ha⁻¹ under farmers' practices, resulting in an average gain of 9.9 q ha⁻¹ (15.5%). The yield advantage can be attributed to the cumulative effects of improved variety, balanced nutrition and better crop management. Notably, the highest yield gain (11.2 q ha⁻¹) observed in 2021 suggests a positive interaction between improved practices and favourable environmental conditions. This supports earlier reports that improved varieties like SR-4 exhibit better responsiveness to inputs and resilience to biotic and abiotic stresses (Parray *et al.*, 2020). The variation in yield advantage across years further indicates the influence of environmental variability on technology performance, a phenomenon also reported by Singh *et al.*, (2015). Overall, the results confirm that bridging the yield gap requires both technological innovation and adaptation to local conditions.

B.3 Relationship Between Yield Attributes and Grain Yield

Correlation and regression analyses revealed significant positive relationships between yield attributes and grain yield across both practices (Fig. 8). Among the attributes, grains per panicle showed the strongest association with yield ($R^2 = 0.659$ in farmers' practice and 0.439 in improved practice), followed by panicle density. This indicates that grain number is the primary determinant of yield variability in the study area, while the relatively weaker association of 1000-grain weight suggests limited variability in this trait. Regression analysis further showed that grains per panicle alone explained 43-65% of yield variation, highlighting its critical role in yield formation. Interestingly, the stronger correlations observed under farmers' practices suggest greater variability and instability in traditional systems, whereas improved practices appear to stabilize yield components. Similar relationships between yield attributes and grain yield have been reported by Imade *et al.* (2015), Kumar *et al.* (2016) and Karki *et al.* (2018).

Table 4: Yield of rice varieties under Frontline Demonstration programme at farmers' field

Year	Name of Varieties	Ecology	No. of demons.	Area under demonstration (ha)	Average yield in Improved Practice (q ha ⁻¹)	Average yield in Farmers practice (q ha ⁻¹)	Additional yield in the improved practice	% age yield increase
2019	• Jhelum/ K-39(FP)* • Shalimar Rice -4(IP)**	Irrigated valley planes	25	10	73.9	65.2	8.7	13.3
2020	• Jhelum/ K-39(FP) • Shalimar Rice-4(IP)	Irrigated valley planes	14	5.6	74.5	64.7	9.8	15.1
2021	• Jhelum/ K-39(FP) • Shalimar Rice-4 (IP)	Irrigated valley planes	25	23.2	73.2	62.0	11.2	18.0
Total (Demos & Area) / Mean yield & % increase in yield			64	38.8	73.8	63.9	9.9	15.5

*FP: Farmers' Practice **IP: Improved Practice

B.4 Gap analysis

Yield gap analysis revealed that extension gap ranged between 8.7 to 11.2 q ha⁻¹ (**Table 5**) with average value of 9.9 q ha⁻¹. The Technology gap varied between 5.5 to 6.8 with an average value of 6.2. These figures indicate that there is scope for enhancing the rice production in the valley by popularizing the latest high yielding varieties like Shalimar Rice-4 along with its package of practices. This can be achieved through collaborative efforts of extension functionaries involving Farm Science Centers (KVKs) and department of agriculture existing in each district of the valley. Earlier Mubarak and

Sheikh (2014) and Sheikh *et al.*, (2014) also reported similar results during their studies on demonstration of rice technologies under Kashmir conditions. Technology Index also varied between 6.8 to 8.5% with an average value of 7.62%. Since technology index is an indicator of the feasibility of the evolved technology at the farmers' fields, so lower value of technology index would mean more feasibility of the technology. Technology index of 7.62% indicates that there is scope for further improvement in productivity of rice in Valley. These findings are in line with those of Mitra *et al.*, (2014) and Singh *et al.*, (2015).

Table 5: Gap analysis and technology Index in Frontline Demonstration on rice at farmers' field

Year	Name of Varieties	Ecology	Extension gap	Technology Gap	Technology Index
2019	Jhelum/ K-39(FP) Shalimar Rice -4(IP)	Irrigated plains of Kashmir valley	8.7	6.1	7.625
2020	Jhelum/ K-39(FP) Shalimar Rice-4(IP)	Irrigated plains of Kashmir valley	9.8	5.5	6.875
2021	Jhelum/ K-39(FP) Shalimar Rice-4 (IP)	Irrigated plains of Kashmir valley	11.2	6.8	8.5
Mean			9.9	6.2	7.75

B.5 Economic impact:

Economic benefits varied during different years of study both in the improved technology and farmers practice (**Table 6**). The cost of cultivation ranged between ₹47280 ha⁻¹ in year 2019 in farmers' practice to Rs.53068 ha⁻¹ in the improved practice in year 2020. This was due to variation in cost of inputs in different years and comparatively higher input requirement in the improved practice. On an average, the cost of inputs was Rs.47647 ha⁻¹ and Rs.50407 ha⁻¹ for farmers practice and improved practice, respectively. Improved practice involved an additional cost of cultivation of Rs.2760 ha⁻¹. Gross and net returns fluctuated during the years of study with maximum values recorded for improved practice (**Table 6**). Gross returns of Rs.176890 ha⁻¹ and Rs. 197222 ha⁻¹

were registered under farmers practice and improved practice, respectively (**Figure 8**). Net returns were Rs. 129243 ha⁻¹ in farmers practice against Rs.146815 ha⁻¹ in improved practice. An additional income of Rs. 17572 ha⁻¹ and effective gain of Rs. 14812 ha⁻¹ was therefore obtained from improved practice. Benefit : cost ratio (2.9) was also high in improved practice compared to farmers practice (2.7). The additional returns, effective gain and higher net returns obtained under improved practices could be may be attributed to high yield potential of SR-4 variety and optimal crop management under existing ecology and environmental conditions (Najeeb *et al.*, 2020).

Table 6: Economic Analysis of frontline demonstration programme on rice at farmers' field

Year	Input cost (₹ ha ⁻¹)		Additional cost in IP	Gross returns* (₹ ha ⁻¹)		Net returns (₹ ha ⁻¹)		Additional returns from IP (₹ ha ⁻¹)	Effective Gain from IP (₹)	B:C ratio	
	Farmers Practice (FP)	Improved Practice (IP)		FP	IP	FP	IP			FP	IP
2019	47280	49242	1962	176536	195694	129256	146452	17196	15234	2.7	3.0
2020	48229	53068	4839	180899	200300	132670	147232	14562	9723	2.8	2.8
2021	47432	48912	1480	173234	195672	125802	146760	20958	19478	2.6	3.0
Average	47647.0	50407.3	2760.3	176890	197222	129243	146815	17572	14812	2.7	2.9

*It also includes the returns from paddy straw owing to its demand in the valley for apple packing and as cattle fodder for lean winter season.

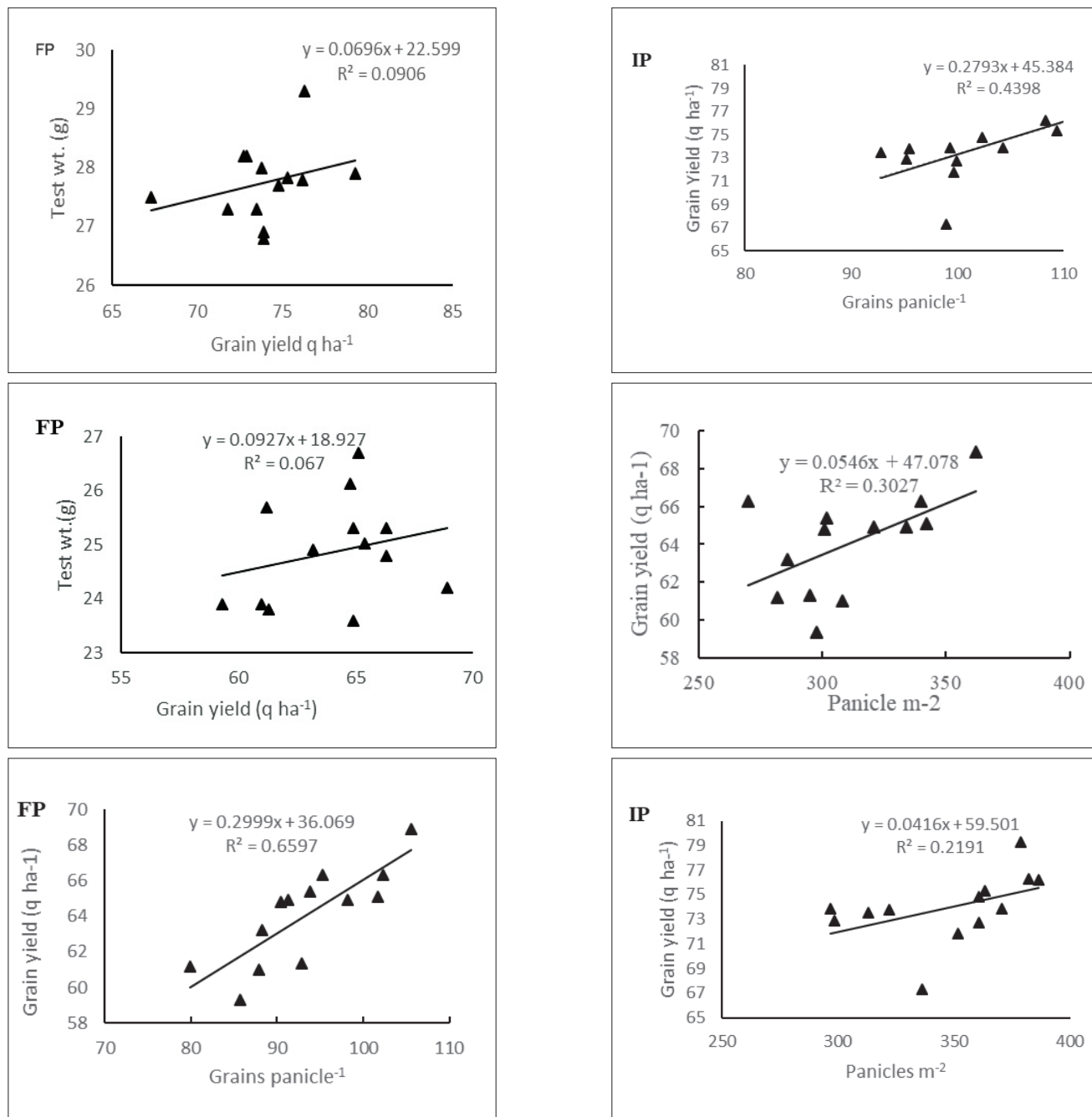


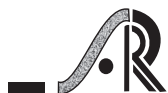
Figure 8: Relationship between yield attributes and grain yield

Conclusion

Rice being staple food for majority of the population possesses a significant status in the Union territory of Jammu and Kashmir. Area under rice however is declining at a fast pace due to diversification into other sectors especially horticulture and non-agriculture activities. This indicates that more production is required from less land. Restricting unabated land conversion through policy measures and technological interventions such as new varieties with high yield potential and resilience to biotic and abiotic stresses coupled with optimum management seem to be way out. Present study highlights the benefits of adopting improved rice practices over traditional practice in terms of rice production and profitability.

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DRRH 7 - World's First Publicly Bred Rice Hybrid for Alkaline (Sodic) and Inland Saline Ecology with *Saltol* QTL

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Abstract

DRRH-7 (IET 30165) is the first publicly bred rice hybrid developed for alkaline (sodic) and inland saline ecosystems. The introgression of the *Saltol* QTL in the restorer line (PSV 729R) provides tolerance to salinity stress under these target environments. The hybrid was developed from the cross IR79156A × PSV 729R. DRRH-7 was evaluated under the All India Coordinated Research Project on Rice (AICRPR) multi-location Alkaline and Inland Saline Tolerant Varietal Trials (AL&ISTVT) during 2021–2024. Across test environments, the hybrid consistently outperformed national and regional tolerant checks in Haryana, Uttar Pradesh and Tamil Nadu. It recorded a mean grain yield of 3.5 t ha⁻¹ under alkaline soil conditions and 3.4 t ha⁻¹ under inland saline conditions, signifying stable yield performance and stress resilience. The enhanced performance under sodic and saline stress highlights the effectiveness of *Saltol*-mediated Na⁺/K⁺ homeostasis in sustaining productivity. DRRH-7 exhibited moderate resistance to key fungal diseases including leaf blast, neck blast, brown spot and grain discoloration, along with moderate tolerance to plant hoppers, thereby ensuring yield stability under biotic stress pressures. The hybrid matures in 127–130 days (seed-to-seed) and possesses a long slender (LS) grain type with desirable milling, cooking and grain quality traits suitable for consumer acceptance. Based on its consistent multi-environment superiority and stress adaptability, DRRH-7 was released for commercial cultivation in the alkaline and inland saline ecosystems of Haryana, Uttar Pradesh and Tamil Nadu by the Central Sub-Committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 6123 (E) dated December 31, 2025 (CG-DL-E-31122025-268976).

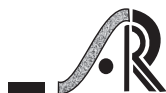
Keywords: Hybrid rice, Alkaline and Inland saline stress, MABB, *Saltol*, resistance to biotic and abiotic stress, long slender grains

Introduction

Salinity constitutes the second most unfavourable abiotic constraint to global rice production after drought, severely impairing productivity across coastal, inland saline and sodic ecosystems. Although hybrid rice technology has evidently enhanced yield potential over conventional inbred cultivars, its deployment under salinity stress conditions remains limited. In the context of escalating population pressure and progressive shrinkage of cultivable land,

the development of stress-resilient hybrids capable of sustaining productivity in marginal environments has become imperative.

To address this challenge, the ICAR-Indian Institute of Rice Research (IIRR) initiated a targeted breeding program to develop a hybrid specifically adapted to alkaline and inland saline ecologies. The restorer line PSV 729R was improved for seedling-stage salinity



tolerance through marker-assisted backcross breeding (MABB) by introgression of *Saltol* QTL. The improved restorer, when crossed with IR79156A, resulted in the development of hybrid IIRRH-155 (IET 30165), subsequently designated as DRRH-7. The hybrid was nominated to the All India Coordinated Research Project (AICRP) on Rice and evaluated under multi-location Alkaline and Inland Saline Tolerant Varietal Trials (AL & ISTVT) during 2021–2024.

Across diverse stress environments in Zones II (Haryana), III (Uttar Pradesh), and VII (Tamil Nadu), IET 30165 consistently demonstrated superior

performance under both alkaline and inland saline conditions, exhibiting stable yield advantages over national and regional checks. In alkaline ecologies, the hybrid recorded grain yield (**3537 kg ha⁻¹**) superiority over CSR10 (26%), FL478 (20%) and the sensitive check, Pusa 44 (40%). Under inland saline conditions, yield advantages (**3372 kg ha⁻¹**) were observed over CSR10 (14%), FL478 (13%) and Pusa 44 (83%). These results validate the effectiveness of *Saltol*-mediated ion homeostasis in conferring enhanced tolerance and yield stability under sodic and saline stress (**Table 1**).

Table 1: Grain yield performance of DRRH 7 in Zone-II (Haryana), Zone-III (Uttar Pradesh) and Zone-VII (Tamil Nadu)

Zones/States	DRRH-7 (IET 30165)	Superiority over checks (%)		
Mean Grain Yield (Kg/Ha)		ED Saline and Alkaline Check (CSR10)	Saline Tolerant Check (FL478)	Sensitive Check (Pusa 44)
Alkalinity*				
Zone-II[11 locations]	3364	2707 (24)	2736 (23)	2014 (67)
Zone-III[5 locations]	3497	2829 (24)	2574 (36)	2153 (62)
Zone-VII[15 locations]	3677	2865 (28)	3227 (14)	3021 (22)
Overall Weighted Mean [31 locations]	3537	2803 (26)	2947 (20)	2524 (40)
Inland Salinity#				
Zone-II [6 locations]	3372	2961 (14)	2974 (13)	1843 (83)
*Alkalinity includes Zone-II (Haryana), Zone-III (Uttar Pradesh) and Zone-VII (Tamil Nadu); # Inland Salinity includes Zone-II (Haryana).				

Alkalinity- Zone II, III and VII

		Year of Testing	DRRH-7 (IET 30165)	ED Saline and Alkaline Check, CSR10	Saline Tolerant Check FL478	Sensitive Check Pusa 44
Mean Yield (Kg/ha)	8	2021	3518	2471	2371	1960
	8	2022	4078	3497	3391	2622
	6	2023	3341	2782	3154	2576
	9	2024	2495	1448	2704	2958
Weighted mean			2607	2079(25)	2097(24)	1681(55)

Inland Salinity Zone-II

Mean Yield (Kg/ha)	1	2021	3793	2753	3053	2120
	1	2022	3800	3220	2987	1407
	2	2023	3484	2847	2687	1837
	2	2024	2835	3048	3215	1928
Weighted mean			3372	2961(14)	2974(13)	1843(83)

The hybrid exhibits moderate resistance to major fungal diseases including leaf blast, neck blast, brown spot, and grain discoloration, along with moderate tolerance to plant hoppers, thereby contributing to enhanced production stability. Grain quality evaluation revealed superior milling attributes, with hulling (80.33%), milling (70.87%) and head rice

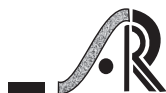
recovery (61.97%) comparable to checks. DRRH-7 possesses intermediate amylose content (24.41%), alkali spreading value (4.0), gel consistency (46 mm) and a long slender grain type (kernel length 6.35 mm; kernel breadth 2.0 mm), fulfilling consumer-preferred cooking and grain quality standards (**Figure 1**).



Figure 1: DRRH-7 (IET 30165) Field View and paddy, brown and polished rice

Agronomically, the hybrid is recommended for sowing from the second week of June to the second week of July, synchronized with monsoon onset or supported by pre-sowing irrigation. A seed rate of 15 kg ha⁻¹ is optimal. Transplanting of 18–22 day-old seedlings at a spacing of 20 × 15 cm (1–2 seedlings per hill) is advised. Effective weed management may be achieved through manual or chemical control, and irrigation should be ensured during moisture sensitive stages, particularly active tillering, panicle initiation, booting and grain filling. DRRH-7 is an early-duration hybrid (127–130 days, seed-to-seed) with sustainable yield potential under recommended management practices within its target ecologies.

Based on its consistent multi-environment performance and stress adaptability, DRRH-7 has been approved for release and commercial cultivation in the alkaline and inland saline ecosystems of Haryana, Uttar Pradesh, and Tamil Nadu by the Central Sub-Committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops (CVRC) vide S.O. 6123 (E) dated December 31, 2025 (CG-DL-E-31122025-268976). Collectively, DRRH-7 represents a significant advancement in hybrid rice breeding for inland saline and alkaline agro-ecosystems, offering a robust technological intervention for enhancing productivity and livelihood security in stress-prone regions.



DRR Dhan 90 (IET 29581): A Nitrogen Use Efficient Rice Variety Adapted to Low Soil Nitrogen Input Conditions

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Abstract

DRR Dhan 90 [IET 29581 (RP6255-BV-RIL-1696)], a low soil nitrogen (N) tolerant rice variety with nitrogen use efficiency (NUE), was developed from the cross of BPT5204/Varadhan. The entry was evaluated in All India Coordinated Research Project on Rice (AICRPR) multi-location Low Nitrogen Tolerance Trials (LNT) during 2021-2024 under 0% N application and 50% of recommended N dosage conditions. DRR Dhan 90 consistently outperformed the checks in Zone VII under low N conditions. Under 50% N condition, the mean grain yield in Zone VII was 4590 kg/ha with superiority over Improved Samba Mahsuri (14%), Rasi (22%) and Varadhan (39%). Under 0% N condition, the variety recorded a mean grain yield of 4098 kg/ha with superiority of 26%, 2% and 46% over the respective checks. The variety exhibited moderate resistance to leaf blast, neck blast, sheath rot and moderate resistance to brown plant hopper, white-backed plant hopper, stem borer and whorl maggot. DRR Dhan 90 possesses desirable grain and cooking quality traits with short bold grains, intermediate amylose content (22.7%) and head rice recovery (64.7%). Based on its consistent multi-environment superiority for yield and adaptability to low N condition, DRR Dhan 90 was released for commercial cultivation in the irrigated ecosystems of Andhra Pradesh, Telangana and Karnataka by the Central Sub-Committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 6123 (E) dated December 31, 2025 (CG-DL-E-31122025-268976).

Keywords: Rice, nitrogen use Efficiency, low nitrogen soil, grain yield and good head rice recovery.

Introduction

Rice (*Oryza sativa* L.) is one of the major staple food crops cultivated extensively under irrigated ecosystems in India, covering nearly 20-22 million hectares, which constitutes about half of the total rice cultivation area in India. Rising fertilizer costs, reduced nitrogen use efficiency, and environmental concerns associated with excessive N application necessitate the development of rice varieties adapted to low N input conditions. Breeding rice varieties with improved nitrogen use efficiency is

therefore an important strategy for sustainable rice production under changing climate scenarios. With this objective, breeding programme for development of low N tolerant rice varieties with nitrogen use efficiency was initiated during 2011 under the National Innovations in Climate Resilient Agriculture (NICRA) project at ICAR-Indian Institute of Rice Research. Several genotypes including released rice varieties and landraces were evaluated and crossing material was developed. The segregating generations

were advanced through pedigree selection under low nitrogen and irrigated conditions. The promising culture RP6255-BV-RIL-1696 was identified based on superior yield performance, adaptation and grain quality. Subsequently, the entry was nominated as IET 29581 in AICRPR LNT trials during *Kharif*-2021. The entry consistently performed well under low soil N conditions across multiple locations and years and was released as DRR Dhan 90 for irrigated ecosystems of Zone VII comprising the states of Karnataka, Telangana and Andhra Pradesh.

Yield Performance

DRR Dhan 90 exhibited stable grain yield performance across coordinated trials conducted during 2021–2024 under low N conditions. Under 50% recommended N application, the weighted mean grain yield in Zone VII was 4590 kg/ha; 4387 kg/ha in Karnataka, 5194 kg/ha in Telangana and 4457 kg/ha in Andhra Pradesh. The variety showed substantial superiority over the low N susceptible check, Improved Samba Mahsuri and positive checks Rasi and Varadhan. Under 0% N application, DRR Dhan 90 recorded a weighted mean grain yield of 4098 kg/ha in Zone VII with corresponding weighted mean grain yields in Karnataka (4290 kg/ha), Telangana (3612 kg/ha) and Andhra Pradesh (4347 kg/ha). The variety consistently maintained superior performance even under low N (0% N) conditions, indicating its suitability for low N input cultivation systems (Table 1, Figure 1A).

Disease and Insect Pest Reaction

DRR Dhan 90 exhibited moderate resistance to important diseases such as leaf blast, neck blast, sheath rot and grain discoloration in National Screening Nursery evaluations conducted during 2021-2023. The variety also showed moderate resistance to major insect pests including BPH, WBPH, stem borer and whorl maggot.

Grain and Cooking Quality

DRR Dhan 90 possesses desirable grain and cooking quality characteristics. The variety recorded good

hulling percentage (78.4%), milling percentage (68.7%) and head rice recovery (64.7%). The grains are short bold type with kernel length of 5.47 mm and kernel breadth of 2.15 mm. The variety possesses intermediate amylose content (22.7%), alkali spreading value of 4.0 and gel consistency of 22.3 mm, indicating acceptable cooking quality (Figure 1B).

Recommendation and Adaptation

DRR Dhan 90 is suitable for cultivation under irrigated ecosystems of Karnataka, Telangana and Andhra Pradesh in Zone VII. The variety performs well under reduced nitrogen conditions including 0% N and 50% recommended N application, thereby reducing fertilizer dependence and improving nitrogen use efficiency.

Table 1: Yield performance of DRR Dhan 90 under low nitrogen conditions

Zone/ State	Mean grain yield (kg/ha)	Superiority over ISM (%)	Superiority over Rasi (%)	Superiority over Varadhan (%)
50% of Recommended N				
Zone VII	4590	14	22	39
Karnataka	4387	29	53	39
Telangana	5194	23	43	21
Andhra Pradesh	4457	-	-	67
0% of Recommended N				
Zone VII	4098	26	2	46
Karnataka	4290	33	13	45
Telangana	3612	33	50	27
Andhra Pradesh	4347	38	12	85



Figure 1A: Field view of DRR Dhan 90 under N-50% treatment



Figure 1B: Single plant view of DRR Dhan 90 under N-low, N-50% and N-Rec treatments (Left); Paddy, Brown rice and Polished rice of DRR Dhan 90 (Right).

Trombay Konkan Khara (IET 30185) Rice Variety Suitable for Coastal Saline Soils in Maharashtra State

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Abstract

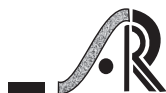
Trombay Konkan Khara (IET-30185) has high yielding rice variety having semi dwarf stature and non-lodging, mid late duration (125 to 130 days), long slender grain type, 37.68% increase over best check variety Panvel 2 in Station trial. It recorded 15.50% yield advantage over overall mean of four years over best check Panvel 2 in Maharashtra state coordinated trial under coastal saline soil condition. Trombay Konkan Khara rice variety developed by Khar Land Research Station, Panvel and Bhabha Atomic Research Centre (BARC), Trombay, Mumbai with an average yield of 3.5 to 4.0 t/ha. Trombay Konkan Khara (IET-30185) is evolved from a cross between CSR 27 / Dwarf mutant of CSR 27. Trombay Konkan Khara (IET-30185) has good milling (64.46%), head rice recovery (62.56%) and translucent kernel type indicating superior grain quality of rice variety.

Keyword: Trombay Konkan Khara, mid late variety, long slender grains, coastal saline soils, dwarf mutant of CSR 27

Introduction

Soil salinity negatively affects agricultural production worldwide. More than 800 million hectares of land globally are salt-affected, including both saline and sodic soils, which represent more than 6% of the world's total land area. In India, 6.73 million ha are under salt-affected area. Rice is considered salt-sensitive as it is not efficient in controlling the influx of Na⁺ through the roots, leading to a rapid accumulation of toxic concentrations in above-ground parts. The problem of salinity has been addressed through better management practices and the introduction of salt-tolerant varieties in affected areas. The Maharashtra state has 720 km of coastal length with 54 creeks. It comprises the districts of Palghar, Thane, Raigad, Ratnagiri and Sindhudurg. The coastal saline soils occur in these

districts due to periodical inundation of cultivable land by creek/sea water during high tides. As per the master plan of development of coastal saline soils of Maharashtra the total area under saline soils in five districts of Konkan is estimated to be 65,465 ha. The high-yielding stress-tolerant rice varieties are expected to provide a yield advantage of about 2 t ha⁻¹ on these soils. Thus, genetic improvement of salt tolerance in rice appears to be economically feasible and a promising strategy for maintaining stable rice production globally. Accordingly, the efforts were made to develop and release the Trombay Konkan Khara to fulfill the requirement of fine grain type, mid late duration, high yielding rice variety for the farmers of the Konkan region of Maharashtra state in collaboration with BARC, Mumbai.



Trombay Konkan Khara (IET - 30185) is semi dwarf stature and non-lodging, mid late duration (125 to 130 days), long slender grain type, 37.68% increase over best variety check Panvel 2 in Station trial, 15.50%

yield advantage on overall mean of four years over check Panvel 2 in Maharashtra state coordinated trial for Kharland (**Table 1 and Figure 1**).

Table 1: Grain Yield (Kg/ha) summary performance of rice culture BARCKKV 16 from *Kharif* 2013 to 2021

Name of Trial	Year	Locations	ECe BARCKKV 16	Grain yield (kg/ha)		
				PNL-2 (Local Check)	% increase over checks	
1. Station Trial						
IVT	2013	01	6.0	3786	2645	43.13
AVT	2014	01	6.0	3398	2572	32.11
Weighted mean/Total		02		3592	2609	37.68
2. Maharashtra Trials						
IVT-Kharland (Maharashtra)	2016	03	-	4618	4185	10.4
IVT-Kharland Maharashtra)	2017	03	-	3683	2803	31.39
AVT-Kharland (Maharashtra)	2018	02	-	3559	3278	8.6
AVT-Kharland (Maharashtra)	2019	02	-	2556	2215	15.4
Weighted mean/Total		10	-	3698	3203	15.5
3. AICRIP Trial						
CSTVT	2021	3	4416	Bhoothnath (Coastal Salinity check)	3264	
				CSR 10 (Salinity check)	2801	
				FL 478 (Salt tolerant check)	3179	
4. Agronomical trial						
	2021		4088		3511	16.43
5. Adaptive trials						
Adaptive	2021	18	-	3847.2	3320.6	15.85



Figure 1: Field view of Trombay Konkan Khara (IET-30185) rice variety

Trombay Konkan Khara (IET-30185) rice culture has recorded 15.85 per cent increase in grain yield

over check Panvel 2 in Adaptive trials conducted on farmer's field during the year *kharif* 2021. Trombay Konkan Khara rice culture has recorded more than 35.29 per cent, 57.65 per cent and 38.91 per cent increase in grain yield over salinity check varieties Bhuthnath, CSR 10 and FL 478 in AICRIP IVT-CSTVT during the year *kharif* 2021.

Trombay Konkan Khara (IET-30185) having good milling (64.46%), head rice recovery (62.56%), amylose content (22.93%) and translucent kernel type indicating superior grain quality of rice variety BARCKKV 16 (**Figure 2**), moderately resistant to stem borer, moderately resistant to BLB disease, high in grain protein content (9.16%), average grain yield 3.5 to 4.0 t/ha under moderate coastal saline soils. (**Tables 2 and 3**).

Table 2: Pest and disease reactions of BARCKKV-16

Designation	Year	Stem Borer		Bacterial Leaf Blight		Leaf Blast	
		Mean	Reaction	Mean	Reaction	Mean	Reaction
BARCKKV 16	2016	0	HR	2	MR	4.0	MS
Panvel 2 (ch)		0	HR	3	MR	3.7	MS
BARCKKV 16	2018	1.5	MR	2	MR	3.3	MS
Panvel 2 (ch)		1.5	MR	5	MS	4.0	MS
BARCKKV 16	2022	--	MR				

R: Resistant, S: Susceptible, MR: Moderately resistant, HS: Highly susceptible, HR: Highly Resistant, MS: Moderately susceptible

Table 3: Summary of grain quality characteristics of BARCKKV-16

Sl. No	Designation	Milling (%)	HRR (%)	Grain chalk	Aroma	WU (ml)	VER	ER	ASV	AC (%)	GC (mm)	GT (°C)	Protein (%)
1	BARCKKV-16	64.46	62.56	A	NS	300	4.25	1.48	4.0	22.93	65	Intermediate (70-74 °C)	9.16*
2	PNL-2 (Ch.)	57.15	48.88	VOC	NS	360	4.25	1.56	4.0	26.85	56	Intermediate (70-74 °C)	4.89**

HRR: Head Rice Recovery, KL: Kernel length, KB: Kernel Breadth, L/B ratio: Length/Breadth, Grain chalk: Grain chalkiness, VER: Volume Expansion ratio, WU: Water uptake, KLAC: Kernel length after cooking, ER: Elongation ratio, ASV: Alkali spreading value, AC: Amylose content, GC: Gel consistency, SS: Short slender, A: Absent

The yield attributing characters and yield of Trombay Konkan Khara and Panvel-2 variety shown significant influence as a result of various spacing and nitrogen levels under coastal saline condition.

The growth, yield attributing characters and yield of BARCKKV16 was found to be statistically significant over Panvel-2 rice variety. The plant height (105.2 cm), number of tillers per panicle (11.64), number of panicles per sq. m (311.67), Panicle length (24.14), number of spikelets per panicle (141.22) and test weight (25.1) were also observed to be statistically significant over Panvel-2 rice variety. The grain and straw yields of BARCKKV16 were significantly highest (40.88 qha⁻¹) and (42.36 qha⁻¹), respectively. There was an increase in the grain (14.06%) and straw (7.17%) yield of BARCKKV 16 over Panvel-2 rice variety. The different spacing had shown a significant effect on growth and yield attributes characters viz., plant height, number of

tillers per panicle, number of panicles per sq.m, spikelet per panicle, test weight. The treatment having spacing of 20 x15 and 20 x 20 cm caused a significant enhancement in the spacing grain (38.26 and 38.08 q ha⁻¹) and straw (40.94 and 41.01 q ha⁻¹) yields. The treatment receiving application of 150 kg N/ha showed a significant enhancement in yield attributing characters. It also recorded significant grain (39.00 qha⁻¹) and straw yield (41.40 qha⁻¹). However, the lowest grain and straw yield was observed in the treatment receiving 50 kg N/ha. The interaction of variety and nitrogen levels showed significant increase in grain yield. The treatment receiving application of 150% N i.e., 150 kg N ha⁻¹ to the BARCKKV 16 rice culture recorded significantly higher grain yield than rest of interactions of nitrogen levels and variety combination.



Paddy



Rice

Figure 2: Grain characters of Trombay Konkan Khara (IET-30185) rice variety

Trombay Konkan Mahan Rice Variety Suitable for Lowland Rice Growing Areas of Maharashtra

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Abstract

Trombay Konkan Mahan (TKR- 35) is high yielding rice variety having semi dwarf stature (105-110 cm) with long slender grain type, good grain quality and late duration (140-145 days) released for commercial cultivation in lowland rice growing areas of Maharashtra state during 2025. This variety is developed by Regional Agricultural Research Station, Karjat in collaboration with Bhabha Atomic Research Centre (BARC), Trombay, Mumbai which recorded an average yield of 5.0 to 5.5 t/ha. Trombay Konkan Mahan is developed from a cross between the PB1 Mutant and Ratnagiri 24. Trombay Konkan Mahan is high milling (69.55%), head rice recovery (61.25%) and translucent kernel type indicating superior grain quality of rice variety with acceptable amylose content (24.8).

Keyword: Trombay Konkan Mahan, high head rice recovery, long slender grains, lowland rice variety.

Introduction

In Maharashtra, rice is the second most important crop of the people, which is grown over an area of 15.25 lakh hectares with an annual rough rice production of 52.03 lakh tonnes. The average productivity of the state is 3.30 t/ha. The average productivity of the state is low as compared to other rice growing states viz., Punjab (5.80 t/ha) and Tamil Nadu (4.90 t/ha).

Konkan region is the major rice producing area of Maharashtra. Nearly 3.31 lakh ha area of Konkan is under rice crop with a production of 14.20 lakh tonnes rough rice. The average productivity of rough rice in Konkan region is 4.28 t/ha. The Konkan region contributes 21.73% in area under rice crop and produce 32.14% rough rice at Maharashtra state level (Maharashtra State Statistics Department, Pune 2023-24 report).

The rice cultivation in Konkan region is carried out on three types of soils classified as upland, midland and lowland requiring early, mid-late and late varieties respectively. The proportion of area under early, mid-late and late varieties is about 40, 40 and 20 per cent respectively. There is a need for long slender grain type and late duration rice variety for *kharif* season in Konkan region of Maharashtra state with higher yield. Accordingly, efforts were made to develop and release the TKR-35 to fulfill the requirement of long slender grain type, late duration, high yielding rice variety for the farmers of the Maharashtra state in collaboration with BARC, Mumbai. Pest and disease reactions of Trombay Konkan Mahan (TKR-35) in Initial Variety Trial Late and Advance Variety Trial (M) - Mid-late and Late conducted during *Kharif* 2020-2022 in Maharashtra State Coordinated Multilocation trials are given (Table 1).

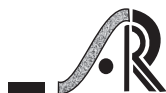


Table 1: Yield (Kg/ha) summary performance of rice culture Trombay Konkan Mahan TKR-35 from Kh-2018 to 2024

Name of Trial	Year	Locations	Grain yield (kg/ha)		
			TKR-35	KJT-2 (Local Check)	% increase over checks
1. Station Trial					
IVT-Late	2018	01	7145	4589	55.7
AVT-Late	2019	01	6328	4423	43.1
Weighted mean		01	6737	4506	49.51
2. Maharashtra Trial					
IVT-Late (Maharashtra)	2020	11	4693	3875	17.4
AVT-Late (Maharashtra)	2021	11	4624	4248	8.9
AVT-Late (Maharashtra)	2022	11	5855	4721	23.9
Weighted mean		11	5089	4276	19.01
3. AICRIP Trial					
IVT-Late (AICRIP)	2024	33	5775	5650	-
Swarna (NC)				5733	-
Salivahana (ZC)				5941	-
IVT-Late (AICRIP-Maharashtra)	2024	04	6312	5017	25.8
Swarna (NC)				6621	-
Salivahana (ZC)				5616	12.4
4. Agronomical trial					
	2025	1	5220	4450	17.3
5. Adaptive trials					
Adaptive	2024	34	4771	4117	15.9

Trombay Konkan Mahan (TKR-35) is a semi dwarf stature (105-110 cm), non-lodging, late duration (140-145 days), long slender grain type, 49.5% increase over best variety check Karjat-2 in station trial, 19.01% yield advantage on overall mean of three years over check Karjat-2 in Maharashtra State under Maharashtra state coordinated mid-late and late trial. The growth, yield attributing characters

and yield of TKR-35 were found to be statistically significant over Karjat-2 rice variety. The plant height (106 cm), number of panicles per sq. m (241), number of spikelets per panicle (207) and test weight (21.06) were also observed to be statistically significant over Karjat-2 rice variety (**Table 2** and **Figure 1**).

Table 2: Ancillary characters of Trombay Konkan Mahan (TKR-35) in Advanced Variety Trial (M)- Mid-late and Late Trials conducted during *Kharif* 2022 in Maharashtra State

Sl. No	Designation	Yield (Kg/ha)	Days to 50% flowering	Plant height (cm)	Panicle/ sqm.	Spikelets / Panicle	Test weight (g)	Grain type
1.	TKR- 35	5855	110	106	241	207	21.06	LS
2.	Karjat-2 (Ch.)	4276	110	93	287	155	22.04	LS

Application of 100 per cent FYM and RDN and transplanting of rice variety Trombay Konkan Mahan (TKR- 35) at a spacing of 20 cm x 15 cm recorded significantly higher growth, yield attributing characters and yield of rice as compare to application of 50 per cent RDN and transplanting of rice variety Karjat 2 at a spacing of 20 cm x 15 cm. The pest and disease reaction of Trombay Konkan Mahan is given in (Table 3).

Table 3: Pest and disease reactions of Trombay Konkan Mahan (TKR- 35) in Initial variety trial late and Advance variety trial (M)- Mid-late and late conducted during *Kharif* 2020-2022 in Maharashtra State

Designation	Stem Borer		Gall midge		Leaf Blast		Bacterial Leaf Blight	
	Score	Reaction	Score	Reaction	Score	Reaction	Score	Reaction
Trombay Konkan Mahan (TKR-35)	1	R	4	MR	3.76	MR	4.6	MS
Karjat-2 (Ch.)	1	R	5	MR	4.70	MS	5.33	MS
TN 1 (Susceptible Check)	8.3	HS	8.3	HS	7.6	S	8.3	HS
EK 70 (Susceptible Check)	7	S	9	HS	8.7	HS	8.3	HS
Ajaya (Resistant Check)	1	R	0.3	HR	3.2	MR	2.1	R
Karjat-1 (Resistant Check)	1	R	0.6	HR	2.5	R	2.3	R

R: Resistant, S: Susceptible, MR: Moderately resistant, HS: Highly susceptible, HR: Highly resistant, MS: Moderately susceptible

Trombay Konkan Mahan (TKR-35) exhibited a 17.3 per cent higher grain yield compared to the check variety Karjat-2 in adaptive on-farm trials conducted during the *kharif* season of 2024. The variety demonstrated superior milling and grain quality attributes, recording a milling recovery of 69.55 per cent, head rice recovery of 61.25 per cent, and a translucent kernel type, along with an acceptable amylose content of 24.8 per cent (Table 4 and Figure 2). TKR-35 showed moderate resistance to stem borer infestation under field conditions. The variety recorded a mean grain yield ranging from 5.0 to 5.5 t ha⁻¹.

Table 4: Summary of grain quality characteristics of Trombay Konkan Mahan (TKR-35)

IET No.	Milling (%)	HRR (%)	KL (mm)	KB (mm)	L/B	Grain type	Grain chalk	VER	WU (ml)	ER (mm)	ASV	AC (%)	GC (mm)
TKR-35	69.55	61.25	6.18	1.98	3.17	LS	A	6.0	280	1.49	3.0	24.8	59
Karjat-2 (Ch.)	65.55	53.21	6.30	1.82	3.46	LS	A	4.5	290	1.46	3.0	25.4	67

HRR: Head Rice Recovery, KL: Kernel length, KB: Kernel Breadth, L/B: Length/breadth ratio, Grain chalk: Grain chalkiness, VER: Volume Expansion ratio, WU: Water uptake, KLAC: Kernel length after cooking, ER: Elongation ratio, ASV : Alkali spreading value, AC: Amylose content, GC: Gel consistency, SS : Short slender, A: Absent



Figure 1: Field view of Trombay Konkan Mahan Rice Variety



Rice



Paddy

Figure 2: Grain characters of Trombay Konkan Mahan Rice Variety

Konkan Sanjay (KJTR 3: IET 29264): A Promising Mid-Late Duration Rice Culture

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Abstract

Konkan Sanjay is a semi-dwarf (110-118 cm), mid-late duration (125-130 days), long slender grain type, non-lodging, higher milling percentage (72.7%), head rice recovery percentage (70.2%) and amylose content (23.34%) released for midland rice growing area of Maharashtra. This was developed by Regional Agricultural Research Station, Karjat, District Raigad, with average grain yield 4.6 to 5.0 t ha⁻¹. Konkan Sanjay is developed from selection of IR 54742-22-19-3R. Konkan Sanjay is high milling recovery (72.7%), head rice recovery (60.2%) and an amylose content of 23.3%, indicating good cooking quality. The culture is moderately resistant to stem borer and leaf blast disease, contributing to its stability across the environments. The average grain yield potential of KJTR-3 ranges from 4.6 to 5.0 t ha⁻¹, making it a promising rice culture for cultivation in Maharashtra.

Keywords: Konkan Sanjay, mid-late duration, high milling percentage, long slender grain and good cooking quality.

Introduction

In Maharashtra rice is the second important crop of the people, which is grown over an area of 15.25 lakh hectares with an annual production of 52.03 lakh tonnes. The average productivity of the state is 3.30 t/ha. The average productivity of the state is low as compared to other rice growing states viz., Punjab (5.80 t/ha) and Tamil Nadu (4.90 t/ha).

Konkan region is the major rice producing area of Maharashtra. Nearly 3.31 lakh ha area of Konkan is under rice crop with production of 14.20 lakh tonnes rough rice. The average productivity of rough rice in Konkan region is 4.28 t/ha. The Konkan region contributes 21.73% in area under rice crop and produces 32.14% rough rice at Maharashtra state level (Maharashtra State Statistics Department, Pune 2023-24 report.)

The rice cultivation in Konkan region is carried out on three types of soils classified as upland, midland and lowland requiring early, mid-late and late varieties respectively. The proportion of area under early,

mid-late and late varieties is about 40, 40 and 20 per cent, respectively. Till date, total 71 rice hybrids and varieties have been released in Maharashtra state but there is no long slender rice variety with mid-late duration and high yield. There is a need to develop high yielding, dwarf and long slender grain type rice variety suitable for transplanted condition of Maharashtra state. Accordingly, efforts were made to develop a rice variety to fulfill the requirement of rice growers of Maharashtra region.

Konkan Sanjay is a semi-dwarf (100-105 cm), non-lodging rice culture of mid-late duration (125-130 days) and long slender grain type. The growth, yield attributing characters and yield of Konkan Sanjay were found to be statistically significant over RP 4-14 rice variety. The plant height (106 cm), number of panicles per sq. m (258), number of spikelets per panicle (189) and test weight (27.72) were also observed to be statistically significant over Karjat-2 rice variety (**Table 1**).

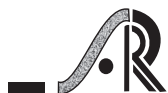


Table 1: Yield and ancillary characters of KJTR 3 in Advance Variety Trial (Maharashtra) Mid-late conducted during *Kharif* 2019- 2021.

Sl. No.	Designation	Yield (Kg/ha)	Days to 50% flowering	Plant height (cm)	Panicles / m ²	Spikelet / panicle	Test weight (g)	Grain Type
1.	KJTR 3	4814	106	112	258	189	27.72	LS
2.	RP 4-14 (Check)	4203	101	108	242	193	24.01	LS

In station trials, Konkan Sanjay recorded 31.31% increase in grain yield over the check variety RP4-14. In the Maharashtra State Coordinated Trials, it exhibited a 14.5% yield advantage over the overall mean of three years compared to RP4-14. In the All India Coordinated Trial (2020), KJTR-3 achieved a grain yield of 4825 kg ha⁻¹, showing superiority of 1.19% over the local check, 20.38% over the zonal check, and 31.48% over

the national check. Application of 150 per cent FYM and RDN and transplanting of rice variety Konkan Sanjay at 20 cm x 15 cm spacing recorded significantly higher growth, yield attributing characters and yield of rice as compared to application of 50 per cent RDN and transplanting of rice variety RP-1-14 at 20 cm x 15 cm spacing. During *Kharif* 2022, it registered a 9.92% increase in grain yield over RP 4-14 (**Table 2**).

Table 2: Grain Yield (Kg/ha) summary performance of rice culture KJTR-3 from *Kharif* 2019 to 2022

Name of Trial	Year	Locations	Grain yield (kg/ha)		
			TKR-35	RP 4-14 (Check)	% increase over checks
1. Station Trial					
IVT	2019	01	5526	3717	48.66
AVT	2020	01	3991	3532	12.99
Weighted mean		01	4759	3625	31.28
2. Maharashtra Trial					
IVT-Mid-late (Maharashtra)	2019	11	4881	4680	4.3
AVT- Mid-late (Maharashtra)	2020	11	4689	3827	22.5
AVT- Mid-late (Maharashtra)	2021	11	4861	4069	19.5
Weighted mean		11	4814	4203	14.5
3. AICRIP Trial					
IVT IM (AICRIP)	2020	03	5859	-	-
NDR 359 (NC)			-	4456	31.48
		Akshaydhan (Western)		4867	20.38
		Local check		5790	1.19
4. Agronomical trial					
	2022	1	4430	4030	9.92
5. Adaptive trial					
Adaptive	2022	26	4965	4296	15.58

Konkan Sanjay is a variety having high milling recovery (72.7%), head rice recovery (60.2%), and an amylose content of 23.3%, indicating good cooking quality (**Table 3**). The culture is moderately resistant to stem borer and leaf blast disease, contributing to its

stability across environments (**Table 4**). The average grain yield potential of KJTR-3 ranges from 4.6 to 5.0 t ha⁻¹, making it a promising rice culture for cultivation in Maharashtra (**Figure 2**).

Table 3: Performance against pests and diseases Maharashtra Screening Nursery-1 (MSN-1) on pooled basis

Sl. No.	Name of entry	Scale Mean (SI)		Pooled Mean (SI)	Reaction
		<i>Kharif 2020</i>	<i>Kharif 2021</i>		
	1) BLB	(2 Loc)	(2 Loc)	(4 Loc)	
1	KJTR 3	6	6	6	MS
2	RP 4-14 (Ch)	7	7	7	S
	2) Leaf Blast	(3 Loc)	(3 Loc)	(6 Loc)	
1	KJTR 3	3.0	4.0	3.5	MR
2	RP 4-14 (Ch)	3.0	4.0	3.5	MR
	3) Stem Borer	(2 Loc)	(2 Loc)	(4 Loc)	
1	KJTR 3	1	3	2	MR
2	RP 4-14 (Ch)	2	2	2	MR

S- Susceptible, MS- Moderately Susceptible, MR- Moderately resistant

Table 4: Summary of grain quality characteristics of KJTR 3 rice culture

Sl. No.	Entry	GT	Mill (%)	HRR (%)	L/B	Grain Chalk	ASV	AC (%)	GC (mm)	Protein (%)	Fe (ppm)	Zn (ppm)
1	KJTR 3	LS	68.50	58.5	3.11	A	3.0	20.6	54	7.44	12.6	11.0
2	RP 4-14 (Ch)	LS	69.89	57.0	3.10	A	3.7	25.4	78	6.73	2.8	16.0

GT-Grain type, Mill. -Milling per cent, HRR- Head Rice Recovery, L/B- Length Breadth ratio, ASV-- Alkali spreading value, AC – Amylose content, GC – Gel consistency.

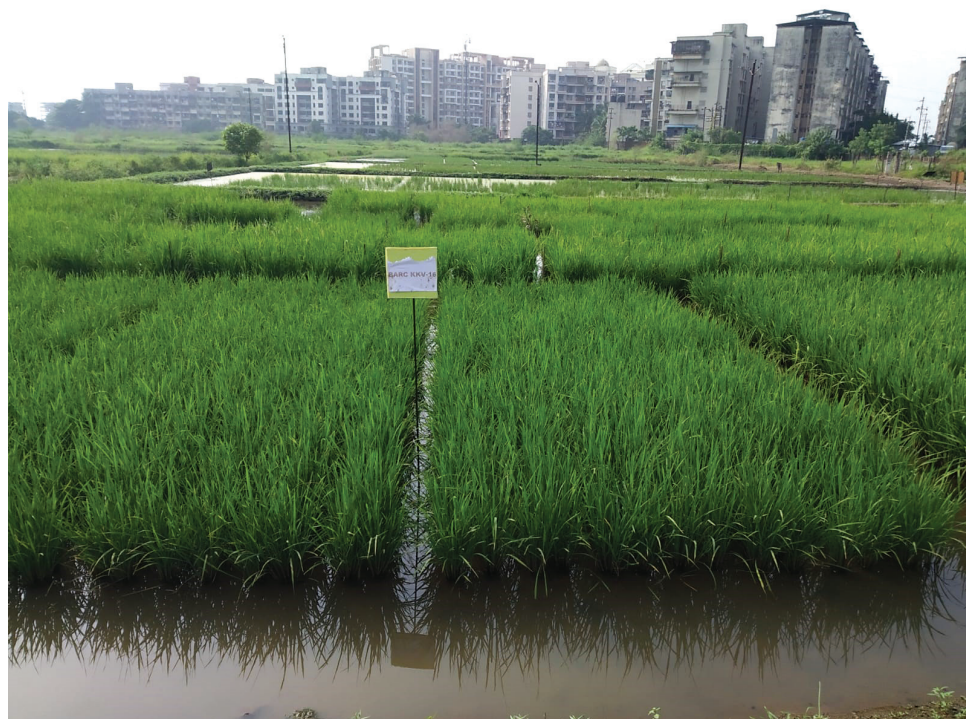


Figure 1: Field view of Konkan Sanjay rice Variety



Paddy



Rice

Figure 2: Grain characters of Konkan Sanjay Rice Variety

**Rice Germplasm Registered during January to June, 2026
At ICAR-National Bureau of Plant Genetic Resources, New Delhi**

S. No.	Crop Name	Botanical Name	National Identity	Donar Identity	INGR No.	Novel Unique Features
1.	Rice	<i>Oryza sativa</i>	IC256562	PB-50/ Baidya raj	26002	• Very strong seed dormancy (0% germination) at all the grain development stages and also 40 days after harvest. • Low moisture imbibing capacity (8.72%) during grain development stages when compared to susceptible genotypes. • High carotenoid content (1.167 mg g⁻¹ FW) and Better reactive oxygen species scavenging system which is evident in lower levels of ROS produced under vivipary treatment
2.	Rice	<i>Oryza sativa</i>	IC256694	PB-182/ Rajamani	26003	• Resistance to pre-harvest sprouting during the entire grain development stage post anthesis and optimum seed dormancy post harvest (0% germination <i>i.e.</i>, Upon germination treatment, seeds remained dormant even 40 days after harvest). • Low moisture imbibing capacity (8.67%) during grain development stages when compared to susceptible genotypes. High carotenoid content (1.287 mg g⁻¹ FW).
3.	Rice	<i>Oryza sativa</i>	IC658989	R158 ISM/ Wazuhophek	26004	• Resistance to Sheath blight (Score 2.2). • Resistance to Bacterial leaf blight (Score 2.2), Resistance to Leaf blast (3.0) and moderate resistance to Neck blast (score 3.3)
4.	Rice	<i>Oryza sativa</i>	IC658990	CRAC4423-49 (Savitri/ Pokkali)	26005	• Osmotic tolerance (higher shoot dry weight: 0.0629 g)
5.	Rice	<i>Oryza sativa</i>	IC658991	CRAC4424-122 (Savitri/ Pokkali)	26006	• Salinity tolerance (a low shoot Na⁺/K⁺ ratio of 0.86 and VSI with SES score of 3)



Tributes to

Prof Ebrahimali Abubacker Siddiq

(15 July 1937 - 29 January 2026)

The Journal of Rice Research joins the Indian agricultural research community in paying respectful tribute to Prof. (Dr.) E. A. Siddiq, one of India's most distinguished rice geneticists, plant breeders and institution builders. His passing marks the loss of a scholar whose work strengthened the scientific foundations of rice improvement and whose values continue to guide generations of researchers.

Born in modest circumstances, Prof. Siddiq's life exemplified discipline, perseverance and faith in the transformative power of knowledge. Through scholarship, integrity and an unwavering commitment to national service, he rose to the highest levels of agricultural science. His journey remains an inspiring reminder that enduring greatness is built not merely on achievement, but on purpose, humility and service.

At a time when India was striving to secure its food and nutritional needs, Prof. Siddiq contributed decisively to rice genetics and breeding. His work helped advance high-yielding and quality rice, the use of genetic resources, heterosis breeding and the development of improved varieties suited to diverse agro-ecologies.

As a leader within the Indian Council of Agricultural Research and the national rice research system, Prof. Siddiq combined vision with accessibility. He strengthened institutional capacity, encouraged collaboration and nurtured young scientists with patience and generosity. Colleagues and students remember him as a mentor who listened carefully, spoke gently and inspired through the quiet strength of example rather than the assertion of authority.

His scientific legacy is visible in improved rice research, in strengthened breeding programmes and, above all, in the many scientists he trained, encouraged and influenced. Prof. Siddiq's life also reminds us that agricultural science must remain connected to society. As rice systems now confront climate change, resource limitations, biodiversity loss and the imperative of sustainability, his example is more relevant than ever.

The Journal of Rice Research records its deep respect and gratitude to Prof. E. A. Siddiq for his outstanding service to rice science, Indian agriculture and the farming community. Though he is no longer with us, his ideals, contributions and spirit will continue to illuminate the path of rice research for generations to come.

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 Pterins* 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. $\times 10^3$) 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.

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