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Society for
Advancement of
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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.
- To cooperate with other organizations having similar aims and objectives.
- To promote any other scientific/professional activities conducive for the advancement of science of rice and rice improvement.

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From the SARR President's desk....

India is the second largest producer and largest exporter of rice Worldwide. Rice production in India increased from 54 million tons in 1980's to 130.84 million tons in 2022-23. The southwest monsoon season began on time in June and I am happy to inform you that the rice plantings are going on all over the country. All India Coordinated Research Project on Rice (AICRP on Rice) Annual Workshop was held during 4-5th May, 2023 in hybrid mode and many of our co-operators participated physically. For the first time in India, ICAR-IIRR has been able to produce genome-edited lines in the background of 'Samba Mahsuri' with a yield superiority of 30-40% over the parental line; and got permission from GOI to evaluate in the AICRPR trials.

I request all the researchers in India to contribute their articles of rice research and development for publication in this Journal.

(Dr. RM Sundaram)
Director, ICAR-IIRR &
President, SARR

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REVIEW ARTICLE **https://doi.org/10.58297/ZJGY4649**

Potassium and Zinc Management in Rice (*Oryza sativa* L.) based on 4R concept - A Review

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Abstract

Plant growth is highly influenced by the nutrient supply from soil and the external application of fertilizers. Plants must receive essential nutrients like N, P, K, S and micronutrients for optimum plant growth and development. In current agricultural practices, especially, in cereal-based cropping systems, the soil nutrient balance like potassium and zinc are disturbed to the negative side due to intensive exploitation of native soil nutrients and low external input application. Employing 4R nutrient stewardship (right time, right dose, right source and right method) in soil nutrient management will ensure higher yield, nutrient uptake, nutrient use efficiency, increase in farm income, and minimal damage to the environment through its demand-specific supplement and management. Equilibrium between different pools of nutrients is the major driving factor for nutrient supply and demand in the soil which can be compensated by the external supply of nutrients through the 4R approach. Adoption of 4R stewardship in rice-based systems will ensure the attainment of maximum yield and nutrient use efficiency provided all other growth factors are in optimal supply and will assist in attaining self-sufficiency in rice production.

Keywords: Rice, Potassium, zinc and 4R concept.

Introduction

Rice-based cropping systems are more input-intensive and deplete substantial quantities of nutrients from the soil, which often exceeds their manual addition through external fertiliser sources leading to the deterioration of soil fertility and the emergence of multi-nutrient deficiencies (Ladha *et al.,* 2003, Vijayakumar *et al.,* 2019a, Vijayakumar *et al.,* 2021a). Moreover, current fertiliser consumption of 24.7 Mt of fertilizer (N + P_2O_5 + K_2O) per year, accounts for approximately 14.0% of total global fertilizer consumption. Research in India revealed that nutrient use efficiency/recovery efficiency of major nutrients like N, P and K are merely in the range of 30-35%, 20-25% and 35-40%, respectively (Subramanian *et al.,* 2020). Fertilizer input alone accounts for about 20-25% of the total production cost. Hence, proper management of nutrients is essential for achieving maximum yield and nutrient use efficiency besides environmental safety. An innovative and science based approach of "4R Nutrient Stewardship" (right fertilizer source, at the right rate, at the right time, with the right placement) that enhances timely nutrient supply, less environmental damage, more production and ensures sustainability (Vijayakumar *et al.,* 2021b).

4R -----	**Right source**	**Right Rate**	**Right Time**	**Right Place**

The research work carried out following the principle of 4R to improve the nutrient use efficiency for achieving higher productivity in rice with respect to potassium and zinc are presented here. The research highlighted here are taken under different soil and climatic conditions. Whereas the 4R strategy for N was documented by many researchers (Singh *et al.,* 2002; Surekha *et al.,* 2016; Vijayakumar *et al.,* 2019b; Vijayakumar *et al.,* 2019c) and hence, 4R practices for nutrients like K and Zn are highly important for rice crop and their management are discussed here.

Potassium (K)

Potassium is the third major essential nutrient element which is required by the plant in large quantities almost equal to nitrogen or sometimes even higher (Vijayakumar *et al.,* 2021a). It has a major role in most of the biological processes in the plant without becoming a part of an organic compound (Cakmak, 2005; Armengaud *et al,* 2009; Liu *et al,* 2011). India is the third largest consumer of NPK fertilizers in the world, with current annual consumption of about 18 million tons (Mt) of N+P_2O_5+K_2O, however, K constitutes only one-seventh of the total. As per soil test values, out of the 371 districts 76 (21%) are low in potassium, 190 (51%) are medium in potassium and 105 (28%) are high in potassium **(Table 1).** The southern states of India like Karnataka (3.02 LMT), Tamil Nadu (2.77 LMT), Andrapradesh (2.41 LMT) and Telangana (1.51 LMT) consumed higher K fertilizers (LMT=Lakhs of metric tonnes) (Indiastat, 2020).

Table 1: K status in Indian soil (post-green revolution era)

Number of Soil Samples	Number of districts studied	Per cent of the districts sampled			Reference
		Low	Medium	High	
1.3 million	184	20.0	53.0	27.0	Ramamoorthy and Bajaj (1969)
4.5 million	310	20.0	42.0	38.0	Ghosh and Hasan (1976)

Compared to N and P, Indian soils are rich in K and thus, the magnitude of response of rice to K application is relatively small and directly varies with the initial available K status. Even though most of the soils are known to supply K adequately through K buffering, response of rice crop to K fertilizer is noticed in certain situations such as intensive cultivation, acidic soils and light textured soils has become common calling for steps to generate information regarding its scientific management practices. In general, the response of rice to K depends on the fertility level of the soil, yield, variety, and season. Therefore, acquiring knowledge and better understanding on K management relies on best agronomic practices and soil management, which is highly important for sustainable production and management.

Depending on soil type, approximately 90 to 98 per cent of total soil K is found in mineral form. The minerals *viz.,* feldspars and micas contain most of the K. Over long periods of time, these minerals weather, or break down, and K is released. As these minerals

Table 2: K balance sheet in different states of India (Ramamurthy *et al.,* 2017)

State	Nutrients addition (000 t)	Removal (R)	Balance	Mining Index
Alluvial Soils				
Punjab	18.7	763.5	-744.8	40.7
Uttar Pradesh	113.6	1777.2	-1663.6	15.6
Haryana	4.6	490.1	-485.5	105.7
Black Soils				
Maharashtra	196.9	2095.6	-1899.1	10.6
Madhya Pradesh	24.1	848.8	-824.7	35.2
Red Soils				
Karnataka	216.1	603.6	-387.5	2.8
Lateritic Soils				
Kerala	87.3	175.6	-88.3	2.0
Desertic Soils				
Rajasthan	**7.0**	**1068.0**	**-1061**	**152.7**

weather, some K moves to the slowly available pool. However, this process is too slow to supply the full K needs of field crops. The removal of K from soil in intensive cereal based cropping systems is equal or more than N. The net negative balance for K in the current agricultural scenario is 69% K. This negative balance is due to more removal of K (1.5 times than other element) and the amount of application lower than that of N and P. This huge negative difference of potassium is partly because crops remove an average of 1.5 times more potassium than nitrogen, and the application of potassium through fertilizers is considerably lower than that of N or P (Sanyal *et al.,* 2009) **(Table 2).**

Many reasons are there for the less attention towards the K viz, the benefits from N and P are more readily apparent from initial stages of crop growth; inadequate use of K fertilizers; lack of crop response to applied K, even on low K testing soils. However, significant responses to applied K is noted even in high K soils. To overcome such anomalies, intensive research on total K, exchangeable and non-exchangeable K, and K-fixing capacity of the soils under different soil-crop-climatic conditions and implementation of 4R to be followed widely. Releasing pattern of K from Mineral-K and their cycle of transformation is given below (Figure 1).

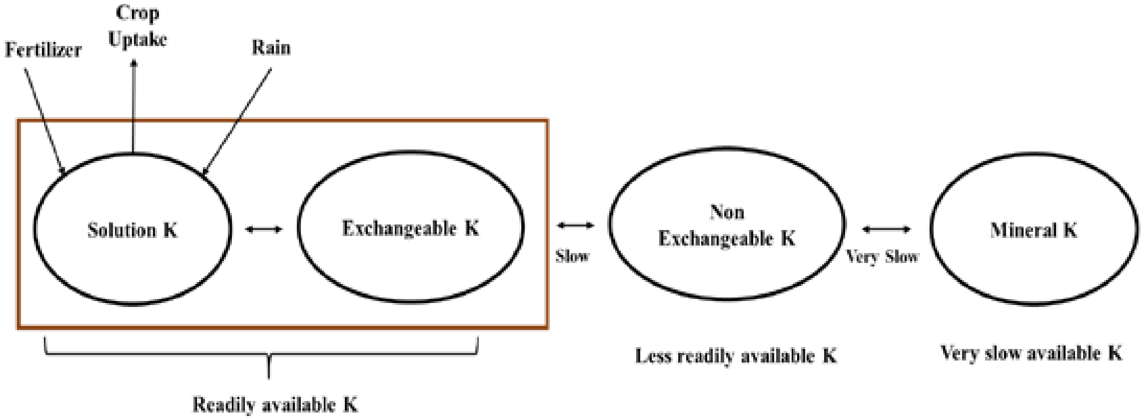

Figure 1: Potassium dynamics in soil

Right Source of K fertiliser

Source of fertiliser comes into the picture as the availability of existing soil K varies with soil factors. Muriate of potash (MOP) is the commonly used K fertiliser in Indian Agriculture. Grain yield was observed with SOP in the areas of S deficiency as it contains 17% sulphur (Surendran, 2005). The highest productivity and profitability were recorded with K_2SO_4 applied as foliar application than potassium nitrate and sulphate of potash. However, soil K application through K_2SO_4 and/or KNO_3 is essential to balance the K removal from soil (Hussain *et al.,* 2020). Moreover, application of graded level of K impacted the extractable K at different locations as 17% increase at Ludhiana, 34, 22, 30 and 14% decrease at Pantnagar, Kanpur, Faizabad and Sabour, respectively (Yadav *et al.,* 2000). Vijayakumar *et al.,* (2019) compared the effect of two potassium source *viz.,* potassium nitrate and muriate of potash on rice growth and yield and found non-significant effect.

Organic source of K

In case of cereal crops, 50-75% of the total biomass is left as a residue after harvesting and India produces around 130 Mt (34% of the total cereal residue) of residues every year (Vijayakumar *et al.,* 2021c). Cereal crops (rice, wheat, maize, millets) produce 352 Mt of residue every year which contributes 70% of the total residues. Recycling of crop residues is particularly important because they usually contain more K than the harvested seed. Crop residues can supply > 200 kg K ha^{-1} annually in rice-wheat system (Yadvinder-Singh *et al.*, 2004). Crop residues of rice and wheat are the major source of organic matter (40% C of the total dry matter) and significant amounts of K as 12-17 kg and 9-11 kg ton^{-1}, respectively. However, K content in Indian rice straw is generally more (up to 25 kg ton^{-1}) than other parts of the world. Rice straw is a rich source of K and its incorporation into the soil increased the available K level of soil. There are many ways to use straw as a K source *viz.,* direct residue incorporation, composting and making ash or bio-char (readily available K). It is also cost-effective to apply ash or biochar blended with organic manures in suitable proportion when a huge amount of waste disposal is a problem (Adeoye *et al*., 2001). Retaining of crop residues markedly increases the K availability in soils and many researchers proposed to use crop residue as a potassium source (Chatterjee and Mondal, 1996; Sarkar, 1997; Mishra *et al*., 2001; Singh *et al*., 2010).

A wide range of K concentrations present in manures, compost, and well-matured composted materials act as a source of nutrients (Hue, 1995). Wood ash, plant residues, distillery wastes and blast furnace dust and cement kiln dusts are some of the other alternate sources of K which can be used for K nutrition in agriculture (Sekhon and Ghosh, 1982). A long-term fertilizer experiment conducted at Akola, Maharashtra found that all the fractions of K improved with application of FYM, Zn and sulphur in combination with NPK (Ravankar *et al.,* 2001). Many researchers have documented that increment of non-Exchangeable-K was observed when K application was carried out with plant resource such as rice straw, farmyard manure, green manure and compost. Application of wheat straw + green manure (GM) + rice straw was found to maintain the maximum level of non-exchangeable K followed by FYM + GM + rice straw (Pannu *et al.,* 2001). Use of FYM and green manure also increased the total K availability in soil but a net negative balance in total K was noticed (Sharma *et al.,* 2013). Continuous use of inorganic fertilizers and organic manures positively improved the potassium fractions in soil over control but resulted in negative balance of potassium based on 36 years of soybean-wheat cropping system. Moreover, the correlation studies revealed that total K was positively correlated with the source of K addition and yield of soybean which was followed by lattice K in the black soil (Sawarkar *et al*., 2013; Meena and Biswas, 2014).

Crop residue recycling (retaining crop residues after harvest) is an important strategy to maintain soil fertility. It is important to incorporate crop residues of potassium exhaustive crops (maize, wheat, rice etc.) into soil to add K to soil and prevent its loss. Retention of straw in the rice filed has improved the exchangeable K and non-exchangeable K by 26 and 2% in paddy soil (Yadvinder-Singh *et al*., 2004) and similarly application of 50% recommended K through rice straw (5 t/ha) increased the exchangeable and Non-Exchangeable K (Pavithra *et al.,* 2017). However, the application of rice straw 5 t/ha in soil could change the soil chemical properties meagerly (Tanh *et al.,* 2016) **(Table 3).** Appropriate time and water management are essential to reduce the negative effects of residue incorporation/retention such as release of phenolic compounds that affect nutrient availability (Chivenge *et al.,* 2020).

Table 3: Effect of rice straw incorporation on soil chemical properties

Treatment	pH	SOC	N	P_2O_5	K_2O
Before Experiment	4.10	0.80	0.08	0.034	0.52
Ash from 5 t ha^{-1} rice straw	4.32	1.09	0.09	0.046	0.60
5 t ha^{-1} rice straw	4.40	1.19	0.11	0.041	0.55

Bio-fertilizers-Potassic solubilizing Bacteria (KSB)

Inclusion of plant growth promoting potassium solubilising rhizobacteria (biological K-fertilizers) enhanced K availability in agricultural soils (Meena *et al.,* 2015). The most important KSB used as K biofertilizers are Bacillus mucilaginosus, Bacillus edaphicus, Bacillus circulans and Bacillus cereus. Generally, microorganisms contribute to the release of K+ from K-bearing minerals by acidolysis mechanism (production of the organic and inorganic acids and production of protons). Release of H+ can directly dissolve the mineral K as a result of slow releases of exchangeable K, readily available exchangeable K (Basak *et al.,* 2017). Among the bacteria, A. tumefaciens OPVS 11, R. pusense OPVS 6 significantly induced the acidolysis mechanisms and solubilise K from muscovite and biotite. Application of crop residue @ 4t ha^{-1} along with 30 kg K_2O + potassium solubilizing bacteria (KSB) gives equal yield to that of 4 t ha^{-1} residue + 60 kg K_2O indicating 50% K_2O saving through residue use (Mehta *et al.,* 2020). These biological agents are widely used in China and South Korea and compensate the shortage of commercial K fertilizers (Sheng and He, 2006). Crops like wheat, sorghum, cotton, rapeseed, tomato and eggplant have been inoculated with KSB biofertilizers and found successful in increasing soil K status, crop growth and yield under pot culture as well as field conditions.

Right Rate of K application

Rate of K application depends on the K requirement of the crop, K supply from the native soil and the efficiency of externally applied fertilizer. In addition, the rate of K recommendation is jointly influenced by placement and timing of application. Potassium application rate and crop K uptake immediately influence the soil available K content (Römheld and Kirkby, 2010). Application of 60 kg K_2O/ha was found optimum for direct seeded basmati rice grown in IGP during *kharif* season. Increasing K rate to 90 did not increase the grain yield significantly, while the lower dose of K (<60 kg/ha) reduced grain yield significantly (Vijayakumar *et al.,* 2019b).

In India, the average response to 60 kg K/ha from 785 trials of *kharif* rice was 6.7 kg grain/kg K and that from 378 trials of *rabi* was 8.48 kg grain/kg K (Kanwar, 1974). Mahapatra and Rajendra Prasad (1970) reported that the data obtained from the farmers' fields during 1967-68 indicated a significant response to the application of 30 to 60 kg of K_2O/ha in the following districts *viz.,* Alluvial soils of Barti (U.P), Purnea and Saharha (Bihar), laterite soils of Cuttack (Orissa), the red soils of Chittoor (A.P) and Shimoga (Karnataka) with tall indica as well as with the high yielding varieties. Swarup and Singh (1989) found that after continuous cropping for twelve years, application of K had no effect on rice yield. Lack of response to applied K was attributed to high amount of available K due to the presence of high amount of natural K bearing minerals, the large contribution of non-exchangeable part of K to the K in the plant. Tandon and Sekon (1988) have reported that response to 30-60 kg K_2O/ha ranged from 210-370 kg grain/ha. In a field experiment on black clayey vertisol with rice at Hyderabad, Surekha *et al.,* (2003) reported significant grain yield increase in rice hybrids as well as high yielding varieties (HYVs) to K application at 40 kg K_2O/ha over no K **(Figure 2).** However, the magnitude of response to K was high in hybrid rice (30 kg grain/ kg K_2O) than that of HYVs (17.6 kg grain/ kg K_2O).

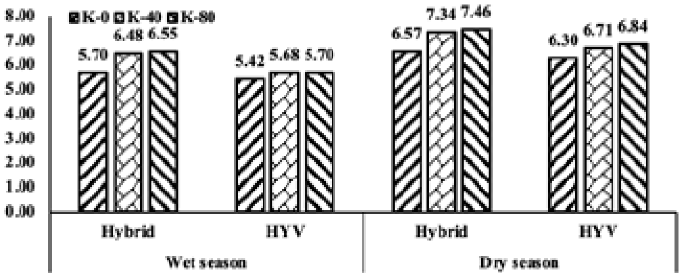

Figure 2: Grain yield (t/ha) of rice as influenced by K application (Surekha *et al*., 2003)

In AICRIP trials of DRR, a significant response to K (50-60 kg K_2O/ha) in rice hybrids was observed at Mandya and Titabar. Further, the split application of K increased grain yield significantly over basal application in the light sandy loam soils of Mandya. From 40 to 50 kg/ha significantly improved grain yield (8%). At Bangalore, Thippeswamy *et al*., (2000) studied the influence of different doses of K fertilizers applied at various growth stages of rice and found that different forms of K *viz.,* water soluble K, hot water-soluble K, available K, 1 N HNO_3 extractable K and 0.1 N HNO_3 extractable K increased with increase in potassium dose up to 80 kg ha^{-1} and decreased with growth stages from tillering to harvest.

Influence of other supplements such as secondary and micronutrients on K use efficiency were evaluated in 60 farmers' fields of Fatehgarh Sahib, Meerut, Baghalpur, Banda and Borabanki with Farmers' fertiliser practice (FFP), FFP with addition of K (+K), FFP with addition of K, S, and Zn (+KM), and FFP with addition of S and Zn (+M) (Singh *et al.,* 2013). Result from the study showed that the application of K along with S and Zn as supplements increase crop yields and productivity in rice-wheat cropping systems. Rice yield in FFP plots ranged from 2.7 t/ha at Banda to 5.9 t/ha at Fatehgarh Sahib. Application of K increased rice grain yields ($p \leq 0.001$) at all locations **(Table 4).** The rice yield increases from applied K in the presence of S and Zn (+M) ranged from 0.4 to 0.7 t/ha across all locations. Highest yield of rice was obtained when K was applied with S + Zn. The increase in yield from added K is However, consistent with reports that application of K has become essential for sustaining high yields in the IGP. K application increased rice yields by 0.6 t/ha in Fatehgarh Sahib and Barabanki, 0.9 t/ha in Meerut, 1 t/ha in Banda, and 1.2 t/ha in Bhagalpur. Application of K, S and Zn with FFP increased rice grain yields by 1.1 t/ha at Fatehgarh Sahib, 1.2 t/ha at Meerut, 1.4 t/ha at Banda, 0.9 t/ha at Barabanki, and 1.4 t/ha at Bhagalpur vis-à-vis FFP alone (Singh *et al.,* 2013).

Table 4: Effect of potassium and sulphur plus Zn (M) additions in rice yield (t/ha) at five locations of northern India

	Fatehgarh Sahib		Meerut		Banda		Barabanki		Bhagalpur	
	No M	+M	No M	+M	No M	+M	No M	+M	No M	+M
No K	5.9	6.6	4.9	5.5	2.7	3.3	5.0	5.4	3.5	4.3
K	6.5	7.0	5.7	6.1	3.7	4.1	5.6	5.9	4.6	4.9
Difference*	0.6	0.4	0.8	0.6	1.0	0.8	0.6	0.5	1.1	0.6

Banerjee *et al*., (2018) conducted the experiment in a randomized complete block design with five different K doses (0, 30, 60, 90, and 120 kg K_2O ha^{-1}) and four replications in hybrid rice. The study revealed that the stem and grain dry matter production at 60 days after transplanting (DAT) and harvest were significantly ($p \leq 0.05$) higher at 90 kg K_2O ha^{-1} application. The grain K concentration improved 116% more than the Zero-K ($p \leq 0.05$) with K fertilization of 90 kg K_2O ha^{-1} **(Table 4).** Potassium fertilization had a significant ($p \leq 0.05$) influence on potassium harvest index (KHI) of the tested hybrid, and it was maximum with 120 kg K_2O ha^{-1}, accounting for 130% higher KHI over the control. The application rates of 30, 60, and 90 kg K_2O ha^{-1} resulted in statistically at par KHI values. Potassium mobilization efficiency index (KMEI) in the tested hybrid rice cultivar ranged from 0.71 to 1.54%.

Right Time of K application

Low potassium use efficiency in cereal-based cropping systems is common as the entire recommended dose of K is applied as basal. The sustained supply of K is highly necessary to fulfil the plant demand, especially at the reproductive stage. But the basal application may cause deficiency during the later stage of the crop. Therefore, split application of fertilizer K in rice crop will give higher KUE than its single/basal application by reducing the leaching losses and luxurious consumption of K (Vijayakumar *et al.,* 2022a). A basal dose of K at puddling is normally recommended, but in coarse-textured sandy loam soils, split application of K (half at transplanting and half at the active tillering stage) provides the yield advantage of 250 kg grain/ha (Konar and Garewal, 1989) as compared to a single application at transplanting.

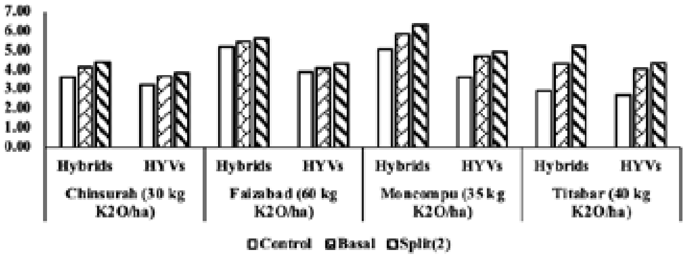

Figure 3: Response of rice to Potassium application (Grain yield t/ha)

Whereas, Thakur *et al*., (1998) failed to obtain any differences in yield between basal and two and three splits at 30 and 45 kg K_2O/ha. In AICRIP trials of DRR (DRR, 1990-96), in addition to significant response to recommended K rate by rice hybrids and HYVs at all the locations **(Figure 3),** split application of K increased grain yield over basal application in the acidic light soils with medium to low available K of Moncompu and Titabar but, had no advantage in heavy and loamy soils with high to me

In a clay loam soil with high available K_2O (454 kg/ha), split application of K failed to bring significant difference in grain yield as compared to application of full dose of potassium at the time of transplanting (Chennabasappa *et al.,* 1998). Ravichandran *et al*., (2011) reported that on clay soils (Vertisol) of Cauvery delta region with high K+ and NH4+ fixation potential, rice yields and N recovery efficiency can be increased by applying K fertilizers one week before N top-dressing. Application of K before N presumably suppressed fixation of NH4+ from applied fertilizer because selective exchange sites in the 2:1-layer clay minerals were occupied by K+. Application of K @ 75 kg ha^{-1} in two splits (basal and panicle emergence) in rice under rice-maize system of IGP had significantly higher grain yield, AEK and REK compared to basal application alone. Residue retention on surface may have further added advantage over no-residue situation (Singh *et al.,* 2020) **(Table 5).** Two split application of 60 kg K_2O/ha (half at basal + half at panicle initiation) increased the growth, yield attributes and yield of direct seeded basmati rice in *kharif* season during both the years of study (Vijayakumar *et al.,* 2019a).

Table 5: Effect of split K application and residue retention on yield and KUE under the rice-maize system (Singh *et al.,* 2020)

Treatment	Yield		AEK (kg grain kg^{-1} K)		REK (%)	
	Rice	Maize	Rice	Maize	Rice	Maize
No K	7.91	7.80	-	-	-	-
75 kg K as basal	8.38	8.40	7.58	9.68	52.4	50.2
75 kg K 2 splits (basal + PI)	8.69	8.90	12.58	17.74	60.8	58.4
75 kg K basal and residue retention	8.86	9.37	15.32	25.32	45.0	41.1
75 kg K 2 splits and residue retention	9.10	9.54	19.19	28.06	53.3	52.8

Right Method of K application

The source-sink dynamics of plant nutrients in the soil eventually determine the nutrient status of soils at any given point of time. The lateral root architecture in rice crop plays pivotal role in nutrient acquisition especially major nutrients *i.e.,* nitrogen (N), phosphorus (P) and potassium (K). The increment in root surface area can increase the uptake of K from the K-enriched zone. In rice, K is known to influence the number of productive tillers, filled grains per panicle, grain weight, tolerance to both high and low temperature, wind stress, physiological disorders and pests and diseases. Usually, all the potassium will be applied to the soil before transplanting as a basal dose. In case of split application, along with nitrogen, it is applied to the soil after draining the water so that the fertiliser will be placed in the mud and field will be irrigated after 24 hours. Samui and Bandopadhyay (1992) reported that application of K @ 90 kg K_2O/ha in split doses either to soil or foliage was found to increase the grain yield of pre-*kharif* direct seeded upland rice over no application of K in clay loam soils of West Bengal with best treatment being soil application of 45 kg K_2O/ha + foliar application of 22.5 kg K_2O/ha at tillering and another 22.5 kg K_2O/ha at panicle initiation. Sarma *et al*., (1995) found that seed hardening with 4% KCl and application of 60 kg K_2O/ha significantly increased plant moisture content and nitrate reductase (NR) - activity and decreased the proline content of the leaf in the direct seeded summer rice crop in sandy loam soils of Assam. Foliar application of 10 kg KCl m^{-3} to rice at panicle initiation, boot leaf and 50% flowering stages significantly increased seed yield and improved quality (seed germination and 100-seed weight) both in the monsoon and winter seasons (Jayaraj and Chandrasekharan, 1997). Splitting a total of 95 kg ha^{-1} of KCl to rice (1/3 at sowing in soil, 1/3 as a foliar spray at flag leaf stage and a 1/3 as foliar spray at grain development) gave significantly higher yields than a soil application all at time (Narang *et al.,* 1997). Similarly, Badar *et al*., (2006) reported that application of KSB with K- and P-bearing minerals on sorghum enhanced dry matter yield by 48%, 65%, and 58% and K uptake by 41%, 93% and 79% in clay, sandy and calcareous soils, respectively. Two foliar sprays of 2% KNO_3 (1st spray active tillering + 2nd spray @ panicle initiation) are recommended as substitute to top dressing of 30 kg K_2O/ha. However, the soil K balance is more negative in case of foliar spray compared to soil application (Vijayakumar *et al.,* 2019c).

Fertigation - Application of fertilisers through irrigation water is getting popular with respect to the water soluble fertilisers like potassic fertilisers. Selecting right source of K (soluble in water, compatible with other fertilisers and devoid of precipitation) is necessary for the efficient application of K (Mohammad 2004). The most common K sources are KCl, KNO_3, and K_2SO_4 and their solubility at 20°C is 34% for KCl, 31% for KNO_3 and 11% for K_2SO_4. The compatibility of potassic fertilisers to the other basic fertilisers is given below **(Table 6)**.

ZINC-(Zn)

Next to major nutrients, zinc (Zn) is the most important micro nutrient element required for rice crop growth and metabolism. After N, Zn was found most wide spread nutrient deficit in India and rest of the world also (Choudhary *et al.,* 2022). Availability of Zn is less under flooded conditions due to formation of sparingly soluble compounds with sulphide and carbonates (Vijayakumar *et al.,* 2022b). In addition, growing of modern high yielding varieties remove large quantities of native soil Zn at the end of every

Table 6: Compatibility of potassic fertilisers with other fertilisers for Fertigation

Nutrient source	NH_4-NO_3	CO $(NH_2)_2$	$(NH_4)_2$ HPO_4	$(NH_4)_2$ HPO_4	$CaNO_3$
KCl	C	C	C	C	I
K_2SO_4	C	C	C	C	I
KNO_3	C	C	C	C	I
KH_2PO_4	C	C	C	C	I
$K_2S_2O_3$	C	C	C	C	I

C= Compatible **I= Incompatible**

harvest, lowering the native soil Zn concentration and contributing to lower grain Zn concentration (De Steur *et al.,* 2014). Further, the availability of Zn for crop uptake from the soil is affected by the concentrations of macro and micro nutrients, the nature and physico-chemical, biological properties of the soil (Fageria *et al.,* 2012; Hafeez *et al.,* 2013). Increasing cropping intensity in a piece of land and changes in the fertilizer input management practices had lowered the Zn availability status in rice grown soils of India which is being practiced on a large-scale (Prasad, 2005).

The Zn content in different agricultural soils is mainly depends on the nature of inherited parent material, ore depositions and agricultural activities such as nutrient supplements through fertilizers, FYM and waste products (Alloway, 2004). Generally, Zn is present in the soil in several chemical forms namely water soluble, exchangeable, organic pool and structural component. Intensity of different forms of Zn, governs by the soil chemical properties *i.e.,* pH, redox potential and organic matter **(Figure 2)**, which plays a critical role in Zn solubility in soils (Alloway, 2009).

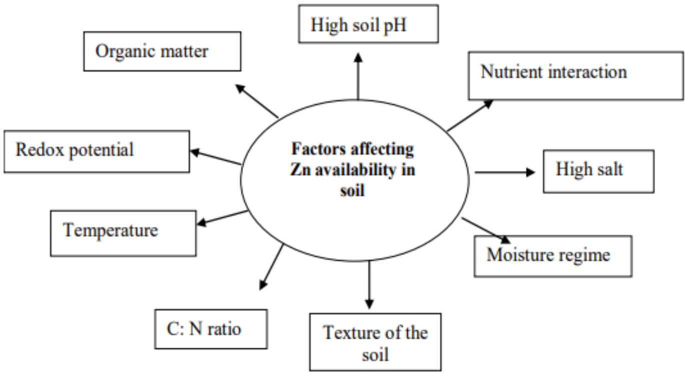

Figure 2: Factors influencing Zn dynamics in soil

Moreover, spread of Zn deficiency is common in alkaline soils due to their high pH and calcareous soil too by formation of $ZnCO_3$. The Zn sufficient soil maintain the water-soluble Zn level in the soil solution to the tune of 4×10-10 to 4×10-6 M. Soil pH is having major control on Zn solubility in soil as depicted in the equation log (Zn2+) =5.8-2 pH by using thermodynamic parameters of reaction. This equation clearly shows that divalent cation (Zn2+) activity is decreased 100-fold for every one unit change in pH. A lot of strategies are made to regulate the water-soluble Zn level in the soil solution to ensure uninterrupted supply of Zn to support the plant growth and development (Senguttuvel *et al.,* 2023).

Strategies to address the Zn deficiency

Right Source of Zinc

As per FAI (2010), several Zn fertilisers are approved by the FCO and available in the market for agricultural use to manage Zn deficiency in soil. Currently, Zn deficiency is cured by the application of $ZnSO_4$ as source of Zn to all crops and the application rate varies from 10 to 25 kg/ha/season based on the crop and soil levels. Zinc Sulphate ($ZnSO_4.7H_2O$) containing about 21% zinc is the most used source of Zn in our country. Availability of good quality zinc sulphate is the main constraint in the current scenario. Therefore, a lot of chemical compounds with enriched Zn content are being developed and available in the market. Next to $ZnSO_4$, chelated Zn (12%) secured second place in the list of widely used Zn fertilisers **(Table 7)**. Apart from these, new fertilisers like zinc coated urea, phosphate and nano sized Zn are used in the rice cropping systems for alleviating Zn deficiency. In most of the experiments, $ZnSO_4$ was found most efficient in correcting Zn deficiency in different crops. The water insoluble ZnO and Zn frits were distinctly inferior to water soluble $ZnSO_4$ on coarse textured sodic soils whereas they tended to approach the efficiency of soluble $ZnSO_4$ on fine textured soils. This was due to high fixation of Zn from soluble sources and low solubility of fixed fraction in the soil. The recommendation for Zn, which is generally marketed as Zn sulfate heptahydrate ($ZnSO_4.7H_2O$), varies from 10 to 25 kg/ha/season, depending upon the crop, environmental, and soil conditions. Moreover, availability and quality of zinc sulphate in the market are not meeting the requirement. Even use of novel nutrient carriers like nanoparticles, composites and Zn infused material will play a major role alleviating the Zn deficiency in soil in near future (Gobinath *et al.,* 2021).

Table 7: Frequently used Zn fertilizers in Indian Fertilizer sector

Chemical	Formula	Percentage
Zinc sulphate monohydrate	$ZnSO_4 . H_2O$	36
Zinc Sulphate Heptahydrate	$ZnSO_4 .7H_2O$	22
Zinc Oxysulfate	$ZnSO_4 .XZnO$	25
Zinc Oxide	ZnO	80
Zinc nitrate	$Zn (NO_3)_2 . 3H_2O$	23
Sodium Zn EDTA	NaZn EDTA	13

In recent times, many initiatives were taken by Government of India such as Fertilizer Control Order (FCO) to manufacture Zn-enriched urea (coating of 2.0% Zn onto urea). A study with different sources of Zn-enriched urea was conducted in sandy clay soil of Delhi to understand the mechanism and efficacy on rice crop (Singh *et al.,* 2009). The yield enhancement was found with Zn-enriched urea ranging from 7.7% (0.5% ZEU-ZnO) to 35.9% (2.0% ZEU-ZS) in aromatic rice crop. Rice grain yield significantly increased by 12 to 180% compared to unfertilized plots through balancing Zn application and Zn source (Slaton *et al.,* 2005). Among Zn sources, zinc chelate (Zn-EDTA) + two foliar sprays (0.5% Zn-EDTA) seem to be the most efficient Zn fertilization strategy for increasing Zn concentration in rice kernel parts, uptake, ZnUEs and productivity (Ghasal *et al.,* 2017). Foliar application of zinc oxide (ZnO) solutions can be one of the potential alternatives for zinc fertilization, but it is restricted due to particle size. Size dependent ZnO chemical can be used in field crops as fertilisers. With respect to nano ZnO, RDF + two foliar sprays of nano ZnO @ 1000 ppm and RDF + two foliar sprays of nano ZnO @ 1500 ppm being on par with each other recorded significantly higher grain yield and total zinc uptake compared to other zinc fertilization methods (Jangid, 2019). Similarly, soil amended nano ZnO improved the DTPA-Zn content in calcareous soil of IGP region (Gobinath *et al.,* 2018).

Prior research on zinc in soil and rice production mostly concentrated on the use of $ZnSO_4$ or other ionic zinc compounds as a source of zinc and the effectiveness of their usage in rice-growing soils (Mandal *et al.,* 2000). But in recent years, farmers have tended to use alternate chemicals. Because zinc chelate (Zn-EDTA) is inexpensive, it is employed as a source of zinc in rice (Das and Saha, 1999).

Right Rate of Zn application

Rate of Zn application differs with soil type and prevalence of its deficiency in soil. For normal soils about 25-50 kg $ZnSO_4$/ha for three crop seasons is recommended (Nayyar *et al.,* 1993). Twice this amount is advocated for sodic soils with pH of more than 10. In the co-ordinated experiments conducted by ICAR-IIRR, alkaline soils of Faizabad recorded linear increase in grain yield up to 100 kg/ha but the rate of response was found to decrease with increments in Zn dose. In contrast, Zn response was curvilinear at Raipur (neutral pH). As per the available literature, maximum achievable grain yields (9.2 t/ha) with Zn nutrition were recorded at medium level (50 kg Zn SO_4/ha) and beyond this level it may cause toxicity to the rice. Potential yield from alkali soils (pH- 9.4-9.7) which are considered unproductive could be realised with higher rate of application of $ZnSO_4$ than the normal application rate due to their fixation behaviour (AICRIP report, 2017). In addition, the beneficial effect of zinc application to rice grown on the alkali soils was far more than that of gypsum.

Correcting Zn deficiency through Zn foliar spray also has an impact on the Zn mobilization in the crops. The application of Zn through foliar at the rate of 0.1% to 0.5% through $ZnSO_4$ increased the Zn concentration in unpolished and polished rice. Thus, a rise in the grain Zn concentration in both unpolished and polished rice may be used as a technique to boost the Zn concentration in diets (Cakmak, 2008). In addition, it is necessary to pay attention to the seasonal climatic conditions in each growing zone to improve grain Zn concentration through Zn foliar spray. Nayyar *et al*., (1993) reported that rate of Zn application varies with the crop and the extent of Zn deficiency and sodic soils whose characteristics are highly conductive for Zn fixation, require relatively much higher doses of Zn than normal soils to ensure an adequate supply of zinc to the rice crop. Similar dose of foliar application namely 0.5% by various chemicals like $ZnSO_4$ and Zn-EDTA may behave differently and achieve a different level of impact on the plant growth and its concentration inside the plant. Combined application of $ZnSO_4$ and ZnEDTA at 0.5% at different intervals significantly improved the Zn content in straw as well in grain (Anusuya *et al.,* 2019). But the efficacy was found higher with $ZnSO_4$ spray rather than EDTA formulation. However, the maximum zinc use efficiency (42.2%) was observed with foliar spray of $ZnSO_4$ @ 0.5% over Zn EDTA spray in the rice genotype IR14M117. In case of soil application, Zn alone and in combination with other nutrients would support the Zn transportation in the plants. Combined application of Zn (6 kg/ha) and sulphur (30 kg/ha) achieved the maximum yield (7.63 t/ha) over control plot (7.09 t/ha) and 7% of yield advantage was observed with combined application of Zn with S. The amount of Zn content in grain and straw was recorded highest with the application of 1.0 kg Zn ha^{-1} as Zn-EDTA than that of 10 and 20 kg Zn ha^{-1} as inorganic $ZnSO_4$ application (Naik and Das, 2008). The split application of $ZnSO_4.7H_2O$ performed better in terms of growth, yield and nutrient content than that of single basal application and split application of Zn-EDTA.

Right Time of Zn application

The split application of Zn sources in soils and its impact on rice's nutrient content is poorly understood. Basal application of Zn is normally recommended practice. Any further delayed application is associated with yield loss (Sadana and Takkar, 1983). But foliar application is resorted to as a mid-season corrective measure. Normally, 0.5% $ZnSO_4$ solution is sprayed thrice starting from third week after planting twice or thrice at weekly intervals. However, a delay in the application of Zn in the soil even by a week causes a yield loss in rice. To ensure efficient utilization of Zn applied to soil and to avoid yield losses, it is desirable to add the recommended dose of zinc within one week of transplanting. Supply of Zn through foliar mode at boot leaf and grain filling stage could be the best and effective practice to enhance and enrich the plant with Zn (Anusuya *et al.,* 2019). Applying Zn at these stages, significantly increase growth, physiology, zinc use efficiency, grain zinc content and yield attributes in rice. Moreover, combination of soil plus foliar application is also under investigation to achieve the maximum Zn enrichment in grains. Combined application of 1.25 kg Zn ha^{-1} through Zn-EDTA and 0.5% foliar spray at maximum tillering (MT) and panicle initiation (PI) stages of rice crop registered the maximum Zn content in different parts of rice (Ghasal *et al.,* 2017). Similarly, higher level of Zn (2.5 kg of $ZnSO_4$) is equivalent to lower dose of Zn-EDTA at 1.25 kg Zn (Zn-EDTA) due to their efficiency in rice crop.

Right Method of Zn application

Application of Zn in the soils has proven to be superior to foliar application due to its assured supply to the crop at an early growth stage to maturity resulting in healthy plants. Another advantage of applying $ZnSO_4$ to soil is that the amount of this material unused by the rice crop to which it is applied becomes available to the subsequent crop. In view of the relatively low efficiency of soil applied Zn in sodic soil, efforts were made to enhance the same by dipping rice seedling roots in ZnO suspension (0.5-2%) and transplanting in Zn enriched nursery. Sadana and Takkar (1983) reported that Zn application irrespective of methods, caused significant increase in grain yield and Zn content of grain. Soil application of $ZnSO_4$ before transplanting produced maximum grain yield (140%) over control. Top dressing $ZnSO_4$, 7 or 15 days after transplanting produced similar grain yield. Foliar spray of 1% or 2% $ZnSO_4$ solution increased yield significantly over control, but was inferior to all other methods of Zn application. Dipping rice seeding roots in a 4% ZnO suspension and supplemented with 1% foliar sprays of $ZnSO_4$ solution gave yields similar to $ZnSO_4$ application. Application of Zn fertilizers or Zn-enriched [nitrogen (N)- phosphorus (P)- potassium (K)] fertilizers (ferti-fortification) offer a rapid solution for increasing Zn concentration in grain and straw. Pooniya *et al*., (2013), observed that co-application of zinc enriched urea, ZEU (2%) along with green manure increased the physiological efficiency and partial factor productivity of basmati rice; while application of 2.0% ZEU as $ZnSO_4.H_2O$ recorded the highest total Zn uptake 3081.6 g ha^{-1}. Ferti-fortification with green manuring to rice through various zinc enriched urea with green manure and foliar spray of 0.2% ($ZnSO_4.H_2O$) could act as an alternate method to enhance the Zn concentration in grain and straw.

Integrated use

Application of organic manures like FYM, GM and amendments like gypsum is known to improve Zn use efficiency. On moderately sodic soils (pH 9.7) the increase in rice yield from Zn application was far greater than Zn applied with gypsum (Takkar and Singh, 1978; Takkar and Nayyar, 1982), probably because of low sodium or adequate calcium supply. But on highly deteriorated sodic soils (pH 10.4) deficient in both calcium and zinc, the best rice yields could be achieved with the application of both gypsum and Zn. Sahahane *et al.,* (2019) reported that combined application of Zn with 75% RDF + microbial inoculation (Anabaena-Providencia consortia (or) Anabaena-Pseudomonas bio-filmed bio-fertilizer) performed statistically better over Zn application with RDF and can be used in nutrient management of rice. Regular incorporation of Sesbania green manure over the years before transplanting of rice helps in improving diethylene triamine penta acetate (DTPA)-extractable micronutrient cations of the soil (Nayyar and Chhibba, 2000).

Growing of Zn rich rice seeds plays a major role in enrichment of Zn in the rice grains than the poor Zn seeds. The range of zinc concentrations in polished and brown rice is 6.3-24.4 g g^{-1} and 13.6-28.4 g g^{-1}, respectively. As per the report submitted by ICAR-IIRR, several rice varieties and landraces had recorded zinc content and top 5 entries having high zinc are Poornima (31.3), Ranbir Basmati (30.9), ADT 43 (30.9), Chittimutyalu (30.5) and Type 3 (30.3) and top 5 entries with less loss after polishing are white Ponni, Bas 386, Kanishk, Giri and Karjat 4 which can be used in breeding programme for development of high Zn varieties for Zn enrichment. SRI coupled with RDF + Zn in hybrid rice assumes greater significance in enhancing the rice productivity with better Zn-biofortified grains besides higher nutrient use efficiencies to combat widespread malnutrition and acute Zn deficiencies in humans and livestock in the northwestern Himalayas **(Table 8)**.

Table 8: Response of rice to different methods of Zn application

Crop	Mode of application and level	Benefits	Reference
Rice	Soil application @ 5 mg/kg	10% and 86% improvement over no Zn	Muthukumararaja and Sriramachandran (2012)
Rice	Soil Application Zn @ 6 kg	5% improvement in yield over control	Singh *et al*., (2012)
Rice	Soil, Soil + Foliar	-	Phupong *et al*., (2010) Girijaveni *et al.,* (2020)

Conclusion

Synchronizing K and Zn demand in the plant by supplying adequate quantity of nutrients during high nutrient demand stage is need of the hour to fetch optimum crop yield and productivity and also ensure the effective utilization of added K and Zn nutrients. Addition of high analysis fertilisers alone will not improve the nutrient use efficiency, while inclusion of multiple nutrient mixtures and bio-inoculants reduces the negative balance of K and Zn via timely and correct addition of nutrients though right source that may lead to higher nutrient use efficiency and good returns on yield and productivity. Current discussions on 4R approach for K and Zn have established the importance of these unnoticed elements and their significance for nutrient use efficiency in rice based cropping system. Further, in depth studies are required to support this management aspect with their nutrient budget, balance sheet, mining ability, fixation behaviour in different soils to improve the productivity and yield in rice based cropping system. Additional research is required to determine the ideal foliar Zn rates for the commercial rice cultivars under a wide variety of growing environments.

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RESEARCH ARTICLE https://doi.org/10.58297/ISRV4770

Molecular Screening and Agronomic Trait Characterization of NLR 34449 X ISM Derived Population for their resistance against Bacterial Blight Disease

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Abstract

Bacterial Blight (BB) disease caused by *Xanthomonas oryzae* pv. *oryzae (Xoo)* is a major limiting factor amongst the diseases of rice in India. NLR34449 is a very popular high yielding variety. It is a popular variety not only in Andhra Pradesh but also in the neighbouring states of South India, but highly susceptible to the bacterial blight disease. A total of 802 BC_1F_2 plants derived from the cross NLR 34449 and ISM were phenotypically screened for bacterial blight resistance, 687 were found to be resistant to BB. Genotyping of these plants revealed ten homozygous positive plants for all the three target BB genes *viz., Xa21, xa13* and *xa5.* They were further assessed for key agro-morphological traits. *viz*., Days to 50% flowering, plant height, number of panicles per plant, thousand grain weight and grain yield per plant. Almost all the traits exhibited variation for key agronomic traits and among them, five plants were found to be performing well not only for bacterial blight resistance but also found to be superior in terms of key agronomic traits like thousand grain weight and single plant yield and flowered earlier than the parents as well. These identified plants will be advanced for further evaluation.

Keywords: Bacterial blight (BB), *xa21, xa13, xa5,* NLR34449, ISM

Introduction

Rice (*Oryza sativa* L.) is the primary staple food in many countries and is one of the most important cereal crops grown all over the world. In India, 122.27 million tonnes of rice is being produced in 45.07 million hectares with a productivity of 2713 kg ha^{-1} (https://desagri.gov.in). In Andhra Pradesh, 7.89 million tonnes of rice is being produced in 2.32 million hectares, with a productivity of 3395 kg ha^{-1} (https://desagri.gov.in). Current global yield increase rates (1.0% per year) of rice are insufficient to meet food demand for the estimated nine billion people in 2050 (Khush, 2001).

Major production constraints of rice in the country are biotic stresses like BB, Blast and abiotic stresses like drought, salinity, and low soil phosphorous coupled with new emerging challenges from climate change, increasing cost of cultivation, and socioeconomic changes. The only way to sustain rice production to meet the increasing population demand is host plant resistance with increased productivity under disease endemic areas. Among the biotic stresses, Bacterial blight caused by *Xanthomonas oryzae* pv. *oryzae* is most destructive and drastically reduces the crop yield by up to 50%

(Khush *et al.,* 1989) or even up to 80% in some areas of Asia (Singh *et al.,* 2001).

Improved cultivars carrying resistance genes have been the most effective and economical strategy to control BB disease (Suh *et al.,* 2013). Moreover, deployment of rice cultivars that have multiple BB resistance genes is expected to enhance the durable resistance against BB. To date, 42 BB resistance genes have been identified from cultivated, mutant population and wild rice species (*O. longistaminata, O. rufipogon, O. officinalis* and *O. Minuta)* designated from *Xa1* to *Xa42* conferring resistance against various strains of *Xoo* (Brar and Khush, 1997; Lee *et al.,* 2003).

Keeping in view, the importance for development of resistant cultivars, the present investigation was carried out to identify BB resistant cultivars along with better yield and yield attributes in BC_1F_2 generation derived by crossing a popular dwarf, high grain number Nellore Mahsuri (NLR34449) with Improved Samba Mahsuri (ISM) BB resistant (harbouring *Xa21, xa13* and *xa5*), high yielding, fine-grain type with good cooking qualities.

Materials and Methods

Plant material

The plant material for the present investigation includes two high yielding fine grain type varieties *viz*., BB resistant Improved Samba Mashuri (ISM) and BB susceptible Nellore Mahsuri (NLR34449) which were used as parents to develop BC_1F_2 population. Varietal characteristics of parents were presented in **Table 1.** These were evaluated for phenotypic screening against bacterial blight (BB) and for key agronomic traits. The donor parent ISM, recipient parent NLR 34449, resistant and susceptible checks were compared along with BC_1F_2 plants.

Table1: Salient Features of parents used in developing BC_1F_2 population

S. No.	Characteristics	Recurrent parent (Nellore Mahsuri)	Donor parent (Improved Samba Mahsuri)
1.	Average days to heading	95-100	95-110
2.	Plant type	Dwarf	Semi dwarf
3.	Average days to maturity	120-125	135-140
4.	Plant height (cm)	75-80	86-95
5.	Panicle exertion	Exerted	Partial exertion
6.	Grain type	Medium slender	Medium slender

Methodology

During *rabi* 2017, Improved Samba Mashuri (ISM) was crossed with Nellore Mahsuri (NLR34449) **(Figure 1)** to develop F_1 seed. True F_1 plants were identified with the help of marker assisted selection using gene specific markers *viz.,* pTA248 (for *Xa21*), xa13 prom (for *xa13*) and xa5FM (*xa5*). These identified true F_1s were then backcrossed with NLR34449, the recurrent parent. Positive BC_1F_1s heterozygous for all the three targeted genes were selfed to produce $BC_1F_{2,}$ which were further confirmed genotypically and homozygous positive plants were identified and evaluated for key agronomic traits.

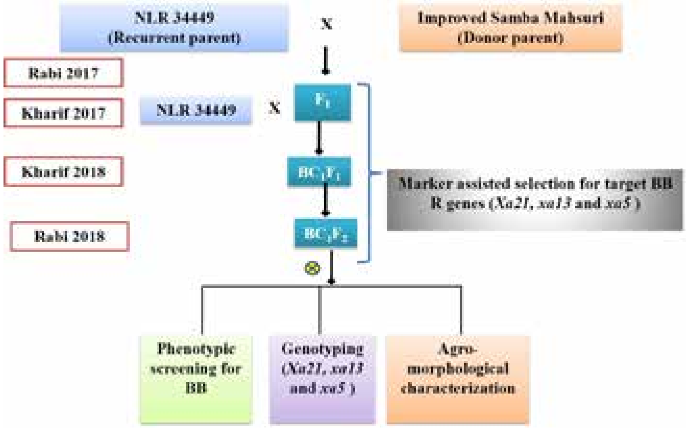

Figure 1: Schematic representation of work strategy deployed in the present study

DNA Extraction and PCR Amplification

DNA was extracted using two weeks old fresh leaf samples collected from nursery with modified CTAB extraction method (Doyle and Doyle, 1987) with few modifications. PCR was carried out for three markers with 10 µl reaction volumes, with 5 picomoles of each forward and reverse primers, 1X PCR master mix (Thermo scientific) and 30-50 ng of each genomic DNA sample. PCR conditions for pTA248, *xa13prom* and *xa5FM* were - initial denaturation at 94 °C for 5 minutes, followed by 35 cycles of denaturation 94 °C for 30 seconds, 55 °C for 30 seconds, annealing and extension 72 °C for 1 minute and final extension was at 72 °C for 7 minutes. Marker polymorphism was visualized on 1.5% agarose gel electrophoresis.

Phenotypic screening against BB

Homozygous positive BC_1F_2 plants selected based on the marker assisted selection were planted in the experimental farm of ICAR-IIRR along with the parents (NLR34449 and ISM) at a spacing of 15 x 20 cm following the agronomic practices. At maximum tillering stage, *Xoo* culture (DXO-20) was adjusted at a concentration of 10^8 cfu/ml (Preece, 1982) and inoculated tips of 3-4 leaves by clipping method following Kauffman *et al.,* (1973). After 15 days of inoculation scores were recorded based on the standard evaluation scale (IRRI, SES 2013).

Agronomic trait evaluation

Selected BC_1F_2 plants which were homozygous positive for all the target genes and with excellent resistance to BB were further evaluated for key agronomic traits along with recurrent (NLR34449) and donor (ISM) parents. Data was recorded for the key traits *viz*., Days to 50% flowering, plant height, number of panicles per plant, grain yield per plant and 1000 grain weight and superior BC_1F_2s identified were further advanced.

Results and Discussion

BB is a serious disease of rice in India, particularly affecting the crop in the irrigated agro-ecosystem caused by the plant pathogenic bacteria *Xanthomonas oryzae* pv. *oryzae* and is one of the devastating diseases of rice causing yield losses ranging from 74-81% (Sundaram *et al.,* 2009, Srinivasan and Gnanamanickam, 2005). When plants are infected at booting stage it results in poor quality grains with a high proportion of broken kernels. Breeding and development of resistant varieties carrying major resistance alleles have been the most effective and economical strategy to control BB with a minimal adverse effect on the environment (Huang *et al.,* 1997; Jena and Mackill, 2008; Singh *et al.,* 2001).

Host plant resistance has been considered as the most economical and eco-friendly strategy for management of biotic stresses (Hulbert *et al.,* 2001). For BB there is no effective chemical control method practiced, hence, the only durable strategy is to grow resistant varieties (Huang *et al.,* 1997). In the present investigation, a total of 802 BC_1F_2 plants derived from NLR34449 X ISM carrying the resistance dominant allele *Xa21* and recessive *xa13, xa5* genes were screened phenotypically and among which 687 were resistant, which were further screened genotypically with the help of targeted gene linked markers. Foreground selection of these plants resulted in the identification of 42, 39 and 10 positives for *Xa21* and *xa13* combination, *Xa21* and *xa5* combination and *Xa21*, *xa13* and *xa5* combination, respectively.

Previous reports of Shanti *et al.,* (2001) identified the triple homozygotes with the help of RG 136 and pTA 248, tightly linked to *xal3* and *Xa21,* respectively and SSR marker RM 122 linked to *xa5* markers. Same set of markers were used for *Xa21* and *xa13* genes whereas RG136 marker was used for *xa5* in reports of Sundaram *et al.,* (2008 & 2009). However, in our present study, we have used pTA248, *xa13prom* and *xa5FM* for foreground selection of *Xa21, xa13* and *xa5,* genes respectively. Similar observations were made by Rekha *et al.,* (2018).

All the three target genes that have been gone through in the present study have been cloned and characterized.

The mode of action of the three resistance genes used in this work are apparently different and might have contributed to make the resistance in the three-gene pyramid lines quite durable.

Phenotypic screening against BB not only revealed three gene positives (plants possessing *Xa21, xa13* and *xa5*) exhibiting excellent resistance to BB, but also observed that two gene positives possessing *Xa21* and *xa13* or *Xa21* and *xa5* were found to be resistant to BB. In the reports of Sundaram *et al.,* (2009), it was observed that triguna lines possessing *xa13* and *xa5* gene combination exhibited good resistance against BB disease along with *Xa21* and *xa13* combination. However, lines possessing *Xa21* and *xa5* combination exhibited longer lesion lengths but in our reports this combination too exhibited good levels of resistance.

Agro-morphological characterization of ten homozygous positive BC_1F_2 plants possessing all the three targeted genes in comparison with parents for the key agronomic traits resulted in identification of five superior plants *viz.,* NLR-87-5-1, NLR-87-16-11, NLR-87-6-15, NLR-87-9-24 and NLR-87-6-7 which were observed to be better than both the parents *viz.,* NLR34449 and ISM in terms of thousand grain weight (14.5-17.0 g), single plant yield (25.5-29.75 g) with fine grain type and complete panicle exertion (**Table 2, Figure 2**). However, no yield penalty was observed in the remaining lines and did not show any variation as compared to NLR34449 parent in terms of flowering duration, panicle exertion and yield parameters. Such observations were earlier reported by Pradhan *et al.,* (2015). These lines were forwarded to BC_1F_3 generation for further breeding programme.

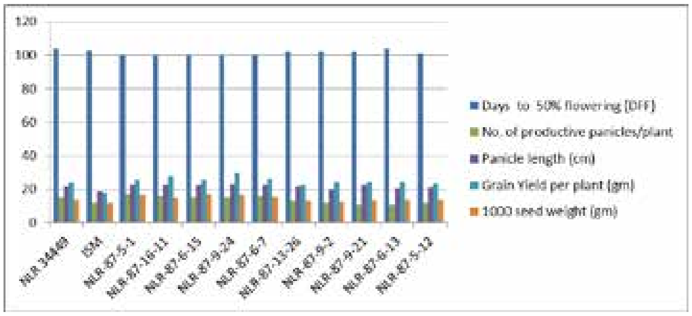

Figure 2: Graphical representation of agro-morphological characterization for yield and its component traits in BC_1F_1 population of the cross between NLR 34449 and ISM

Conclusion

The improved versions of Nellore mahsuri possessing BB and blast resistance, developed in the present study may offer a distinct advantage to farmers of NLR34449, whose fields are affected by both bacterial blight and blast. Further, Cultivation of

Table 2: Agro-morphological characterization for yield and its component traits in BC_1F_2 population of the cross between NLR34449 and ISM

S. No.	Plant identity	Days to 50% flowering (DFF)	Plant height (cm)	No. of productive panicles/plant	Panicle length (cm)	Grain Yield per plant (gm)	1000 seed weight (gm)	Grain type	Panicle exerstion
1	NLR 34449	104	78	15	22	24	14	MS	FE
2	ISM	103	82	12	19	18	12	MS	PE
3	NLR-87-5-1	100	81	17	22.6	25.5	16.75	MS	FE
4	NLR-87-16-11	100	80	16	22.5	27.50	14.5	MS	FE
5	NLR-87-6-15	100	79	15	22.5	25.75	17.0	MS	FE
6	NLR-87-9-24	100	80	15	23.0	29.75	16.75	MS	FE
7	NLR-87-6-7	100	80	16	22.5	26.5	15.5	MS	FE
8	NLR-87-13-26	102	81	13	22	22.85	12.95	MS	FE
9	NLR-87-9-2	102	82	12	19.75	24.5	12.5	MS	FE
10	NLR-87-9-21	102	83	11	22.5	24.5	13.50	MS	FE
11	NLR-87-6-13	104	80	11	20.75	24.15	14.0	MS	FE
12	NLR-87-5-12	101	80	12	21	23.5	13.75	MS	FE

MS: Medium slender; FE: Fully Exerted such improved backcross derived lines of NLR34449 possessing resistance against bacterial blight and blast could help to improve rice production in the disease endemic areas in many states of India, wherein fine-grain type varieties like NLR34449, Samba Mahsuri, HMT Sona etc. are preferred.

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RESEARCH ARTICLE https://doi.org/10.58297/KRLR3434

Parental Polymorphism between Samba Mahsuri and False Smut Tolerant Landraces using SSR and InDel Markers

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Abstract

In the present study, 868 SSR and 475 InDel markers were selected to study parental polymorphism of two different crosses between recipient parent Samba Mahsuri and false smut donor lines IC379047 and IC334233 at ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad. Out of 1343 markers used for parental polymorphism, 100 markers were polymorphic between parental lines Samba Mahsuri and landrace IC379047 and the total polymorphism percentage recorded was 7.44%. Ninety-nine markers exhibited polymorphism between parental lines Samba Mahsuri and IC334233 and 7.37% of total polymorphism percentage was recorded between the parents. The identified polymorphic markers could be further used for QTL mapping studies in false smut resistance.

Keywords: Rice, false smut, polymorphism, SSRs and InDel markers.

Introduction

Rice (*Oryza sativa* L) is a widely cultivated cereal crop all over the world. It is a nutritionally indispensable food crop with carbohydrates being the major fraction along with protein and vitamins; and 21% of energy for more than half of the world's population. The major rice producing countries are China which ranks first in production of 148.3 million metric tons followed by India and Indonesia with production of 122.27 and 35.3 million metric tons respectively (UASD, 2021). To meet the demand of increasing human population, the higher rice productivity can be achieved by developing varieties having stable yielding ability across the areas along with resistance to various pest and diseases. The germplasm consisting of landraces, modern cultivars, breeding stocks, wild forms and wild relatives of the cultivated crop species could be the valuable genetic source to identify the promising donors. Germplasm refers to sum total of genetic material *i.e.,* possible alleles of the various genes present in crop species and its wild relatives, which can be used for exploiting the genes governing various traits for biotic and abiotic stresses; and ultimately in breeding of the new variety. In previous studies at ICAR-IIRR, Hyderabad, landrace IC379047 (Mancha) and germplasm IC334233 were identified as a tolerant source for the false smut disease through artificial screening. The identified lines were crossed to the popular high yielding but disease susceptible cultivar Samba Mahsuri (an elite fine-grain *indica* rice cultivar). The two parental genotypes in crosses *viz.,* Samba Mahsuri x IC379047 and Samba Mahsuri x IC334233 were phenotypically diverse and genomic diversity was assessed using the marker system.

Molecular markers have wide applications in several genetic research and breeding programme such as genetic diversity assessment, Quantitative Trait Loci (QTL) identification, gene mapping, marker-based gene targeting and characterization of alien introgression lines from wild species of rice. DNA markers like Restriction Fragment Length Polymorphism (RFLP), Random Amplified Polymorphic DNA (RAPD), Sequenced Tagged Sites (STS), Cleaved Amplified Polymorphic Sequence (CAPS) and Simple Sequence Repeats (SSR) have been used in molecular studies over the past few decades. PCR and gel-based markers have several practical utilities for the researchers and breeders. In addition, the recently identified InDel markers are user friendly and also has ease of accessibility and technical simplicity. These markers have been attained great importance over the last two decades in several genotyping studies because of their co-dominant nature, reproducible, high polymorphism, multiallelic nature, widely distributed across the genome, require less DNA quantity and are cost effective (Usman *et al.*, 2018 and Chukwu *et al.*, 2019). The SSR markers are present in both coding and non-coding genomic region with lower level of mutation rate (10^{-2} and 10^{-4}) per generation. They are used in several studies such as population structure and evolutionary studies, linkage map construction, genetic mapping and marker assisted selection (Edwards and Balley, 2010 and Gonzaga *et al.*, 2015). QTL mapping requires mapping population and sufficient number of polymorphic markers identified between the parental lines. Different mapping populations are used for mapping studies like double haploids, F_2 populations, F_2 derived F_3 population, near isogenic lines (NILs), and recombinant inbred lines (RILs). Each mapping population has its own advantages and disadvantages. The polymorphic markers identified between the parental lines are used for the genotyping of mapping population. Phenotypic and genotypic data of mapping population was used for the QTL mapping using mapping tools. The main objective of our research was to identify the polymorphic SSR markers between the parental genotypes for further QTL mapping studies for false smut disease tolerance.

Materials and Methods

The experimental material for the study comprised of false smut donor lines IC379047 and IC334233 and recipient genotype Samba Mahsuri (high yielding variety susceptible to false smut disease), and SSR and InDel markers were collected from the Department of Genetics and Plant Breeding, ICAR-IIRR, Hyderabad.

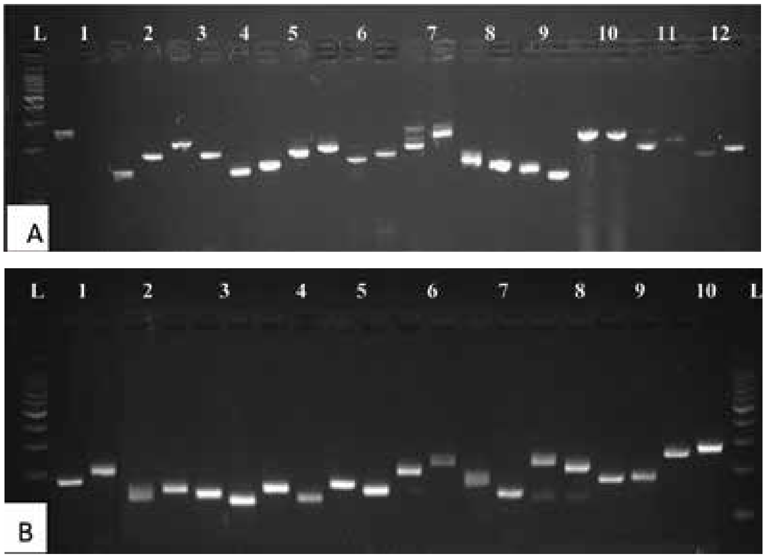
Young leaf samples were collected from the field and plant genomic DNA was isolated by CTAB method (Doyle and Doyle, 1987). The leaf samples were ground in CTAB buffer using pestle and mortar. The ground samples were transferred into Eppendorf tube and incubated at 65 ^{o}C for 30 min. The samples were centrifuged for 15 min at 13000 rpm, the supernatant (genomic DNA) was transferred to an Eppendorf tube and equal amount of 24:1 chloroform and isoamyl alcohol was added and again centrifuged for 10 min at 13000 rpm. The supernatant was taken into new Eppendorf tube and equal amount of chilled isopropanol was added and incubated at -20 ^{o}C for 15 min. Centrifugation was done for 10 min at 13000 rpm. The pellet formed in the tube was washed with 70% chilled ethanol and kept out overnight to dry and stored at 4 ^{o}C in Tris EDTA (TE) buffer for further genomic study.

A total of 1343 SSR markers distributed on 12 rice chromosomes were used for the parental polymorphism survey. Among 1343 primers, 868 markers were selected from www.gramene.org. and remaining 475 were newly developed InDel marker set chosen from the study conducted by Hechanova *et al.*, 2021. For PCR analysis, a total 10 µl PCR reaction mixture contained 30-50 ng of 2 µl genomic DNA template, 1 µl of 10X buffer, 5.2 µl of sterilized distilled water, 0.5 µl of 2.5 mM dNTP, 3 units of 0.3 µl Taq polymerase and 1 µl of primer was prepared and PCR amplification was carried out in Bio-Rad PCR machine. The thermal cycles were programmed as follows, mixture was incubated at 94 °C for 5 min; then 35 cycles of 1 min of denaturation at 94 °C, 30 sec of annealing at 58 °C and 1 min of extension at 72 °C; and 10 min of final extension at 72 °C. The PCR products were separated in 3.5% agarose gel with 1X Tris-borate-EDTA (TBE) buffer and the band sizes of the PCR products were detected and visualized through gel documentation unit. Graphical mapping of the markers on all 12 rice chromosome was done using web based tool *Oryza*BASE.

Results and Discussion

Landraces are reported as genetic reservoirs of many useful genes, which could be introgressed into the cultivars. With respect to rice false smut disease, resistance source has not been identified till date and the disease has been severely affecting the rice production and can become the great cause for the huge yield loss in future. Hence, there is a need to identify the resistance source against false smut. An attempt is made to identify the tolerant sources against false smut through artificial screening at ICAR-IIRR farm, Hyderabad. The tolerant sources for false smut disease were used as donors and high yielding but false smut susceptible variety Samba Mahsuri was used as the recipient parent. The polymorphism survey between two parental genotypes in two separate crosses *viz.,* Samba Mahsuri x IC379047 and Samba Mahsuri x IC334233 was carried out using 1343 SSR markers. The per cent of polymorphism was calculated by formula *i.e.,* the number of polymorphic markers to the total number of markers for each chromosome multiplied by 100. Among the 1343 markers used in polymorphic study for the Samba Mahsuri x IC379047, 100 SSR markers were found to be polymorphic **(Table 1)**. The total polymorphism percentage between parents Samba Mahsuri and landrace IC379047 recorded was 7.44%. The highest percentage of polymorphism was observed on chromosome 1 (14.08%) followed by chromosome 2 and 7 (10.71%) and lowest polymorphic percentage value was recorded on chromosome 12 (1.26%).

Among the total 1343 markers used for the polymorphism study for cross Samba Mahsuri x IC334233, and out of 868 rice markers chosen from Gramene, only 27 SSRs were found as polymorphic and were distributed on all rice chromosomes except on chromosome 7. Among 475 SSRs chosen from InDel marker set designed, 72 markers were found to be polymorphic and were also distributed among all the 12 rice chromosomes. It was found 99 out of 1343 markers as polymorphic between the two genotypes in the study **(Table 1).** The total polymorphism percentage between parents Samba Mahsuri and germplasm IC334233 recorded was 7.37%. The highest percentage of polymorphism was observed on chromosome 6 (10%), which means out of 142 markers positioned on chromosome 6, 13 markers were found to be polymorphic followed by chromosome 1 (9.15%) and lowest polymorphic percentage value was recorded on chromosome 9 (4.30%). Polymorphism percentage for all the 12 rice chromosome for two crosses are represented in **Table 2.** The banding pattern of the polymorphic markers for two crosses has shown in the gel image **(Figure 1).** The frequency distribution and representation of the polymorphic markers on rice chromosomes for two crosses has shown in **Figure 2** and **Figure 3.**



S. No	Marker	S. No	Marker
1	A09P06588	L	Ladder
2	A09P12377	1	RM23946
3	A09P21225	2	RM216
4	A10P08920	3	RM25031
5	A10P09104	4	RM21749
6	RM6470	5	RM28766
7	RM5543	6	RM5479
8	RM17624	7	RM17377
9	RM1204	8	RM18182
10	RM142	9	RM15981
11	RM3394	10	RM22763
12	RM427		

Figure 1: Identified polymorphic SSR and InDel markers between A. Recipient parent (Samba Mahsuri) and donor (IC379047); B. Recipient parent (Samba Mahsuri) and donor (IC334233)

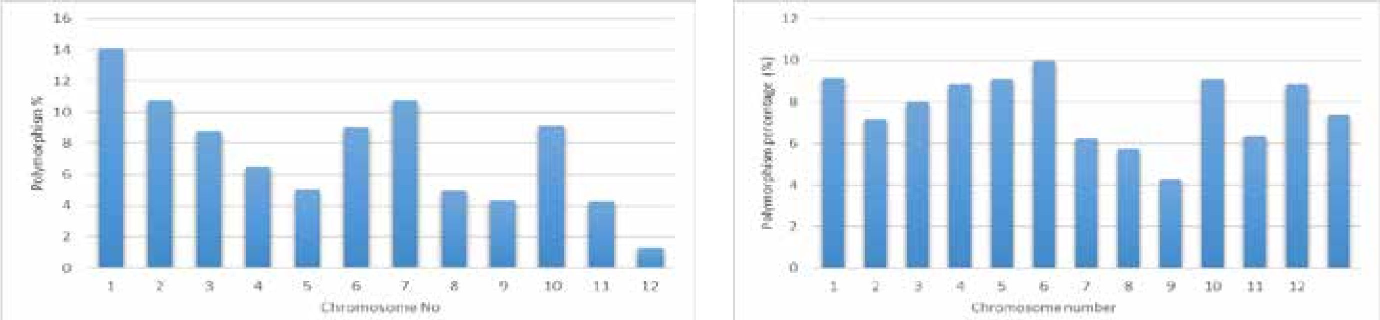


Figure 2: A. Frequency distribution of polymorphic markers identified between Samba Mahsuri x IC379047; B. Frequency distribution of polymorphic markers identified between Samba Mahsuri x IC334233

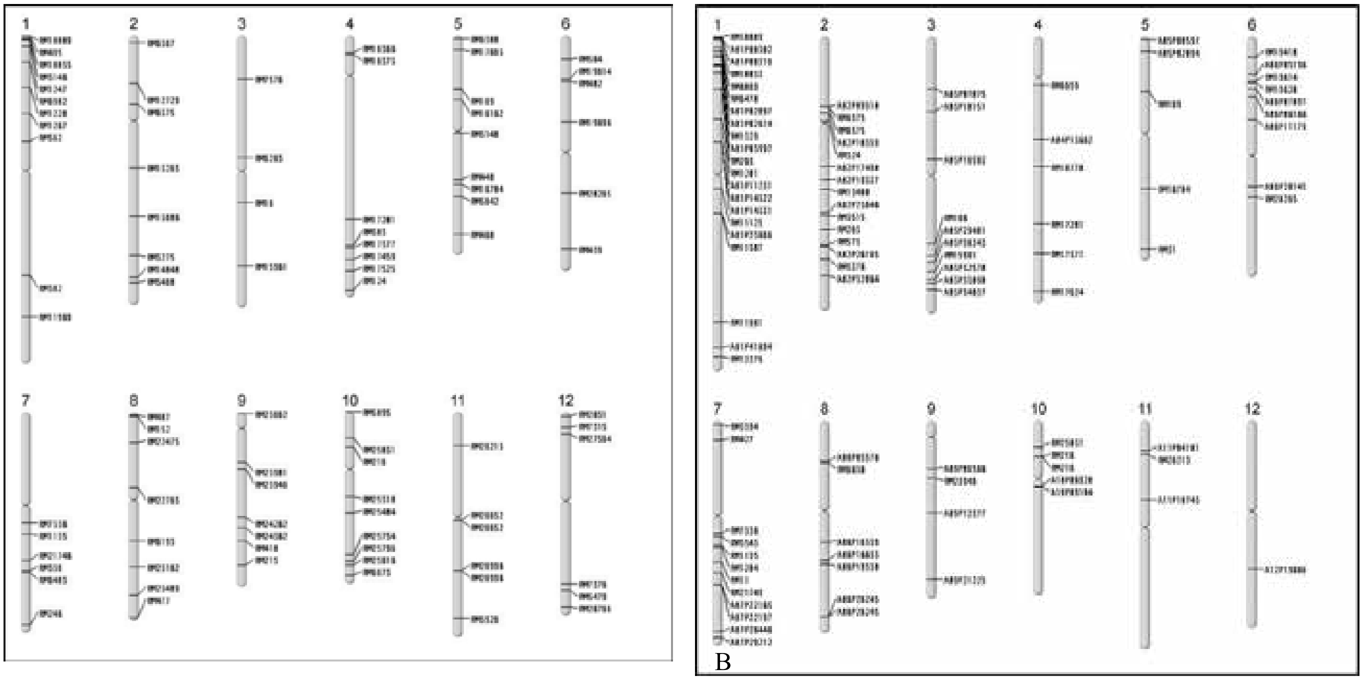


Figure 3: A. The distribution of the polymorphic markers on 12 rice chromosome for cross Samba Mahsuri x IC379047; B. The distribution of the polymorphic markers on 12 rice chromosome for cross Samba Mahsuri x IC334233

Table 1: Details of identified polymorphic SSR and InDel markers for the cross Samba Mahsuri x IC379047 and Samba Mahsuri x IC334233

Chromo some No.	Polymorphic marker identified between		Chromo some No.	Polymorphic marker identified between		Chromo some No.	Polymorphic marker identified between		Chromo some No.	Polymorphic marker identified between	
	Samba Mahsuri x IC379047	Samba Mahsuri x IC334233		Samba Mahsuri x IC379047	Samba Mahsuri x IC334233		Samba Mahsuri x IC379047	Samba Mahsuri x IC334233		Samba Mahsuri x IC379047	Samba Mahsuri x IC334233
1	RM11307	A01P00302	2	RM324	RM13608	5	RM31	A04P20855	8	RM6838	A08P05578
	RM11981	A01P11231		A02P09510	RM14040		RM169	A04P22100		A08P05578	A08P16339
	RM10009	A01P23866		A02P10359	RM5460		RM18704	RM303		A08P16339	A08P02005
	RM1329	A01P29533		A02P17490			A05P00597			A08P19330	A08P24236
	RM8069	A01P10284		A02P19327			A05P02094			A08P26245	A08P19324
	RM283	A01P02097		A02P23648		6	RM19620	A05P00597		A08P26245	RM22763
	RM1201	A01P37714		A02P28165			RM19614	A05P01457			RM407
	RM12276	A01P08402		A02P32084			RM19410	A05P00226	9	RM23946	A09P06590
	RM10033	A01P14811	3	RM168	A03P16583		RM20265	A05P22287		A09P06588	A09P11829
	RM6470	A01P17986		RM15981	A03P30243		A06P05198	A05P08866		A09P12377	RM23946
	A01P41894	A01P34148		RM15981	A03P33090		A06P07097	RM169		A09P21225	RM24382
	A01P00302	RM1220		A03P07075	A03P10151		A06P08188	RM440	10	RM216	A10P09104
	A01P00316	RM6902		A03P10151	A03P24625		A06P11179	RM480		RM25031	A10P17146
	A01P02097			A03P16583	A03P29286		A06P20145	RM5140		A10P08920	RM216
	A01P02814			A03P29401	A03P00091	7	RM11	A07P06109		A10P09104	RM25031
	A01P03997			A03P30243	RM15981		RM21749	A07P27655			RM25754
	A01P11231			A03P32570	RM7576		RM7338	A07P13588	11	RM26213	A11P10743
	A01P14322			A03P33090	RM16		RM5543	A07P15254		A11P10743	A11P04101
	A01P14331			A03P34037			RM1204	A07P23358		A11P04101	A11P22653
	A01P23866		4	RM17201	A04P08530		RM3394	A07P19443		Chr.11.8.9	A11P27658
2	RM6375	A02P10359		RM17377	A04P04207		RM427	A07P21651			A11P28918
	RM573	A02P01132		RM17624	A04P31237		RM1135				RM26998
	RM3515	A02P01124		RM142	A04P34324		A07P22185		12	A12P19886	A12P02180
	RM5378	A02P17490		RM6659	A04P11418		A07P22197				A12P23064
	RM263	A02P09510		RM16770	A04P12051		A07P28448				A12P24258
	RM6375	RM3275		A04P13862	A04P12977		A07P29212				A12P22450
	RM13400	RM12729		RM307	A04P13832						RM27564
											RM28766
											RM2851

It was observed that the InDel marker set showed higher base pair difference between the parents compared to the SSR markers used. The polymorphic markers identified from the newly designed InDel marker set showed three times higher polymorphism than RM markers indicating that the InDel marker set exhibited higher allelic diversity between the parental lines. It was also reported that around 27 SSRs were found to be common in both the crosses across the genome except at chromosome 4,7 and 12 **(Table 3).** In addition to the parental lines, the polymorphic markers identified between parents were used for the hybrid confirmation study, in which the markers clearly exhibited both the alleles in F_1s indicating the true hybrid.

Similar studies on parental polymorphism have also been carried out by various researchers. Hable *et al.*, (2020) found the highest polymorphism percentage of 40.96% for chromosome 4 and on chromosome 9 recorded lowest polymorphic percentage (9%). Polymorphism percentage between the parents

Table 2: Polymorphism percentage for all the 12 rice chromosome for cross Samba Mahsuri x IC379047 and Samba Mahsuri x IC334233

S. No.	Chromosome No.	Total No. of markers used		No. of polymorphic markers obtained		Polymorphism (%)	
		Samba Mahsuri x IC379047	Samba Mahsuri x IC334233	Samba Mahsuri x IC379047	Samba Mahsuri x IC334233	Samba Mahsuri x IC379047	Samba Mahsuri x IC334233
1	1	142	142	20	13	14.08	9.15
2	2	140	140	15	10	10.71	7.14
3	3	125	125	11	10	8.80	8.00
4	4	124	124	8	11	6.45	8.87
5	5	99	99	5	9	5.05	9.09
6	6	100	100	9	10	9.00	10.00
7	7	112	112	12	7	10.71	6.25
8	8	122	122	6	7	4.91	5.74
9	9	93	93	4	4	4.30	4.30
10	10	55	55	5	5	9.09	9.09
11	11	94	94	4	6	4.25	6.38
12	12	79	79	1	7	1.26	8.86
Total markers		**1343**	**1343**	**100**	**99**	**7.44**	**7.37**

Table 3: Common polymorphic SSR and InDel markers identified between Samba Mahsuri x IC379047 and Samba Mahsuri x IC334233

Sl. No.	Markers	Chromosome No.	Sl. No	Markers	Chromosome No.
1	A01P00302	1	15	RM169	5
2	A01P11231	1	16	A06P05198	6
3	A01P23866	1	17	A06P08188	6
4	A01P02097	1	18	A06P11179	6
5	A01P37714	1	19	A06P20145	6
6	A02P10359	2	20	A08P05578	8
7	A02P17490	2	21	A08P16339	8
8	A02P09510	2	22	RM23946	9
9	A03P16583	3	23	A10P09104	10
10	A03P30243	3	24	RM216	10
11	A03P33090	3	25	RM25031	10
12	A03P10151	3	26	A11P10743	11
13	RM15981	3	27	A11P04101	11
14	A05P00597	5			

Rajendrakasturi and URG-30 reported was 29.02%. Chandu *et al*., (2020) using 800 SSR markers observed 20. 75% of total polymorphism percentage between Samba Mahsuri and *O. rufipogon* WR119 parents. The highest polymorphism percentage for chromosome 6 (26.67%) and lowest for chromosome 10 (8.93%) was also reported by Rathi *et al.,* (2021) with total percentage of polymorphism (16.67%) between Improved Samba Mahsuri and local landrace Badshabhog using 576 random SSR markers. Kulkarni *et al.,* 2020 found total polymorphism percentage of 6.93 between the parents IR58025A and KMR-3R using 1904 genomic SSR markers**.**

Conclusion

The identified polymorphic markers on all 12 rice chromosomes are useful for linkage analysis and QTL mapping for the traits of interest in the biparental mapping populations derived from the two crosses *viz.,* Samba Mahsuri x IC379047 and Samba Mahsuri x IC334233. Genotyping and QTL mapping using these markers for false smut resistance will help in mapping QTLs for resistance to false smut disease. Development of the false smut resistant rice varieties through marker assisted breeding method is feasible using the detected polymorphic markers flanking the QTLs.

Acknowledgment

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Correlation and Path Coefficients Analysis for Yield and its Contributing Traits in Rice (*Oryza sativa* L.) under Sodic Soil

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Abstract

Yield is the complex trait that depends on various attributes. Therefore, the knowledge about the relationship of different attributes to yield is crucial for making efficient selection strategy. The grain yield per plant exhibited highly significant and positive association with biological yield per plant followed by panicle bearing tillers per plant, spikelets per panicle, grains per panicle, chlorophyll content in F_1s at both genotypic and phenotypic level. Highest positive direct effect on grain yield per plant was exerted by biological yield per plant and harvest-index in F_1s at both genotypic and phenotypic level. Therefore, biological yield per plant and harvest index should be utilized in making selection strategy for yield improvement in rice.

Keywords: Rice (*Oryza sativa* L.), correlation, path, grain yield and sodic soil.

Introduction

Rice (*Oryza sativa* L.) is the most important staple food crop of the world. Asia is the leader in rice production accounting for about 90% of the world's production. India has the world's largest rice-growing area (45 million hectares) and ranks second in overall production (130.29 million tonnes) after China, with an average yield of 2895 kg/hectare (Anonymous 2021-22).

The knowledge of factors responsible for high yields has been rendered difficult since yield is a complex character that manifests through multiplicative interactions of other characters known as yield components (Grafius, 1959). For rational approach in breeding for higher yield, several workers emphasized use of component approach for successful breeding programme (Moll *et al*., 1962, Bhatt, 1970). Therefore, the identification of important yield contributing characters, out of numerous plant traits, is necessary because it would be impossible and impractical to concentrate and work on improving many characters at a time. The correlation and path coefficient analysis help us in identification of important yield contributing characters.

Correlation is a statistical measure, which is used to find out the degree (strength) and direction of relationship between two or more variables or characters. The coefficient of correlation expresses association between two variables, but tells us nothing about the causal relations of variables, *i.e.,* which variable is dependent and which is independent. Therefore, the study of path-coefficients is necessary. The concept of path analysis was developed by Wright (1921), but the technique was first used for plant selection by Dewey and Lu (1959). Path-coefficient is simply a standardized partial regression coefficient, which splits the correlation coefficient into the measures of direct and indirect effects. In other words, it measures the direct and indirect contribution of various independent characters on the dependent character like yield. It also estimates residual effects. Path analysis clearly indicates the relative importance of different yield components so that one may identify the most important yield components.

Materials and Methods

This experiment was carried out at the Main Experimental Station of A.N.D. University of Agriculture & Technology, Narendra Nagar (Kumarganj), Ayodhya (U. P.) India. The experimental material was based on a line x tester set of 63 hybrids (F_1's) developed by crossing 21 lines (females) with 3 testers (males). An attempt was made to make a sixty three cross combinations during *kharif* season 2017 to generate F_1's. The 63 F_1's along with parents and two checks, Jaya and CSR 43 were evaluated to work out the correlation and path coefficient of their various attributes on grain yield under the sodic soil in Randomized Complete Block Design with three replications during *kharif* 2018. Estimation of correlation coefficients was done as per Searle, 1961 and path-coefficient analysis was done as per Dewey and Lu, 1959.

Results and Discussion

The estimates of simple correlation coefficients at phenotypic and genotypic levels computed between eighteen characters under study are presented in **Table 1** and **2**, respectively. The phenotypic correlation coefficients and genotypic correlation coefficients for 18 traits were analyzed in the F_1s of 63 cross combinations and their 24 parents. Differences in magnitude as well as in direction were observed for different traits. However, both genotypic correlation coefficient and phenotypic correlation coefficient exhibited similar signs with few exceptions. In general, both positive and negative character associations were observed among different traits. Further, it was also observed that the estimates of genotypic correlation coefficient were higher than the corresponding phenotypic correlations.

The grain yield per plant exhibited highly significant and positive association with biological yield per plant (0.9018, 0.8798), followed by panicle bearing tillers per plant (0.6410, 0.6329), spikelets per panicle (0.6210, 0.6166), grains per panicle (0.6136, 0.6096), chlorophyll content (0.4976, 0.4858), panicle length (0.3741, 0.3589), plant height (0.3020, 0.2978), flag leaf area (0.2755, 0.2746) in F_1s at genotypic and phenotypic level respectively. Therefore, these characters emerged as most important associates of grain yield in rice. The strong positive association of grain yield with the characters mentioned above has also being reported in rice by earlier workers (Sarawgi *et al.,* 1997, Chaudhary and Motiramani 2003, Qamar *et al.,* 2005, Ramkrishnan *et al.,* 2006, Zahid *et al.,* 2006, Eradasappa *et al.,* 2007b, Petchiammal and Kumar 2007, Kishor *et al.,* 2007, Rahaman *et al.,* 2011, Bhadru *et al.,* 2011, Krishnamurthy and Kumar, 2012, Ahamed *et al.,* 2014, Kumar *et al,,* 2018 and Shrivastav *et al.,* 2020.

Biological yield per plant showed positive and highly significant correlation with grain yield per plant (0.8798), spikelets per panicle (0.6962), grains per panicle (0.6685), panicle bearing tillers per plant (0.5862), chlorophyll content (0.5068), panicle length (0.3942), plant height (0.2611), protein content (0.2506), flag leaf area (0.2278), leaf nitrogen (0.2213), harvest index (0.1849), leaf temperature (0.1792) and amylose content (0.1677), in F_1s. These similar result reported by those of Chaudhary and Motiramani, 2003; Ahamed *et al.,* 2014; Kumar *et al.,* 2018. Harvest index showed positive and highly significant correlation with grain yield per plant (0.6131), panicle bearing tillers per plant (0.3711), flag leaf area (0.2173), plant height (0.1897), biological yield per plant (0.1849), L:B ratio (0.1754), grains per panicle (0.1618) and chlorophyll content (0.1605) in F_1s. These finding are accordance with the result of Ahamed *et al.,* 2014; Kumar *et al.,* 2018. Amylose content showed positive and highly significant correlation with 1000-grain weight (0.2856), spikelets per panicle (0.2408), chlorophyll content (0.2269), panicle bearing tillers per plant (0.2212), biological yield per plant (0.1677) and grains per panicle (0.1599) in F_1s. But grain yield per plant (0.1218) shows positive and significant correlation in F_1s. Protein content showed positive and highly significant correlation with biological yield per plant (0.2506), plant height (0.2439), panicle length (0.2038) and grains per panicle (0.1748) in F_1s. But grain yield per plant (0.1269) shows positive and significant correlation in F_1s. The estimates of correlation coefficients obtained in present study are broadly in conformity with previous reports in rice (Sarawgi *et al.,* 1997, Chaudhary and Motiramani, 2003, Qamar *et al.,* 2005, Zahid *et al.*, 2006, Kishore *et al.*, 2007, Rahman *et al.*, 2011, Bhadru *et al.,* 2011, Ahamed *et al.*, 2014, Kumar *et al.*, 2018 and Shrivastav *et al.*, 2020.

Path coefficient analysis is a tool to partition the observed correlation coefficient into direct and indirect effects of yield components on grain yield. Path analysis provides more clear picture of character associations for formulating efficient selection strategy. Path coefficient analysis differs from simple correlation in that it points out the causes and their relative importance, whereas, the later measures simply the mutual association ignoring the causation. The concept of path coefficient was developed by Wright S. (1921) and technique was first used for plant selection by Dewey and Lu (1959). Path analysis has emerged as a powerful and widely used technique for understanding the direct and indirect contributions of different characters to economic yield in crop plants so that the relative importance of various yield contributing characters can be assessed. The direct and indirect effects of seventeen characters on grain yield per plant estimated by path coefficient analysis using phenotypic and genotypic correlations is depicted in **Table 3** and **4** respectively.

Highest positive direct effect on grain yield per plant was exerted by biological yield per plant (0.7908, 0.7756), followed by harvest-index (0.4598, 0.4669), amylose content (0.0270, 0.0179), L:B ratio (0.0203, 0.0149) in F_1s at genotypic and phenotypic level respectively. Thus, biological yield per plant and harvest-index emerged as most important direct yield components on which emphasis should be given during simultaneous selection aimed at improving grain yield in rice. These characters have also been identified as major direct contributors towards grain yield by Sarawgi *et al.*, (1997), Mishra and Verma (2002), Petchiammal and Kumar (2007), Kishore *et al.*, (2007), Amahed *et al.,* (2014), Kumar *et al.,* (2018) and Shrivastav *et al.*, (2020).

In the present study, path analysis identified biological yield per plant followed by harvest-index as most important direct as well as indirect yield contributing traits or components which merit due consideration at time of devising selection strategy aimed at developing high yielding varieties in rice.

Table 1 : Estimates of phenotypic correlation coefficients (F_1s) between 18 characters in rice under sodic soil

Characters	Days to 50% flowering	Chlorophyll content	Leaf nitrogen	Leaf temperature	Flag leaf area (cm²)	Plant height (cm)	Panicle bearing tillers/ plant	Panicle length (cm)	Spikelets/ panicle	Grains/ panicle	Spikelet fertility (%)	Biological yield/ plant (g)	Harvest index (%)	L/B ratio	1000-grain weight (g)	Amylose content	Protein content (%)	Grain yield/ plant (g)
Days to 50% flowering	1.0000	-0.0890	-0.0426	-0.1428*	-0.1169	-0.1332*	-0.2511**	-0.1200	-0.1163	-0.1586**	-0.1770**	-0.2185**	-0.2122**	0.1243*	-0.1886**	0.3199**	-0.0564	-0.2665**
Chlorophyll content		1.0000	0.4797**	-0.1013	0.0735	0.3982**	0.4386**	0.2136**	0.3765**	0.4122**	0.2424**	0.5068**	0.1605**	0.2001**	0.1584**	0.2269**	0.1242*	0.4858**
Leaf nitrogen			1.0000	-0.3626**	0.1247*	0.3799**	0.2338**	0.1577**	0.2044**	0.2512**	0.2180**	0.2213**	-0.0116	0.2293**	-0.0316	-0.0669	0.1130	0.1683**
Leaf temperature				1.0000	-0.0669	-0.2023**	0.0002	-0.1676**	0.0018	-0.0367	-0.1158	0.1792**	0.0723	0.1778**	0.1067	-0.0138	0.0042	0.1912**
Flag leaf area (cm²)					1.0000	0.4854**	0.1429*	0.1972**	0.2649**	0.2428**	0.0588	0.2278**	0.2173**	0.3121**	0.1774**	-0.1033	0.0147	0.2746**
Plant height (cm)						1.0000	0.1458*	0.3185**	0.2576**	0.2362**	0.0435	0.2611**	0.1897**	0.0245	0.1011	-0.1463*	0.2439**	0.2978**
Panicle bearing tillers/ plant							1.0000	0.1392*	0.5719**	0.5393**	0.0788	0.5862**	0.3711**	0.3527**	0.1053	0.2212**	-0.1510*	0.6329**
Panicle length (cm)								1.0000	0.3438**	0.3375**	0.0302	0.3942**	0.0931	0.2187**	-0.1311*	-0.0504	0.2038**	0.3589**
Spikelets/ panicle									1.0000	0.9452**	0.1077	0.6962**	0.1306*	0.1405*	-0.0068	0.2408**	0.1539*	0.6166**
Grains/panicle										1.0000	0.4179**	0.6685**	0.1618**	0.2270**	-0.0736	0.1599**	0.1748**	0.6096**
Spikelet fertility (%)											1.0000	0.1431*	0.1386*	0.2921**	-0.1151	-0.1599**	0.1225*	0.1801**
Biological yield/plant (g)												1.0000	0.1849**	0.0809	0.1052	0.1677**	0.2506**	0.8798**
Harvest index (%)													1.0000	0.1754**	0.1368*	-0.0545	-0.1613**	0.6131**
L/B ratio														1.0000	0.0826	0.0821	0.1024	0.1492*
1000-grain weight (g)															1.0000	0.2856**	-0.1437*	0.1543*
Amylose content																1.0000	-0.1984**	0.1218*
Protein content (%)																	1.0000	0.1269*

,** Significant at 5% and 1% probability levels, respectively

Table 2: Estimates of genotypic correlation coefficients (F_1s) between 18 characters in rice under sodic soil

Characters	Days to 50% flowering	Chlorophyll content	Leaf nitrogen	Leaf temperature	Flag leaf area (cm²)	Plant height (cm)	Panicle bearing tillers/ plant	Panicle length (cm)	Spikelets/ panicle	Grains/ panicle	Spikelet fertility (%)	Biological yield/ plant (g)	Harvest index (%)	L/B ratio	1000-grain weight (g)	Amylose content	Protein content (%)	Grain yield/ plant (g)
Days to 50% flowering	1.0000	-0.1260	-0.0800	-0.1867	-0.1431	-0.1751	-0.3274*	-0.1611	-0.1483	-0.1976*	-0.2238*	-0.2798**	-0.2585**	0.1517	-0.2420*	0.3953**	-0.0678	-0.3278**
Chlorophyll content		1.0000	0.5008**	-0.1101	0.0752	0.4143**	0.4575**	0.2438*	0.3839**	0.4256**	0.2735**	0.5244**	0.1890	0.2073*	0.1617	0.2329*	0.1278	0.4976**
Leaf nitrogen			1.0000	-0.3831	0.1319	0.4009**	0.2478*	0.1836	0.2106*	0.2710**	0.2691**	0.2264*	0.0053	0.2537**	-0.0395	-0.0702	0.1153	0.1755
Leaf temperature				1.0000	-0.0710	-0.2064*	-0.0034	-0.1730	0.0012	-0.0387	-0.1254	0.1763	0.0982	0.1876	0.1091	-0.0141	0.0051	0.1947*
Flag leaf area (cm²)					1.0000	0.4893**	0.1446	0.2033*	0.2660**	0.2443*	0.0624	0.2339*	0.2351*	0.3206**	0.1831	-0.1034	0.0149	0.2755**
Plant height (cm)						1.0000	0.1464	0.3225**	0.2593**	0.2397*	0.0506	0.2697**	0.2051*	0.0232	0.1035	-0.1473	0.2457*	0.3020**
Panicle bearing tillers/plant							1.0000	0.1427	0.5790**	0.5463**	0.0825	0.6056**	0.4087**	0.3654**	0.1053	0.2234*	-0.1544	0.6410**
Panicle length (cm)								1.0000	0.3565**	0.3489**	0.0279	0.4199**	0.1075	0.2300*	-0.1442	-0.0520	0.2097*	0.3741**
Spikelets/ panicle									1.0000	0.9507**	0.1232	0.7129**	0.1458	0.1459	-0.0073	0.2413*	0.1540	0.6210**
Grains/ panicle										1.0000	0.4184**	0.6866**	0.1758	0.2315*	-0.0760	0.1604	0.1752	0.6136**
Spikelet fertility (%)											1.0000	0.1556	0.1492	0.3078**	-0.1214	-0.1688	0.1287	0.1869*
Biological yield/plant (g)												1.0000	0.2659**	0.0845	0.1051	0.1714	0.2601*	0.9018**
Harvest index (%)													1.0000	0.1952*	0.1593	-0.0585	-0.1781	0.6560**
L/B ratio														1.0000	0.0831	0.0839	0.1057	0.1525
1000-grain weight (g)															1.0000	0.2920**	-0.1480	0.1569
Amylose content																1.0000	-0.1991*	0.1222
Protein content (%)																	1.0000	0.1278

Table 3: Estimates of phenotypic direct and indirect (F_1s) effect of 17 characters on grain yield per plant in rice under sodic soil

Characters	Days to 50% flowering	Chlo-rophyll content	Leaf nitrogen	Leaf tem-perature	Flag leaf area (cm²)	Plant height (cm)	Panicle bearing tillers/ plant	Panicle length (cm)	Spike-lets/ panicle	Grains/ panicle	Spikelet fertility (%)	Bio-logical yield/ plant (g)	Harvest index (%)	L/B ratio	1000-grain weight (g)	Amylose content	Protein content (%)	Grain yield/ plant (g)
Days to 50% flowering	0.0043	-0.0004	-0.0002	-0.0006	-0.0005	-0.0006	-0.0011	-0.0005	-0.0005	-0.0007	-0.0008	-0.0009	-0.0009	0.0005	-0.0008	0.0014	-0.0002	-0.2665
Chlorophyll content	-0.0007	0.0084	0.0040	-0.0009	0.0006	0.0033	0.0037	0.0018	0.0032	0.0035	0.0020	0.0043	0.0013	0.0017	0.0013	0.0019	0.0010	0.4858
Leaf nitrogen	-0.0001	0.0011	0.0022	-0.0008	0.0003	0.0008	0.0005	0.0003	0.0004	0.0005	0.0005	0.0005	0.0000	0.0005	-0.0001	-0.0001	0.0002	0.1683
Leaf temperature	-0.0039	-0.0028	-0.0099	0.0274	-0.0018	-0.0055	0.0000	-0.0046	0.0000	-0.0010	-0.0032	0.0049	0.0020	0.0049	0.0029	-0.0004	0.0001	0.1912
Flag leaf area (cm²)	0.0004	-0.0003	-0.0004	0.0002	-0.0035	-0.0017	-0.0005	-0.0007	-0.0009	-0.0009	-0.0002	-0.0008	-0.0008	0.0011	-0.0006	0.0004	-0.0001	0.2746
Plant height (cm)	-0.0011	0.0032	0.0031	-0.0016	0.0039	0.0081	0.0012	0.0026	0.0021	0.0019	0.0004	0.0021	0.0015	0.0002	0.0008	-0.0012	0.0020	0.2978
Panicle bearing tillers/ plant	0.0039	-0.0069	-0.0037	0.0000	-0.0022	-0.0023	-0.0156	-0.0022	-0.0089	-0.0084	-0.0012	-0.0092	-0.0058	0.0055	-0.0016	-0.0035	0.0024	0.6329
Panicle length (cm)	-0.0018	0.0031	0.0023	-0.0024	0.0029	0.0046	0.0020	0.0146	0.0050	0.0049	0.0004	0.0058	0.0014	0.0032	-0.0019	-0.0007	0.0030	0.3589
Spikelets/panicle	0.0001	-0.0002	-0.0001	0.0000	-0.0001	-0.0001	-0.0003	-0.0002	-0.0005	-0.0005	-0.0001	-0.0003	-0.0001	0.0001	0.0000	-0.0001	-0.0001	0.6166
Grains/panicle	-0.0015	0.0040	0.0024	-0.0004	0.0023	0.0023	0.0052	0.0032	0.0091	0.0096	0.0040	0.0064	0.0016	0.0022	-0.0007	0.0015	0.0017	0.6096
Spikelet fertility (%)	-0.0003	0.0004	0.0003	-0.0002	0.0001	0.0001	0.0001	0.0000	0.0002	0.0007	0.0016	0.0002	0.0002	0.0005	-0.0002	-0.0003	0.0002	0.1801
Biological yield/plant (g)	-0.1694	0.3931	0.1716	0.1390	0.1767	0.2025	0.4547	0.3058	0.5400	0.5185	0.1110	0.7756	0.1434	0.0628	0.0816	0.1301	0.1944	0.8798
Harvest index (%)	-0.0991	0.0749	-0.0054	0.0337	0.1015	0.0886	0.1733	0.0435	0.0610	0.0755	0.0647	0.0863	0.4669	0.0819	0.0639	-0.0255	-0.0753	0.6131
L/B ratio	0.0018	0.0030	0.0034	-0.0026	0.0046	-0.0004	0.0052	-0.0033	0.0021	0.0034	0.0043	0.0012	0.0026	0.0149	0.0012	0.0012	0.0015	0.1492
1000-grain weight (g)	-0.0011	0.0009	-0.0002	0.0006	0.0011	0.0006	0.0006	-0.0008	0.0000	-0.0004	-0.0007	0.0006	0.0008	0.0005	0.0059	0.0017	-0.0009	0.1543
Amylose content	0.0057	0.0041	-0.0012	-0.0002	-0.0018	-0.0026	0.0040	-0.0009	0.0043	0.0029	-0.0029	0.0030	-0.0010	0.0015	0.0051	0.0179	-0.0036	0.1218
Protein content (%)	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	-0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	-0.0001	0.0001	-0.0001	-0.0001	0.0005	0.1269

Residual factors = 0.1217, Bold figures indicate direct effects

Table 4: Estimates of genotypic direct and indirect (F_1s) effect of 17 characters on grain yield per plant in rice under sodic soil

Characters	Days to 50% flowering	Chlorophyll content	Leaf nitrogen	Leaf temperature	Flag leaf area (cm²)	Plant height (cm)	Panicle bearing tillers/ plant	Panicle length (cm)	Spikelets/ panicle	Grains/ panicle	Spikelet fertility (%)	Biological yield/plant (g)	Harvest index (%)	L/B ratio	1000-grain weight (g)	Amylose content	Protein content (%)	Grain yield/ plant (g)
Days to 50% flowering	**-0.0095**	0.0012	0.0008	0.0018	0.0014	0.0017	0.0031	0.0015	0.0014	0.0019	0.0021	0.0027	0.0025	0.0014	0.0023	-0.0038	0.0006	-0.3278
Chlorophyll content	-0.0003	**0.0027**	0.0014	-0.0003	0.0002	0.0011	0.0012	0.0007	0.0010	0.0011	0.0007	0.0014	0.0005	0.0026	0.0004	0.0006	0.0003	0.4976
Leaf nitrogen	-0.0004	0.0027	**0.0053**	-0.0020	0.0007	0.0021	0.0013	0.0010	0.0011	0.0014	0.0014	0.0012	0.0000	0.0013	-0.0002	-0.0004	0.0006	0.1755
Leaf temperature	-0.0026	-0.0016	-0.0054	**0.0141**	-0.0010	-0.0029	0.0000	-0.0024	0.0000	-0.0005	-0.0018	0.0025	0.0014	0.0056	0.0015	-0.0002	0.0001	0.1947
Flag leaf area (cm²)	0.0016	-0.0009	-0.0015	0.0008	**-0.0114**	-0.0056	-0.0016	-0.0023	-0.0030	-0.0028	-0.0007	-0.0027	-0.0027	0.0036	-0.0021	0.0012	-0.0002	0.2755
Plant height (cm)	-0.0015	0.0035	0.0033	-0.0017	0.0041	**0.0083**	0.0012	0.0027	0.0022	0.0020	0.0004	0.0022	0.0017	0.0005	0.0009	-0.0012	0.0020	0.3020
Panicle bearing tillers/plant	0.0145	-0.0203	-0.0110	0.0002	-0.0064	-0.0065	**-0.0443**	-0.0063	-0.0257	-0.0242	-0.0037	-0.0269	-0.0181	0.0162	-0.0047	-0.0099	0.0068	0.6410
Panicle length (cm)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0001**	0.0000	0.0000	0.0000	0.0000	0.0000	0.0042	0.0000	0.0000	0.0000	0.3741
Spikelets/panicle	-0.0076	0.0196	0.0107	0.0001	0.0136	0.0132	0.0295	0.0182	**0.0510**	0.0484	0.0063	0.0363	0.0074	0.0074	-0.0004	0.0123	0.0078	0.6210
Grains/panicle	0.0097	-0.0209	-0.0133	0.0019	-0.0120	-0.0118	-0.0269	-0.0172	-0.0468	**-0.0492**	-0.0206	-0.0338	-0.0086	0.0114	0.0037	-0.0079	-0.0086	0.6136
Spikelet fertility (%)	-0.0027	0.0032	0.0032	-0.0015	0.0007	0.0006	0.0010	0.0003	0.0015	0.0050	**0.0119**	0.0018	0.0018	0.0037	-0.0014	-0.0020	0.0015	0.1869
Biological yield/ plant (g)	-0.2212	0.4147	0.1791	0.1394	0.1850	0.2133	0.4789	0.3321	0.5638	0.5430	0.1231	**0.7908**	0.2103	0.0668	0.0831	0.1356	0.2057	0.9018
Harvest index (%)	-0.1189	0.0869	0.0024	0.0452	0.1081	0.0943	0.1880	0.0495	0.0670	0.0808	0.0686	0.1223	**0.4598**	0.0898	0.0733	-0.0269	-0.0819	0.6560
L/B ratio	0.0016	0.0021	0.0026	0.0019	0.0033	0.0008	0.0038	0.0024	0.0015	0.0024	0.0032	0.0009	0.0020	**0.0203**	0.0069	0.0019	0.0011	0.1555
1000-grain weight (g)	0.0017	-0.0012	0.0003	-0.0008	-0.0013	-0.0007	-0.0008	0.0010	0.0001	0.0005	0.0009	-0.0008	-0.0011	0.0006	**-0.0072**	-0.0021	0.0011	0.1569
Amylose content	0.0107	0.0063	-0.0019	-0.0004	-0.0028	-0.0040	0.0060	-0.0014	0.0065	0.0043	-0.0046	0.0046	-0.0016	0.0023	0.0079	**0.0270**	-0.0054	0.1222
Protein content (%)	0.0003	-0.0005	-0.0005	0.0000	-0.0001	-0.0010	0.0006	-0.0008	-0.0006	-0.0007	-0.0005	-0.0010	0.0007	0.0004	0.0006	0.0008	**-0.0039**	0.1278

Residual factors =0.03, Bold figures indicate direct effects

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Characterization of African Rice (*Oryza glaberrima* Steud.) Germplasm for Grain Iron and Zinc Content

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Abstract

Micronutrient deficiency is one of the major challenges for food security in developing nations. There is a need for the identification of micronutrient-rich genotypes for their direct use in the genetic enhancement of staple food crops using plant breeding strategies. In the present study, grain iron (Fe) and zinc (Zn) contents of 29 accessions of *Oryza glaberrima* along with check varieties were analyzed for three seasons. Grain Fe ranged from 6.40 ppm to 12.10 ppm with a mean of 8.57 ppm, while Zn content exhibited manifold variation by ranging from 7.30 ppm to 34.40 ppm in the brown rice. There was a two-fold variation in Fe and Zn concentrations between accessions indicating the potential to boost these micronutrients in rice grain. Fifteen African rice accessions were better than the checks for grain Fe content, while four accessions outperformed checks with higher Zn content. Altogether, one *O. glaberrima* accession, CG 239 was found to be having high Zn content (34.7 ppm) in the brown rice making it a valuable source for biofortification of popular rice varieties using conventional and molecular approaches.

Keywords: Iron, zinc, biofortification, *Oryza glaberrima*, brown rice

Introduction

Rice (*Oryza sativa* L.) is the primary source of nourishment for more than half of the world's burgeoning population. Nearly 20% of the daily calories consumed by 3.5 billion people across the globe come from rice, with Asia accounting for 90% of world rice consumption (Muthayya *et al.*, 2014). Nevertheless, the levels of the key micronutrients such as iron (Fe) and zinc (Zn) are insufficient in order to meet the daily dietary requirements (Bouis and Welch, 2010). The deficiency is also inherently difficult to apprehend inflicting economic mayhem of several countries globally (Maganti *et al.,* 2019). Annually, micronutrient deficiencies tend to account for seven percentage of the global disease burden annually (Muthayya *et al.,* 2014) with over three billion people suffering predominantly from Fe and Zn malnutrition in developing nations (Sperotto *et al.,* 2010). Iron (Fe) is a key player in hemoglobin synthesis and erythrocyte production (Lynch, 2003), while zinc (Zn) acts as a stabilizer of the structures of membranes, cellular components and for detoxification of highly aggressive free radicles (Cakamn, 2000). Almost 40 per cent of the zinc binding proteins are needed for gene regulation and 60 per cent enzymes and proteins are involved in ion transport (Andreini *et al.,* 2006). Therefore, insufficient levels of Fe and Zn in the diet tend to have adverse health consequences making it imperative to enhance their concentration and bioavailability in rice grain (Solomon, 2003).

In this regard, biofortification with nutrient enrichment of staple crops through plant breeding has been considered as a sustainable approach which is technically feasible without compromising agronomic productivity (Nestel *et al.,* 2006). The approach has been game-changing for alleviating hidden hunger as indicated by recent successes in rice, maize and wheat crops with the combined efforts of researchers and policymakers. Recently, the breeding target is approximately fixed at 40 ppm for iron and 30 ppm for zinc biofortification (Tripathy, 2020). This could be achieved with the identification of germplasm with high efficiency of Fe and Zn accumulation in the endosperm with their bioavailability from existing germplasm collection. Selection of such micronutrient-rich cultivars could be either within the existing germplasm or generation of new material *de novo* through genetic modification and utilizing them as donors pose to be a potent and reliable way to provide trace elements nutrition benefits to the native farmers and local population (Prom-u-thai *et al.,* 2006).

Accordingly, exploitation of large genetic variation existing in wild species and landraces is an important approach to increase micronutrients concentration. Several studies reported high Fe and Zn contents in the brown rice of some wild rice species and their derivatives (Gregorio *et al.,* 2000; Anandan *et al.,* 2011; Norton *et al.,* 2014). African rice, *Oryza*

Table 1: List of *O. glaberrima* accessions and checks used in the present investigation

S. No.	Entry	Accession No.	Origin	Biological status
1	CG 208	EC 861784	Guinea	Traditional cultivar/ Landrace
2	CG 209	EC 861785	Guinea	Traditional cultivar/ Landrace
3	CG 211	EC 861787	Guinea	Traditional cultivar/ Landrace
4	CG 214	EC 861790	Guinea	Traditional cultivar/ Landrace
5	CG 215	EC 861791	Guinea	Traditional cultivar/ Landrace
6	CG 216	EC 861792	Guinea	Traditional cultivar/ Landrace
7	CG 217	EC 861793	Guinea	Traditional cultivar/ Landrace
8	CG 218	EC 861794	Guinea	Traditional cultivar/ Landrace
9	CG 219	EC 861795	Guinea	Traditional cultivar/ Landrace
10	CG 220	EC 861796	Guinea	Traditional cultivar/ Landrace
11	CG 221	EC 861797	Guinea	Traditional cultivar/ Landrace
12	CG 223	EC 861799	Guinea	Traditional cultivar/ Landrace
13	CG 225	EC 861801	Guinea	Traditional cultivar/ Landrace
14	CG 226	EC 861802	Guinea	Traditional cultivar/ Landrace
15	CG 227	EC 861803	Guinea	Traditional cultivar/ Landrace
16	CG 228	EC 861804	Guinea	Traditional cultivar/ Landrace
17	CG 229	EC 861805	Guinea	Traditional cultivar/ Landrace
18	CG 230	EC 861807	Guinea	Traditional cultivar/ Landrace
19	CG 231	EC 861808	Guinea	Traditional cultivar/ Landrace
20	CG 232	EC 861809	Guinea	Traditional cultivar/ Landrace
21	CG 233	EC 861810	Guinea	Traditional cultivar/ Landrace
22	CG 234	EC 861811	Guinea	Traditional cultivar/ Landrace
23	CG 236	EC 861813	Guinea	Traditional cultivar/ Landrace
24	CG 237	EC 861814	Guinea	Traditional cultivar/ Landrace
25	CG 239	EC 861816	Guinea	Traditional cultivar/ Landrace
26	CG 240	EC 861817	Guinea	Traditional cultivar/ Landrace
27	CG 241	EC 861818	Guinea	Traditional cultivar/ Landrace
28	CG 242	EC 861819	Guinea	Traditional cultivar/ Landrace
29	CG 243	EC 861820	Guinea	Traditional cultivar/ Landrace
30	IR 64	-	Philippines	Variety
31	BPT 5204	-	India	Variety
32	Chittimutyalu	-	India	Traditional variety/ Landrace

glaberrima is known to possess ample genetic diversity for essential micronutrients like Fe and Zn apart from its well-known resistance to biotic and abiotic stress (Kennedy and Burlingame, 2003; Oko and Ugwu, 2011; Oko *et al.,* 2012; Amoatey *et al.,* 2015; Lakshmi *et al.,* 2019). With this view, the present investigation was aimed to identify superior accessions of *Oryza glaberrima* to develop biofortified varieties for combating micronutrient malnutrition.

Materials and Methods

Plant material

The experimental material comprised of 29 accessions of *Oryza glaberrima* obtained from IRRI along with three *O. sativa* checks (IR64, BPT5204 and Chittimutyalu) **(Table 1).** The accessions and checks were grown for three seasons at ICAR-Indian Institute of Rice Research, Hyderabad during *rabi* 2020-21, *kharif 2021 and rabi* 2021-22.

Grain Fe and Zn estimation

For the estimation of grain Fe and Zn in brown rice, the seed samples were dehusked and 5 g of each sample in two replications was analyzed using energy dispersive X-ray fluorescent spectrophotometer (ED-XRF) as per the standardized protocols (Rao *et al.,* 2014). The high Fe and Zn rich genotypes identified along with check varieties were re-evaluated in *kharif* 2021 and *rabi* 2021-22 for the estimation of grain Fe and Zn contents.

Results and Discussion

The popular high yielding rice varieties are usually deficient in grain Fe and Zn trace elements (Anuradha *et al.,* 2012; Pradhan *et al.,* 2020). Enhancing the Fe and Zn contents in rice grain through the utilization of elite promising lines with enormous genetic potential is highly recommended in biofortification programmes (Chandel *et al.,* 2010). Few land races and wild species of rice such as *O. nivara*, *O. glaberrima*, *O. rufipogon*, *O. latifolia*, *O. officinalis*, and *O. granulata* retain high amounts of Fe and Zn, 2-3 folds higher than the cultivated rice that make them to be good sources for biofortification (Garcia-Oliveira *et al.,* 2008, Sarla *et al.,* 2012, Roy and Sharma 2014, Swamy *et al.,* 2016; Mishra *et al.,* 2020). In the present investigation, grain Fe content showed a good amount of variation in the *O. glaberrima* accessions ranging from 6.40 ppm (CG 236) to 12.10 ppm (CG 227) with a mean of 8.57 ppm **(Table 2, Figure 1)**. Brown rice accessions were categorized as low with <12 ppm Fe content, moderate with 12.1-15 ppm Fe and >15.1 ppm as considered high as suggested by. Accordingly, all the accessions except CG 227 were designated as low Fe bearers including checks. Fifteen accessions recorded higher Fe content compared to the checks *viz*., IR64 (7.60 ppm), BPT5204 (8.60 ppm) and Chittimutyalu (8.40 ppm). Of these fifteen accessions, CG 227 (12.10 ppm) followed by CG 239 (11 ppm) recorded the highest Fe content.

Figure 1: Histogram depicting the iron and zinc contents in rice accessions

Likewise, grain Zn content showed a good amount of variation ranging from 7.30 ppm (CG 220) to 34.40 ppm (CG 239) in brown rice **(Table 2, Figure 1).** Genotypes were classified as low (<20 ppm), moderate (20.1-29 ppm) and high (>29 ppm) Zn containing accessions as suggested by Maganti *et al.,* (2019). Of the 29 accessions along with checks, 11 accessions were categorized as low, 19 as moderate, while three (CG 227, CG 239, CG 233) were high Zn containing accessions. Compared to the check varieties IR64 (16.70 ppm), BPT5204 (27.40 ppm) and Chittimutyalu (22.80 ppm), *O. glaberrima* accessions namely, CG 223 (28.1 ppm), CG 227 (33.9 ppm), CG 233 (29.5 ppm) and CG239 (34.40 ppm) recorded higher zinc content. Of these, two accessions namely, CG 239 (34.40 ppm) and CG 227 (33.9 ppm) recorded the highest Zn content, while CG 240 (15.50 ppm) recorded the lowest. Interestingly, both the accessions CG 227 and CG 239 revealed a good amount of grain Fe content addition to high Zn content. Altogether, the accessions exhibited two-fold variations in Fe and Zn concentrations suggesting the genetic potential to enhance these micronutrients **(Figure 2)**. Similar research for Fe and Zn biofortification was carried out by Tripathy (2020), who reported manifold variations in grain Fe and Zn content in 92 genotypes of brown rice local land races, improved breeding lines and released varieties. Correspondingly, studies on biofortification related to wild species and landraces of rice were taken up by Brar *et al.,* (2011); Anuradha *et al*., (2012); Maganti *et al.,* (2019) who reported the immense potential of landraces and wild rice accessions in the biofortification of popular varieties through conventional and non-transgenic methods.

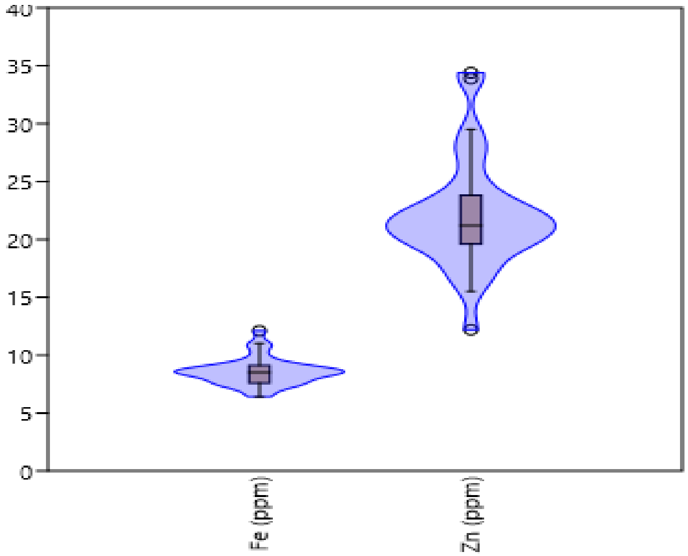

Figure 2: Box plot comparing the amount of variation in grain Fe and Zn contents

Table 2: Performance of *O. glaberrima* accessions and checks (*O. sativa*) for grain iron and zinc content during *rabi* 2020-21

S.No.	Accession	Fe (ppm)	Zn (ppm)
1	CG 208	7.20	23.80
2	CG 209	7.30	22.10
3	CG 211	8.50	20.70
4	CG 214	7.60	21.10
5	CG 215	8.90	20.50
6	CG 216	8.60	22.70
7	CG 217	7.40	21.50
8	CG 218	10.10	21.50
9	CG 219	9.50	18.60
10	CG 220	8.80	17.30
11	CG 221	8.20	21.20
12	CG 223	8.60	28.10
13	CG 225	10.80	19.60
14	CG 226	9.10	22.10
15	CG 227	12.10	33.90
16	CG 228	7.60	19.80
17	CG 229	8.20	23.00
18	CG 230	8.70	22.40
19	CG 231	8.00	21.10
20	CG 232	8.50	24.30
21	CG 233	8.60	29.50
22	CG 234	9.10	19.70
23	CG 236	6.40	25.50
24	CG 237	8.10	20.90
25	CG 239	11.00	34.40
26	CG 240	6.70	15.50
27	CG 241	7.80	17.70
28	CG 242	9.30	19.30
29	CG 243	8.90	19.70
30	IR 64	7.60	16.70
31	BPT 5204	8.60	27.40
32	Chittimutyalu	8.40	22.80

In this context, the identified accessions (CG 227 and CG 239) with high grain Zn and Fe content along with checks were again subjected to micronutrient analysis for two seasons. In the first season, CG 227 recorded an Fe content of 9.7 ppm and Zn content of 29.8 ppm, while CG 239 posed to be a dense micronutrient accession with 10.0 ppm and 34.1 ppm of Fe and Zn contents, respectively **(Table 3).** Both the accessions performed better than the check varieties *viz*., IR64 with 6.9 ppm Fe and 17.1 ppm Zn; BPT5204 with 8.9 ppm Fe, 25.6 ppm Zn and Chittimutyalu with an Fe content of 7 ppm and Zn content of 22.2 ppm. Likewise, the results were similar in second season with CG 227 (Fe-6.9 ppm and Zn-18.7 ppm) exhibiting comparatively lower Zn content and CG 239 (Fe-10.8 ppm and Zn-34.7 ppm) out-performing the check varieties by recording high grain Fe and Zn contents. The results for Fe and Zn estimation were quite consistent after all the seasons of evaluation for the two accessions. In this regard, the high zinc donor (CG 239) unearthed in the current study makes it a prospective donor for biofortification in marker-assisted breeding program.

Table 3: Mean performance of the identified promising accessions with checks evaluated in all the seasons

	***Rabi* 2020-21**		***Kharif* 2021**		***Rabi* 2021-22**	
Accession	**Fe (ppm)**	**Zn (ppm)**	**Fe (ppm)**	**Zn (ppm)**	**Fe (ppm)**	**Zn (ppm)**
CG 227	12.10	33.90	9.7	29.8	6.9	18.7
CG 239	11.00	34.40	10.0	34.1	10.8	34.7
IR-64	7.60	16.70	6.9	17.1	6.8	17.5
BPT 5204	8.60	27.40	8.9	25.6	8.3	25.3
Chittimutyalu	8.40	22.80	7.0	22.2	6.4	21.1

Conclusion

African rice is a rich source of natural allelic variations for grain micronutrient traits. In order to combat micronutrient deficiencies, biofortification of rice varieties with higher densities of trace elements is addressed to be effective. Our present investigation was useful in the identification of one *O. glaberrima* accession *viz.,* CG 239 with high Zn concentration that could be utilized as a potential donor in crop improvement programmes targeting biofortification.

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Genetic Parameters and Association Studies for Morphological, Physiological and Grain Quality Parameters in Rice (*Oryza sativa* L.)

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Abstract

The present investigation was undertaken to study the extent of variability and correlation coefficients of 19 morphological traits, yield components, physiological and physico-chemical grain quality traits in a set of 30 high yielding diverse rice genotypes. Phenotypic and genotypic coefficients of variations were high for net assimilation rate at 60-90 DAT followed by grain yield/plant and volume expansion ratio. Moderate to high heritability estimates were recorded for all parameters under study except for productive tillers/plant. The perusal of results on association and path coefficient analysis revealed that significant and positive correlation coupled with positive direct effects were manifested by test weight, RWC at 60 DAT and harvest index indicating simultaneous improvement of grain yield along with the improvement of these characters.

Keywords: Rice, physiological parameters, Net assimilation rate, relative water content

Introduction

Rice (*Oryza sativa* L.), as a staple food crop for more than half of the world's population is playing a pivotal role in providing human nutrition, energy supply and food security to Asian countries. India is one of the largest countries in terms of energy consumption from agriculture and rice comprises a major part of it (Kennedy *et al*., 2019). Assessment of genetic variability in any crop is essential for making the progress in crop improvement. Information on the nature of inheritance and association of grain yield with morphological, physiological and grain quality traits will help in formulation of effective breeding programme

Materials and Methods

The experimental material consisted of 30 rice genotypes which includes four released varieties, one pre released culture and 25 advanced breeding lines. Thirty days old seedlings of these genotypes were transplanted in Randomized Block Design (RBD) in 5 rows of 3 m length with three replications by adopting 20 x 15 cm spacing between and within the rows. All recommended package of practices were adopted to raise a healthy crop. At different stages of plant growth, data was recorded on various growth parameters and physiological traits *viz.,* root length and shoot length at harvesting, leaf area index at flowering (LAI), relative water content (RWC), net assimilation rate (NAR), harvest index (HI) and grain yield/plant. Five hills from each replication of all genotypes were uprooted from different rows and washed to remove the soil. Root length was measured from base of the stem to tip of the root using scale while the shoot length or culm length was measured in centimetres from ground base to the base of the panicle. Samples were taken at tillering, panicle initiation, flowering, grain filling and harvesting stages. For measurement of leaf area index, leaves were collected from five adjacent plants from each genotype in three replications. Leaf Area Meter (Model No. LP-80) was used for measurement of LAI and the average was expressed as leaf area plant^{-1} in cm^{2}. Relative water content of leaf samples collected from different treatments was determined by following the method described by Slatyer and Mc Liroy (1967), while net assimilation rate was calculated as per the formula suggested by Gregory (1926). The dry matter accumulation of root, stem, leaf, panicle and total plant was calculated by collecting the samples from five adjacent plants from each treatment in three replications. Five hills were uprooted from different rows and washed to remove soil and were dried first in shade and then the plants were separated into root, stem, leaves and reproductive parts and then dried in hot air oven at 80 °C till a constant weight is obtained. The weights of respected parts were recorded and expressed as g plant^{-1}. Samples were taken at tillering, panicle initiation, flowering, grain filling and at harvesting stages. The harvest index (HI) is the ratio of economic yield to total biological yield and is expressed in percentage. The harvest index of rice of different genotypes was calculated using the following formula.

$$\text{Harvest index (HI) in \%} = \frac{\text{Economic yield (g plant}^{-1}\text{)}}{\text{Total biological yield (g plant}^{-1}\text{)}} \text{X } 100$$

The mean data calculated for all characters under study was utilized for estimating genetic parameters were computed according to Burton and Devane (1953). Genotypic and phenotypic correlation coefficients were estimated using the method given by Johnson *et al.*, (1955). Path coefficient analysis was carried out by the procedure originally proposed by Wright (1921) which was subsequently elaborated by Dewey and Lu (1959) to estimate the direct effects as well as the indirect effects of the individual characters on yield.

Results and Discussion

The results of analysis of variance for 19 characters studied in rice genotypes indicated the existence of significant differences among all the genotypes studied. The general mean, maximum and minimum range, genotypic and phenotypic coefficient of variation, heritability and genetic advance as per cent of mean values obtained for various yield components, grain quality traits and physiological parameters were presented in **Table 1.** Wide range of variation was observed for plant height (94.8-134.8 cm) and water uptake (145.3-301.7 ml) among the nineteen characters studied. LAI at flowering stage varied from 4.3 to 7.2 with a mean value of 5.9 while RWC at 60 DAT ranged from 61.0 to 90.7 among the genotypes under study. Highest phenotypic and genotypic coefficients of variation was observed for net assimilation rate at 60-90 DAT (39.57 and 40.0 respectively) while days to 50% flowering manifested the least values (6.76 and 7.13 respectively). Knowledge of genetic parameters will help in understanding the nature of gene action for the characters under study. In the present investigation, the results of variability parameters revealed that low estimates of genotypic and phenotypic coefficients of variation were recorded for plant height (8.11, 9.40), days to 50 per cent flowering (6.76, 7.13), panicle length (6.19, 7.47), spikelet fertility percentage 6.4, 7.57), kernel length (7.95, 9.96), protein content (7.63, 7.77), root length and shoot length at harvesting and relative water content at 60 DAT indicating less variation among the genotypes for these characters under study. The estimates of heritability ranged from 22.36 (productive tillers/plant) to 99.67 (water uptake). Maximum genetic advance as per cent of mean was manifested by NAR at 60-90 DAT (80.51) followed by volume expansion ratio (48.72) while productive tillers/plant (6.99) manifested minimum value for genetic advance as per cent of mean.

Table 1: Variability, heritability and genetic advance as per cent of mean for morphological, physiological and grain quality traits in rice

S. No.	Character	Mean	Range		Coefficient of variation		Heritability (%)	Genetic advance as per cent of mean
			Minimum	Maximum	GCV (%)	PCV (%)		
1	Plant height (cm)	112.7	94.8	134.8	8.11	9.40	74.50	14.42
2	Days to 50 per cent flowering	109.5	98.0	118.3	6.76	7.13	89.79	13.20
3	Productive tillers per plant	6.9	5.9	9.20	7.18	8.18	22.36	6.99
4	Panicle length (cm)	25.6	21.5	29.1	6.19	7.47	68.68	10.56
5	Spikelet fertility (%)	86.2	68.1	94.9	6.54	7.57	74.61	11.63
6	Test weight (g)	17.3	12.7	23.2	11.15	12.45	45.95	15.57
7	Grain yield per plant (g)	30.8	21.9	58.6	22.32	24.41	83.60	42.04
8	Kernel length (mm)	5.9	5.2	7.5	7.95	9.96	63.64	13.06
9	Kernel breadth (mm)	1.9	1.4	2.8	17.70	18.69	55.80	27.24
10	L/ B ratio	3.1	2.2	4.2	14.54	15.85	44.29	19.93
11	Water uptake (ml)	210.9	145.3	301.7	17.71	17.74	99.67	36.42
12	Volume expansion ratio	4.9	3.4	7.6	23.73	23.82	99.31	48.72
13	Amylose content (%)	22.5	17.3	27.9	12.13	12.39	95.88	24.47
14	Protein content (%)	7.3	6.0	8.4	7.63	7.77	96.64	15.46
15	LAI at Flowering	5.9	4.3	7.2	14.04	15.58	81.26	26.07
16	RWC at 60 DAT	73.5	61.0	90.7	9.16	9.95	84.60	17.35
17	NAR (mg cm^{-2} d^{-1}) at 60-90 DAT	0.32	0.13	0.63	39.54	40.00	97.70	80.51
18	Root length (cm) at harvesting	30.4	26.2	35.2	8.25	9.70	72.25	14.44
19	Shoot length (cm) at harvesting	121.3	103.1	135.2	7.60	8.85	73.79	13.45

Low to moderate heritability and genetic advance as per cent of mean was noticed by number of productive tillers/ plant, test weight and L/B ratio indicating that these traits might not be improved by simple selection. Similar results were reported by Bandi *et al*., (2018), Dhavaleshvar *et al*., (2019), Sudeepthi *et al.,* (2020) and Rao *et al*., (2017). Moderate to high estimates of genotypic as well as the phenotypic coefficient of variation coupled with high heritability and high genetic advance as per cent of mean were recorded for grain yield per plant, water uptake, volume expansion ratio and amylose content among yield components and quality parameters. Singh *et al*., (2020),Veni *et al*., (2013) and Devi *et al*., (2020) also reported similar findings. Among physiological traits under study, root length and shoot length at harvest, leaf area index at flowering and net assimilation rate at 60-90 DAT manifested moderate to high heritability coupled with genetic advance as per cent of mean indicating the preponderance of additive gene action, thus, direct selection for these traits may be effective for improvement of these characters. Remaining all other traits under study recorded either low to moderate genotypic and phenotypic coefficient of variation or low to moderate heritability and genetic advance as per cent of mean suggesting that both additive and non-additive gene actions are involved in the inheritance of these traits. Similar results were reported by Srivastava *et al*., (2017), Akshitha *et al*., (2020) and Sudeepthi *et al*., (2020).

The perusal of association studies between yield components, physical grain quality and physiological traits revealed that significant and positive association of grain yield/plant with test weight, root length at harvesting, harvest index, relative water content at 60 DAT indicating simultaneous improvement of grain yield with improvement of these characters **(Tables 2 and 3).** Hence, priority should be given to these traits while making selection for improvement of grain yield. These results are in confirmation with the

Table 2: Phenotypic and genotypic correlation coefficients of grain yield with morphological and grain quality traits in rice

Character		PH	DFF	PTPP	PL	SFP	TW	KL	KB	L/B	WU	VER	AC	PC	GYPP
PH	r_p	1.0000	-0.1688	-0.1055	0.532**	0.0651	0.330**	0.1537	0.0195	0.0853	-0.1720	0.0682	-0.0271	-0.272**	0.0548
	r_g	1.0000	-0.1834	-0.377**	0.610**	0.1794	0.527**	0.1376	0.0335	0.0921	-0.2049	0.0882	-0.0098	-0.322**	0.0679
DFF	r_p		1.0000	-0.1218	-0.1983	0.220*	-0.2070	-0.1410	-0.1825	0.1167	0.1497	-0.1411	-0.234*	-0.1132	-0.1346
	r_g		1.0000	-0.1876	-0.289**	0.228*	-0.291**	-0.2049	-0.253*	0.1699	0.1567	-0.1592	-0.267*	-0.1351	-0.1404
PTPP	r_p			1.0000	-0.0554	-0.1336	-0.0420	0.0276	0.0042	-0.0355	-0.0032	0.1970	0.0145	-0.1611	0.1739
	r_g			1.0000	-0.253*	-0.1462	0.0337	0.347**	0.0168	0.0200	-0.0307	0.390**	0.0077	-0.308**	0.1915
PL	r_p				1.0000	-0.1559	0.346**	0.292**	0.265*	-0.0910	-0.1095	-0.0910	0.1468	-0.1727	-0.0661
	r_g				1.0000	-0.239*	0.632**	0.410**	0.373**	-0.1087	-0.1313	-0.1215	0.1623	-0.212*	-0.1447
SFP	r_p					1.0000	0.224*	-0.258*	0.0369	-0.0976	-0.473**	-0.407**	-0.237*	-0.281**	-0.0483
	r_g					1.0000	0.211*	-0.408**	0.1340	-0.308**	-0.544**	-0.471**	-0.281**	-0.335**	-0.0407
TW	r_p						1.0000	0.340**	0.441**	-0.247*	-0.358**	-0.295**	-0.270*	-0.1417	0.1758
	r_g						1.0000	0.398**	0.925**	-0.880**	-0.523**	-0.416**	-0.401**	-0.210*	0.296**
KL	r_p							1.0000	0.257*	0.1735	-0.1231	-0.0004	-0.1562	0.0881	-0.1308
	r_g							1.0000	0.366**	0.0976	-0.1542	0.0145	-0.1912	0.1105	-0.1613
KB	r_p								1.0000	-0.891**	-0.265*	-0.1751	-0.1157	-0.1154	0.1107
	r_g								1.0000	-0.881**	-0.373**	-0.239*	-0.1805	-0.1866	0.1693
L/B	r_p									1.0000	0.1686	0.1094	0.0325	0.1533	-0.1794
	r_g									1.0000	0.273**	0.1774	0.0794	0.262*	-0.261*
WU	r_p										1.0000	0.707**	0.1837	0.0186	0.0968
	r_g										1.0000	0.710**	0.1872	0.0185	0.1056
VER	r_p											1.0000	0.245*	-0.1885	0.1630
	r_g											1.0000	0.247*	-0.1950	0.1744
AC	r_p												1.0000	-0.2023	-0.1588
	r_g												1.0000	-0.222*	-0.1865
PC	r_p													1.0000	-0.334**
	r_g													1.0000	-0.362**

* Significant at 5% and ** Significant at % levels

PH= Plant height (cm),DFF= Days to 50 per cent flowering,PTPP= Productive tillers per plant,PL= Panicle length (cm),SFP= Spikelet fertility percentage, TW= Test weight (g),KL= Kernel length (mm),KB= Kernel breadth (mm),L/B= Length/Breadth ratio,WU= Water uptake (ml),VER= Volume expansion ratio,AC= Amylose content (%), PC=Protein content (%), GYPP= Grain yield per plant (g).

Table 3: Phenotypic and genotypic correlation coefficients of grain yield with physiological parameters in rice

Character		RLH	SLH	LAIF	RWC (60 DAT)	NAR (60-90 DAT)	HI	GYPP
RLH	r_p	1.0000	-0.351**	0.0312	0.1959	0.1869	0.1638	0.260*
	r_g	1.0000	-0.506**	-0.0188	0.236*	0.2041	0.1044	0.332**
SLH	r_p		1.0000	0.359**	-0.1168	-0.334**	-0.302**	-0.0776
	r_g		1.0000	0.492**	-0.1219	-0.393**	-0.466**	-0.1086
LAIF	r_p			1.0000	-0.2037	-0.402**	-0.271**	-0.0639
	r_g			1.0000	-0.230*	-0.441**	-0.483**	-0.0812
RWC (60 DAT)	r_p				1.0000	0.329**	0.0238	0.1703
	r_g				1.0000	0.366**	0.0785	0.218*
NAR (60-90 DAT)	r_p					1.0000	0.236*	-0.0273
	r_g					1.0000	0.327**	-0.0380
HI	r_p						1.0000	0.265*
	r_g						1.0000	0.214*

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

RLH=Root length at harvesting (cm), SLH=Shoot length at harvesting (cm),LAIF=Leaf area index at flowering; RWC= Relative Water Content (%), NAR=Net assimilation rate (mg cm^{-2} d^{-1}), HI=Harvest index (%), GYPP=Grain yield per plant (g)

findings of Haider *et al.*, (2012) and Hossain *et al.*, (2015), Gunasekaran *et al.*, (2017) and Manickavelu *et al.*, (2006), Among yield components, significant and positive correlations were noticed for plant height with panicle length (0.532**, 0.610**) and test weight (0.330**,0.527**) at both phenotypic and genotypic levels, days to 50 per cent flowering with spikelet fertility percentage (0.220*, 0.228*) suggesting that the genotypes with tall plant stature possessed longer panicles with bold grains and long duration genotypes used in the study had more fertile spikelets when compared with medium duration genotypes. When both yield components and grain quality parameters are considered, panicle length manifested significantly positive correlation with test weight (0.346**, 0.632**) kernel length (0.292**, 0.410**) and kernel breadth (0.265**, 0.373**) suggesting that the genotypes with longer panicles had long bold grain resulting in high test weight. These results were in agreement with previous findings of Tejaswini (2016), Premkumar *et al.*, (2016) and Gunasekaran *et al.,* (2017). Among quality parameters, L/B ratio exhibited significant and positive correlation with water uptake (0.273**) and protein content (0.262*) at genotypic level. Further, water uptake had positive relationship with volume expansion ratio (0.707**, 0.710**) and amylose content (0.184, 0.187) indicating that the genotypes which absorb more water during cooking produced high volume of cooked rice and possessed high amylose content. These results were in accordance with the findings of Premkumar *et al.,* (2016), Gunasekaran *et al.,* (2017) and Singh *et al.,* (2020).

Among physiological parameters, significant and positive association of root length at harvesting was observed with relative water content at 60 DAT (0.236*) at genotypic level and grain yield/plant (0.260*, 0.332**) suggesting that the genotypes with deeper root system will efficiently maintain the water balance thus, high grain yield is anticipated. Similar results were reported by Mishra *et al.,* (2019). Shoot length at harvesting also manifested significantly positive relationship with leaf area index at flowering (0.359**, 0.492**) and negative and significant correlation with NAR at 60-90 DAT (-0.334**, -0.393**), harvest index (-0.302**, -0.466**) suggesting that the genotypes with tall plant stature possess more leaf area index resulting in the production of more photosynthates, more leaf and total dry matter at harvesting. Further strong associations were observed between net assimilation rate at 60-90 DAT with harvest index (0.236*, 0.327**) indicating the scope for simultaneous improvement of these characters. Significant and positive relationship was manifested between relative water content at 60 DAT and harvest index (0.236*,0.327**) & harvest index also exhibited similar association with grain yield/plant (0.265*, 0.214*) suggesting simultaneous improvement of these traits. Manickavelu *et al.,* (2006), Rahman *et al.,* (2012) and Haider *et al.,* (2012) also reported similar findings in their studies.

In contrast, significant and negative association was observed between plant height and protein content (-0.272**,-0.322**), plant height and productive tillers per plant (-0.377**) indicating that the genotypes with tall plant stature used in the study possessed less productive tillers and low protein content. These results are in agreement with the findings of Devi *et al.*, (2019), Parimala *et al.*, (2020) Gunasekaran *et al.*, (2017), Singh *et al.,* (2020) for test weight and Sameera *et al.*, (2016) for kernel breadth. Significantly negative relationship was observed between test weight with L/B ratio (-0.247*,-0.880**), water uptake (-0.358**,-0.523**), volume expansion ratio (-0.295**,-0.416**) and amylose content (-0.270*,-0.401**) both at phenotypic and genotypic levels suggesting that the genotypes with less test weight had slender grain, high water absorption capacity thus, producing more cooked rice. Similar results were reported by Gunasekaran *et al.,* (2017) for grain yield per plant at genotypic level; Mohanty *et al.*, (2012) for kernel length (KL), kernel breadth (KB)and L/B ratio at phenotypic level and Singh *et al.,* (2020) for KB and L/B ratio at genotypic level. Likewise, genotypes with less KB manifested more L/B ratio, high water uptake and VER which is evident from significant and negative association of kernel breadth with L/B ratio (-0.891**, -0.881**), water uptake (-0.265*, -0.373**) at both phenotypic and genotypic levels and VER (-0.239*) at genotypic level. L/B ratio (-0.261*) and protein content (-0.334**,-0.362**) exhibited significant and negative relationship with grain yield/plant revealing that the genotypes with low grain yield had slender grain type and recorded high protein content. These results were in agreement with previous findings of Tejaswini (2016) for grain yield per plant at phenotypic level and Premkumar *et al.,* (2016) and Gunasekaran *et al.,* (2017) for grain yield per plant at genotypic level.

The direct effects as well as indirect effects of various morphological, yield components, physiological and quality traits were presented in **Tables 4 and 5.** Among yield component traits, test weight manifested positive correlation coupled with positive direct effect (0.1980, 0.1356) both at phenotypic and genotypic levels. These results are in agreement with Lakshmi *et al.,* (2020) at phenotypic level and Singh *et al.*, (2020) at genotypic level. In contrast, amylose content exhibited significantly negative correlation (-0.261*) along with negative direct effect (-0.0116,-2.1068). Similar results were reported by Premkumar *et al.*, (2016) at genotypic level. Among physiological traits under study, positive correlations coupled with positive direct effects were observed with RWC at 60 DAT (0.2300,0.4292) & harvest index (0.2818, 0.2039). At phenotypic level, similar results were reported by Manickavelu *et al.*, (2006) and Katiyar *et al.*, (2019) at phenotypic level and Roy *et al.*, (2015) at genotypic level. Hence, the traits *viz.,* test weight, relative water content at 60 DAT and harvest index may be given importance while making selection for improvement of grain yield in rice.

Table 4: Direct and indirect effects of morphological and grain quality traits on grain yield in rice

Character		PH	DFF	PTPP	PL	SFP	TW	KL	KB	L/B	WU	VER	AC	PC
PH	P	**0.0179**	0.0030	0.0019	-0.0095	-0.0012	-0.0059	-0.0027	-0.0003	-0.0015	0.0031	-0.0012	0.0005	0.0049
	G	**0.2921**	-0.0536	-0.1100	0.1781	0.0524	0.1539	0.0402	0.0098	0.0269	-0.0598	0.0258	-0.0028	-0.0941
DFF	P	0.0445	**-0.2637**	0.0321	0.0523	-0.0581	0.0546	0.0372	0.0481	-0.0308	-0.0395	0.0372	0.0617	0.0298
	G	0.1525	**-0.8314**	0.1560	0.2404	-0.1894	0.2422	0.1704	0.2103	-0.1412	-0.1303	0.1324	0.2217	0.1123
PTPP	P	-0.0038	-0.0043	**0.0356**	-0.0020	-0.0048	-0.0015	0.0010	0.0001	-0.0013	-0.0001	0.0070	0.0005	-0.0057
	G	0.2940	0.1465	**0.7806**	0.1974	0.1141	-0.0263	-0.2706	-0.0131	-0.0156	0.0240	-0.3041	-0.0060	0.2405
PL	P	-0.0967	0.0361	0.0101	**-0.1818**	0.0283	-0.0629	-0.0531	-0.0482	0.0165	0.0199	0.0166	-0.0267	0.0314
	G	-0.6779	0.3216	0.2812	**-1.1119**	0.2654	-0.7030	-0.4554	-0.4152	0.1208	0.1460	0.1351	-0.1805	0.2362
SFP	P	-0.0213	-0.0722	0.0438	0.0511	**-0.3279**	-0.0736	0.0845	-0.0121	0.0320	0.1552	0.1335	0.0778	0.0920
	G	-0.2956	-0.3754	0.2409	0.3934	**-1.6481**	-0.3471	0.6724	-0.2208	0.5083	0.8960	0.7766	0.4635	0.5523
TW	P	0.0652	-0.0410	-0.0083	0.0685	0.0444	**0.1980**	0.0673	0.0874	-0.0489	-0.0710	-0.0583	-0.0534	-0.0281
	G	-0.0715	0.0395	-0.0046	-0.0858	-0.0286	**0.1356**	-0.0540	-0.1397	0.1194	0.0709	0.0564	0.0544	0.0285
KL	P	-0.0403	0.0370	-0.0072	-0.0766	0.0677	-0.0892	**0.2625**	-0.0674	-0.0455	0.0323	0.0001	0.0410	-0.0231
	G	0.0963	-0.1435	0.2427	0.2868	-0.2857	0.2787	**0.7002**	0.2565	0.0683	-0.1080	0.0102	-0.1339	0.0774
KB	P	0.0002	-0.0021	0.0000	0.0031	0.0004	0.0051	0.0030	**0.0115**	-0.0103	-0.0031	-0.0020	-0.0013	-0.0013
	G	-0.0714	0.5388	-0.0358	-0.7952	-0.2853	-1.8520	-0.7802	**2.1297**	1.8770	0.7952	0.5094	0.3843	0.3975
L/B	P	-0.0010	-0.0013	0.0004	0.0011	0.0011	0.0029	-0.0020	0.0103	**-0.0116**	-0.0020	-0.0013	-0.0004	-0.0018
	G	-0.1941	-0.3579	-0.0422	0.2289	0.6497	1.8541	-0.2055	1.8568	**-2.1068**	-0.5742	-0.3738	-0.1672	-0.5525
WU	P	-0.0217	0.0189	-0.0004	-0.0138	-0.0596	-0.0451	-0.0155	-0.0334	0.0212	**0.1260**	0.0890	0.0231	0.0023
	G	0.0453	-0.0346	0.0068	0.0290	0.1201	0.1156	0.0341	0.0825	-0.0602	**0.2210**	-0.1569	-0.0414	-0.0041
VER	P	-0.0044	0.0092	-0.0128	0.0059	0.0265	0.0192	0.0000	0.0114	-0.0071	-0.0461	**-0.0652**	-0.0159	0.0123
	G	-0.0644	0.1162	-0.2842	0.0887	0.3438	0.3031	-0.0106	0.1745	-0.1294	-0.5179	**-0.7295**	-0.1799	0.1423
AC	P	0.0101	0.0869	-0.0054	-0.0545	0.0881	0.1002	0.0580	0.0430	-0.0121	-0.0682	-0.0908	**-0.3714**	0.0752
	G	0.0096	0.2614	-0.0076	-0.1591	0.2757	0.3932	0.1874	0.1769	-0.0778	-0.1836	-0.2418	**-0.9804**	0.2180
PC	P	0.1419	0.0591	0.0841	0.0902	0.1466	0.0740	-0.0460	0.0603	-0.0800	-0.0097	0.0984	0.1057	**-0.5222**
	G	0.5532	0.2319	0.5289	0.3646	0.5751	0.3608	-0.1897	0.3203	-0.4501	-0.0318	0.3348	0.3817	**-1.7164**
GYPP	P	0.0548	-0.1346	0.1739	-0.0661	-0.0483	0.1758	-0.1308	0.1107	-0.1794	0.0968	0.1630	-0.1588	-0.334**
	G	0.0679	-0.1404	0.1915	-0.1447	-0.0407	0.296**	-0.1613	0.1693	-0.261*	0.1056	0.1744	-0.1865	-0.362**

*Residual Effect = 0.279 (P), 0.231 (G) ; * Significant at 5% level and ** Significant at 1% level; Diagonal bold values indicate direct effects*

PH= Plant height (cm), DFF= Days to 50 per cent flowering, PTPP= Productive tillers per plant, PL= Panicle length (cm), SFP= Spikelet fertility percentage, TW= Test weight (g), KL= Kernel length (mm), KB= Kernel breadth (mm), L/B= Length/Breadth ratio, WU= Water uptake (ml), VER= Volume expansion ratio, AC= Amylose content (%), PC=Protein content (%), GYPP= Grain yield per plant (g).

Table 5: Direct and indirect effects of physiological traits on grain yield in rice

Character		RLH	SLH	LAIF	RWC (60 DAT)	NAR (60-90 DAT)	HI
RLH	P	**0.0186**	-0.0065	0.0006	0.0036	0.0035	0.0030
	G	**0.0495**	0.0251	0.0009	-0.0117	-0.0101	-0.0052
SLH	P	0.0158	**-0.0450**	-0.0161	0.0053	0.0150	0.0136
	G	0.0927	**-0.1832**	-0.0901	0.0223	0.0720	0.0854
LAIF	P	-0.0054	-0.0624	**-0.1740**	0.0354	0.0700	0.0472
	G	0.0034	-0.0896	**-0.1823**	0.0419	0.0803	0.0880
RWC (60 DAT)	P	0.0451	-0.0269	-0.0468	**0.2300**	0.0756	0.0055
	G	0.1014	-0.0523	-0.0987	**0.4292**	0.1570	0.0337
NAR (60-90 DAT)	P	-0.0346	0.0618	0.0744	-0.0608	**-0.1851**	-0.0437
	G	-0.0527	0.1016	0.1139	-0.0945	**-0.2584**	-0.0844
HI	P	0.0462	-0.0850	-0.0764	0.0067	0.0666	**0.2818**
	G	0.0213	-0.0950	-0.0985	0.0160	0.0666	**0.2039**
GYPP	P	0.260*	-0.0776	-0.0639	0.1703	-0.0273	0.265*
	G	0.332**	-0.1086	-0.0812	0.218*	-0.0380	0.214*

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

Diagonal bold values indicate direct effects

RLH=Root length at harvesting (cm), SLH=Shoot length at harvesting (cm),LAIF=Leaf area index at flowering; RWC= Relative Water Content (%), NAR=Net assimilation rate (mg cm^{-2} d^{-1}), HI=Harvest index (%), GYPP=Grain yield per plant (g)

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Screening and Variability Studies in Rice Genotypes for Drought Tolerance and Yield

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Abstract

In the present investigation, laboratory and field screening of nine rice genotypes, namely, TM 12061, TM 12077, TM 12012, TM 14035, TM 16017, Senthuram, Vandhana, TKM 12 and Anna (R) 4 was taken up to assess their drought tolerance potential. For laboratory screening, the effect of different levels of PEG concentration namely*, -0.2, -0.4, -0.6* and *-1.0* MPa on germination, shoot length and root length were studied. There was a considerable decrease in the germination potential among all the genotypes with increase in PEG concentration. The culture, TM 12077 showed higher level of tolerance to PEG induced drought stress showing 30.8% germination with 3.2 cm and 8.85 cm shoot and root length, respectively at higher level of PEG concentration (1.0 MPa). In field screening under managed stress condition, the cultures, TM 12077 and TM 12012 showed higher accumulation of proline (4.15 mg/g). Chlorophyll stability index was more than 80% in the genotypes, TM 12012, TM 12077, and TM 12061. The culture TM 14035, the varieties Anna (R) 4 and Vandhana matured early in 115 days. Plant height was found to be moderate in Vandhana (103.3 cm), TM 12077(105.4 cm), TM 12061 (108.2 cm) and TM 12012 (110.5 cm) under managed stress condition. The number of tillers per plant, number of panicles/sqm and yield/hectare were maximum in the culture, TM 12077 under managed stress condition. Based on laboratory and field screening, the cultures TM 12077, TM 12012, and TM 12061 were found promising for water stress environment and can be utilized as donors in the breeding programs for drought tolerance in rice. High heritability coupled with moderate to high GA as per cent of mean was recorded for plant height, tillers per plant, chlorophyll Stability index and total chlorophyll content indicating the presence of additive gene effects and scope for their improvement through direct selection.

Keywords: Rice, drought tolerance, screening, variability

Introduction

Rice is the most important and widely cultivated food crop. Drought is one of the most challenging abiotic stresses that severely impairs rice production. Climate change increases the frequency and severity of drought (Wassmann *et al*., 2009). Global warming and unpredictable rainfall patterns in recent years have led to excessive drought spells causing severe yield losses. Drought stress can occur at any growth stage and can cause a significant yield reduction. Most of the improved rice varieties grown in drought prone areas were originally bred for irrigated conditions and were never selected for drought tolerance (Kumar *et al*., 2008). Development of drought tolerant rice varieties is an important strategy to minimize rice yield losses in drought prone areas. The complex nature and polygenic control of drought tolerant traits, however, is a major bottleneck for the current research in drought tolerance and maintenance of yield in rice under drought conditions is a multifaceted phenomenon controlled by the cumulative effects of several traits.

The ability of rice genotype to adapt against drought stress during seedling stage is important when early-season drought occurs. The germination and seedling growth stage are the most sensitive stages to drought stress, implying the importance of the plant's tolerance to drought in the early growth stages (Wolny *et al*., 2018, Reddy *et al*., 2021). Drought affects growth and development, pigment content, photosynthetic activities, membrane integrity and osmotic adjustment apart from yield loss. Understanding the morphological, biochemical, and physiological mechanisms involved in rice under drought will play a very important role in breeding drought-tolerant cultivars. Hence, the present investigation aims to assess the drought tolerance potential of different rice genotypes by studying the impact of water stress on germination and early growth in addition to the effect on different morphological, biochemical, physiological and yield traits along with yield under induced water stress conditions. Since, a critical analysis of the genetic variability is a prerequisite for any crop improvement programme and for adopting of appropriate selection techniques, the present study also aims to assess the extent of genetic variability available for yield and drought tolerant traits in the experimental material.

Materials and Methods

Laboratory screening

Laboratory studies for assessing the drought tolerance in nine rice genotypes *viz*., TM 12061, TM 12077, TM 12012, TM 14035, TM 16017, Senthuram, Vandhana, TKM 12 and Anna (R) 4 was carried out at Agricultural College and Research Institute, Eachangkottai during 2020 using different concentrations of PEG for creating water stress. Seed materials were collected from Rice Research Station, Tirur and Tiruvallur, Tamil Nadu. Seeds of each genotype were surface sterilized with 70% ethanol for five minutes and washed thoroughly with sterilized distilled water. Seed germination test was performed by evenly distributing the seeds on a 10 cm diameter sterilized Petri dish with layers of germination paper. Distilled water was used as a control (0 MPa) and osmotic potentials of -0.2, -0.4, -0.6 and -1.0 MPa were created by adding PEG 6000 at 4, 8, 10 and 14 g per 100 ml distilled water. Each Petri dish was moistened with 10 ml distilled water (control) and different concentrations of PEG. Observations on germination, shoot and root length of the seedlings under different levels of PEG induced water stress were recorded on seventh day. The experiment was laid out in Complete Randomized Block Design (CRBD) with four levels of drought stress and four replications.

Field screening

Field experiment was conducted at Rice Research Station, Tirur during *kharif*, 2020. Nine rice genotypes TM 12061, TM 12077, TM 12012, TM 14035, TM 16017, Senthuram, Vandhana, TKM 12 and Anna (R) 4 were raised in the nursery and the twenty-five days old seedlings were transplanted in the main field in RBD with three replications adopting the spacing of 20 x 15 cm. Irrigation was stopped and water stress was imposed for 15 days from 60 DAS. Effect of water stress on physiological parameters such as proline content, chlorophyll stability index and total chlorophyll content were studied at the end of stress period *i.e.,* 75 DAS. Observations on days to maturity, plant height, number of tillers per plant, number of panicles per square meter, root length (cm), root volume (cc) and grain yield (recorded on plot basis and expressed as kg/ha) were also recorded at the time of harvest and the mean was used for analysis.

Variability studies were carried out for nine traits, namely, days to maturity, plant height, number of tillers per plant, number of panicles per square meter, root length (cm), chlorophyll Stability Index, Proline content, Total chlorophyll content and plot yield. The estimates on phenotypic variability, genotypic variability, phenotypic coefficient of variation, genotypic coefficient of variation, heritability, genetic advance as per cent of mean were estimated for yield and drought parameters as per the procedures described by Johnson *et al*., (1955).

Results and Discussion

Effect of different levels of PEG concentration on germination, shoot length and root length is presented in **Table 1.** In the present study, germination percentage varied from 97% to 100% in control and there was a considerable decrease in the germination potential among all the genotypes with increase in PEG concentration from 0.2 MPa to 1.0 MPa. Elevated drought stress was noticed to slow down water uptake by seeds, thereby inhibiting their germination, shoot and root elongation. However, differential tolerance was observed among the rice genotypes studied. The culture, TM 12077 showed higher level of tolerance to PEG-induced drought stress showing 30.8% germination with 3.2 cm and 8.85 cm shoot and root length, respectively at higher level of PEG concentration (1.0 MPa), when compared to Anna (R) 4, which was found to be moderate in drought tolerance with 14.8% germination at the same level of PEG concentration. TKM 12 showed poor ability to cope up with tolerance reaction to drought even at 0.6 MPa and showed considerable reduction in germination (21.4%) and shoot (2.3 cm) and root length (5.0 cm). The decrease in germination percentage and seedling growth as a result of the decrease in osmotic potentials has been reported by several authors (Pirdashti *et al*., 2003, Vibhuti *et al*., 2015, Ishlam *et al.,* 2018).

Understanding of biochemical and physiological mechanism which enables plants to adapt to water stress could help in the selection of tolerant genotypes (Zaharieva *et al.,* 2001). Under water-deficit conditions, plants have developed osmotic adjustment, one of the fundamental mechanisms of drought adaptation. Osmotic adjustment helps in the maintenance of turgor and cell volume during drought and has been emphasized in the context of drought tolerance of crops. Accumulation of osmo-protectants, such as proline, glycine, betaine and

Table 1: Germination Percentage, Shoot length (cm), Root length (cm) of different rice genotypes under varied PEG levels

Genotypes	Germination Percentage (%)					Shoot length (cm)					Root length (cm)				
	Control	0.2 MPa	0.4 MPa	0.6 MPa	1.0 MPa	Control	0.2 MPa	0.4 MPa	0.6 MPa	1.0 MPa	Control	0.2 MPa	0.4 MPa	0.6 MPa	1.0 MPa
TM 12061	100.0	88.4	84.9	55.4	28.4	12.8	10.0	8.0	6.7	2.5	20.45	17.45	15.73	11.00	8.23
TM 12077	100.0	91.8	85.4	60.7	30.8	14.9	10.4	8.7	7.2	3.2	19.6	17.25	15.50	11.20	8.85
TM 12012	100.0	90.5	84.7	48.0	24.1	14.1	10.4	8.1	6.8	2.3	23.70	18.20	16.70	8.85	7.60
TM 14035	100.0	89.4	83.9	41.4	26.7	14.0	10.6	8.2	7.0	2.8	16.80	13.40	11.90	9.00	7.25
TM 16017	100.0	89.7	81.4	43.6	27.0	13.4	9.0	8.2	6.5	2.5	22.50	17.50	15.45	8.15	7.10
TKM (R)12	98.0	80.5	71.4	21.4	0.0	11.4	8.5	5.5	2.3	0.0	12.40	10.95	9.85	5.00	0.00
Anna (R)4	97.0	84.6	79.4	38.9	14.8	11.2	10.1	6.7	4.2	1.9	19.75	17.80	16.25	11.80	8.25
Senthuram	98.0	88.7	79.4	45.8	18.4	12.7	10.4	6.6	4.7	1.0	12.70	10.40	9.75	7.95	7.50
Vandhana	98.0	89.1	79.0	37.4	15.7	12.0	10.0	6.1	5.6	0.6	18.75	16.80	10.25	7.80	7.25
SEd	0.44	0.42	0.39	0.36	0.34	0.20	0.18	0.16	0.14	0.13	0.18	0.185	0.12	0.114	0.11
CD (0.05)	0.92	0.88	0.85	0.82	0.81	0.40	0.37	0.35	0.30	0.28	0.37	0.34	0.26	0.22	0.20

soluble sugar, provides osmotic adjustments for the plants. Proline content can act as a biochemical marker under drought screening of plants (Pandey and Shukla, 2015), since higher accumulation of proline is usually associated with drought tolerance. Among the nine genotypes that were subjected to managed water stress under field condition and analyzed for proline content (mg/g), the rice cultures, TM 12077 and TM 12012 showed higher accumulation of proline (4.15 mg/g) followed by TM 12061 (4.13 mg/g) **(Figure 1).**

Figure 1: Effect of water stress on Proline content of different rice genotypes

Chlorophyll stability index (CSI) is an indication of the stress tolerance capacity of plants. Plants with high CSI tend to stay green even under stress which is very important for photosynthetic activity. Chlorophyll stability index was recorded to be higher in the genotype, TM 12012 (80.76%) followed by TM 12077 (80.34%) and TM 12061 (80.23%) **(Figure 2).** A higher CSI helps the plants to withstand stress through better availability of chlorophyll which leads to increased photosynthetic activity, more dry matter production, and higher productivity (Madan Mohan *et. al.,* 2000). CSI is an indicative of the maintenance of photosynthetic pigments under drought and is a more dependent parameter for drought tolerance than chlorophyll content. High total chlorophyll content of 1.50 g was recorded in TM 12061, TM 12077 and TM 16017 and it was minimum (1.21 mg/g) in the variety, TKM (R) 12. Madan Mohan *et al*., (2000) reported that drought tolerant plants possess high value of total chlorophyll, while Gowri (2005) observed decrease in chlorophyll content under water scarcity situation than irrigated environment.

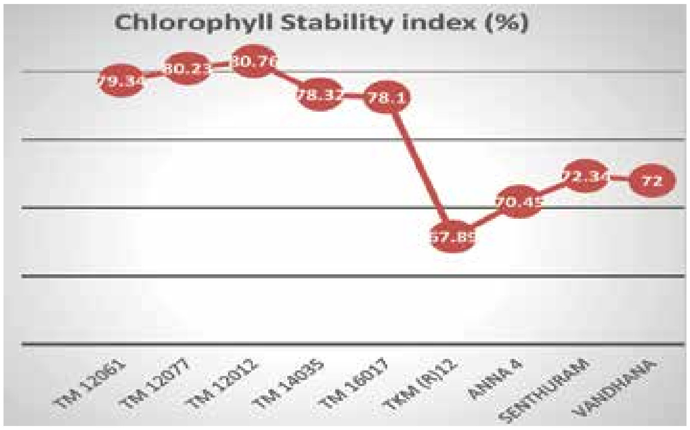

Figure 2: Effect of water stress on Chlorophyll stability index of different rice genotypes

Rice genotypes reacted to drought stress with reductions in height, leaf area and biomass production, tiller abortion, changes in rooting patterns, and a delay in development. The effect on the plant depended on the severity of the stress. Under managed stress conditions, the culture TM 14035 and the varieties, Anna (R) 4 and Vandhana matured in 115 days. Plant height was found to be moderate in Vandhana (103.3cm), TM 12077(105.4 cm), TM 12061 (108.2 cm) and TM 12012 (110.5 cm) under stress condition. The number of tillers and number of panicles/sqm was maximum in TM 12077 (14 and 302 respectively) whereas the variety Anna(R) 4 recorded minimum number of tillers (8.00) and number of panicles/sqm (226). Under managed stress condition, maximum yield was recorded by the culture TM 12077 (4692 kg/ha) followed by TM 12061 (4563 kg/ha).

Root characteristics of the plants are the vital attributes for enhancing production under drought stress. Rice

Table 2: Effect of water stress on physiological parameters of different rice genotypes under managed stress condition

Genotypes	Proline Content	Chlorophyll Stability Index	Total Chlorophyll content
TM 12061	4.13	80.23	1.50
TM 12077	4.15	80.34	1.50
TM 12012	4.15	80.76	1.48
TM 14035	4.10	78.32	1.48
TM 16017	4.05	78.10	1.50
TKM (R)12	3.52	67.89	1.21
Anna (R) 4	3.78	70.45	1.29
Senthuram	4.02	72.34	1.38
Vandhana	4.00	72.00	1.37
Mean	3.97	75.6	1.41
SEd	0.07	1.02	0.13
CD (0.05)	0.14	2.09	0.37

production under water stress can be predicted by considering root mass (dry) and length into account (Comas *et al*., 2013). Generally, rice varieties with profound and prolific root system show better adaptability to drought (Mishra *et al*., 2019, Kim *et al*., 2020). Plants with longer roots have access to extract water from deeper layers of soil which is important especially when the water recedes to lower strata due to drought, while higher root volume directly relates to more root hairs and better availability of water to plants when the water level is reduced below field capacity. Hence, root characters are primary traits of drought tolerance and show the inherent potential of genotypes to withstand drought. Varieties bred for dry / semi-dry conditions should therefore, possess better root architecture than lowland varieties. Root length (cm) was found to be higher in TM 12077 (17.8 cm) followed by TM 12061 (17.5 cm) and Vandana (16.9 cm). Root volume was maximum in TM 12061 (60 cc) followed by TM 12077 (59 cc), among the genotypes studied under managed stress condition **(Table 3).** Drought resistant entries had recorded higher root volume and root length than the susceptible genotypes. This is also in accordance with the findings of Yogameenakshi *et. al.,* (2003) and Sheeba *et. al.,* (2010).

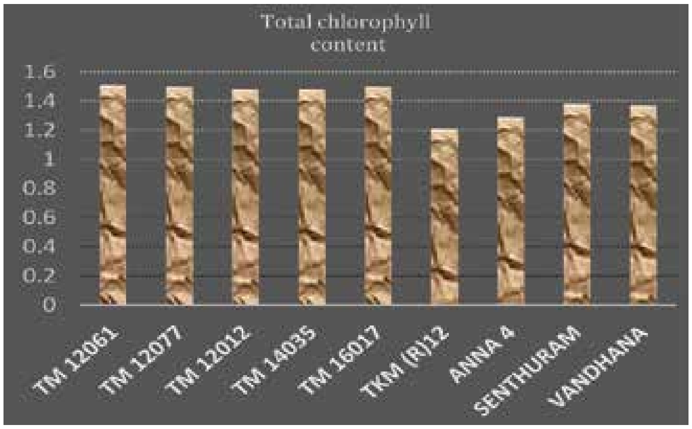

Figure 3: Effect of water stress on total chlorophyll content of different rice genotypes

Genetic Variability Studies

The available variability in a population can be partitioned into genetic parameters such as coefficients of variation, heritability, and genetic advance to serve as basis for selection of desirable genotypes. The genotypic coefficient of variation estimates the heritable variability, while phenotypic component measures the role of environment on genotype. PCV and GCV estimates are classified as low (0-10%), moderate (10%-20%) and high (>20%) according to Johnson *et al.,* (1955). The magnitude of difference between phenotypic coefficient of variance (PCV) and genotypic coefficient of variance (GCV) was less for the traits, namely, days to maturity, plant height, chlorophyll Stability Index, proline content and total chlorophyll content indicating little influence of environment. Relatively more difference between PCV and GCV was observed for number of panicles per square meter, root length and plot yield indicating the sensitive nature of these traits to environmental fluctuations. Similar conclusions were drawn by Prajapati *et al.,* (2011) and Mohan *et al.,* (2015). None of the traits recorded higher magnitude of PCV and GCV, whereas PCV was moderate for the traits, namely, plant height (15.40), tillers per plant (14.92), number of panicles / sqm (11.39%), root length (14.20%) and plot yield (13.85%). GCV was also moderate for the traits, namely, plant height (15.11%) and tillers per plant (11.69%) indicating the presence of variability in these traits for the genotypes and hence, the possibility of improving these characters through selection. Moderate PCV and low GCV was recorded by the traits, namely, number of panicles per square meter, root length and plot yield **(Table 4)** which indicated excessive effect of environment in their expression.

Genotypic coefficient of variation measures the extent of genetic variability present for a trait, but it is not sufficient for determination of the amount of heritable variability. In addition, estimation of heritability and genetic Advance as per cent of mean is also needed to assess the heritable portion of total variation and extent of genetic gain expected for effective selection. According to Johnson *et al.,* (1955), broad sense heritability was classified as low

Table 3: Effect of water stress on biometrical / agronomical parameters of different rice genotypes under managed stress condition

Genotypes	Days to Maturity	Plant height (cm)	No. of tillers / Plant	No. of panicles/sqm	Root Length (cm)	Root volume (cc)	Yield (kg/ha)
TM 12061	119	108.2	14.0	296	17.5	60	4563
TM 12077	117	105.4	14.0	302	17.8	59	4692
TM 12012	122	110.5	12.0	270	15.4	53	4277
TM 14035	115	91.0	10.0	256	14.8	49	4402
TM 16017	117	95.4	10.0	262	14.2	51	4025
TKM (R)12	122	115.0	10.0	242	16.2	39	3744
Anna (R) 4	115	96.0	8.00	226	15.5	42	3900
Senthuram	123	93.6	11.0	232	14.0	36	3060
Vandhana	115	103.3	10.0	250	16.9	55	4157
SE	11.20	11.46	11.11	8.48	0.66	1.58	49.33
C.D. (5%)	31.05	31.77	30.81	23.50	1.83	4.39	136.74
CV (%)	10.73	11.95	22.86	6.66	7.25	5.56	2.06

Table 4: Components of genetic parameters for yield and yield attributing traits in rice

Characters	PCV	GCV	Heritability in broad sense (%)	Genetic advance as per cent of mean
Days to maturity	4.48	4.33	93.24	8.61
Plant Height	15.40	15.11	96.20	30.53
Tillers per plant	14.92	11.69	61.69	18.86
No. of Panicles / sqm	11.39	8.72	58.51	13.74
Root Length	14.20	8.33	34.47	10.08
Chlorophyll Stability Index	6.89	6.71	94.90	13.46
Proline content	4.31	4.06	89.07	7.89
Total Chlorophyll content	6.35	6.21	95.71	12.52
Plot Yield	13.85	9.28	44.93	12.81

(<30%), medium (30% to 60%) and high (>60%). In the present study, high heritability was recorded for the traits, namely, days to maturity (93.2%), plant height (96.2%), tillers per plant (61.7%), chlorophyll Stability index (94.9%), proline content (89.07%) and total chlorophyll content (95.7%). The presence of high heritability indicates that these characters are least influenced by the environment. This serves as an index of transmissibility of traits from parents to their offspring. However, character exhibiting high heritability may not necessarily give high genetic advance (Gandhi *et al.*, 1964) because of involvement of non-additive gene action. Thus, selection for the characters should be based on high heritability as well as high genetic advance (Johnson *et al.*, 1955). The range of genetic advance as per cent of mean was classified as low (0-10%), moderate (10-20%) and high (>20%) by Johnson *et al.,* (1955). The genetic advance as per cent of mean was high for plant height (30.5) and moderate for tillers per plant (18.9), number of panicles per sqm (13.7), root length (10.1), chlorophyll stability index (13.5), total chlorophyll content (12.5) and plot yield (12.8). Presence of high/ moderate heritability along with genetic advance as per cent of mean for the traits plant height, tillers per plant, number of panicles per sqm, root length, chlorophyll stability index, total chlorophyll content and plot yield indicated that these characters were attributable to additive gene effects which are fixable revealing that improvement in these characters would be possible through direct selection.

Based on laboratory and field screening, the cultures, TM 12077, TM 12012 and TM 12061 were found promising for water stress environment and can be tested for yield performance before variety release and /or utilized as donors in the breeding programs for drought tolerance in rice. The characters, plant height, tillers per plant, chlorophyll Stability index and total chlorophyll content registered high heritability coupled with moderate to high GA as per cent of mean indicating the role of additive gene action in governing these traits and their potential for improvement through direct selection.

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RESEARCH ARTICLE **https://doi.org/10.58297/WQWI6097**

Estimates of Genetic Variability, Heritability and Genetic Advance in Rice (*Oryza sativa* L.) Under Sodic Soil

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Abstract

The experiment was carried out to evaluate the genetic variability, heritability and genetic advance in rice under the sodic soil condition. Results revealed highly significant variations within parents and hybrids. The five characters *viz.,* number of spikelet's per panicle, grain per panicle, amylose content, flag leaf area and 1000-grain weight showed high estimates of heritability coupled with high estimates of genetic advance as well as less than one average degree of dominance and predictability ratio nearly one in F_1's. This indicated that the inheritance of these five characters was governed by additive gene action and the direct selection for these characters would be rewarding.

Keywords: Rice (*Oryza sativa* L.), genetic variability, heritability, genetic advance and sodic soil

Introduction

Rice (*Oryza sativa* L.) is the most important staple food crop of the world. Asia is the leader in rice production accounting for about 90% of the world's production. India has the world's largest rice-growing area (45million hectares), and ranks second in overall production (130.29 million tonnes) after China, with an average yield of 2895 kg/hectare (Anonymous 2021-22). The success of any breeding programme mainly depends on the quantum of genetic variability and the extent to which the desirable characters are heritable (Tiwari *et al*., 2011). Heritability and genetic advance are the direct selection parameters, so correct knowledge of heritability and genetic advance is much more essential in formulation of selection strategy. Although the information on above aspects in rice is available, but most of these studies are based on irrigated and normal soil conditions and literature based on salinity conditions are quite meager. Therefore, further studies aimed at generating and comparing information on above aspects in rice, are warranted to facilitate the development of high yielding rice cultivars for above ecosystem.

Materials and Methods

This experiment was carried out at the Main Experimental Station of A.N.D. University of Agriculture and Technology, Narendra Nagar, Ayodhya, India. The experimental material was based on a line x tester set of 63 hybrids (F_1's) developed by crossing 21 lines (females) with 3 testers (males). An attempt was made to make a sixty three cross combinations during *kharif* season 2017 to generate F_1's. The 63 F_1's along with parents and two checks, Jaya and CSR 43 were evaluated to find out the genetic variability, heritability and genetic advance effects of their various attributes on grain yield under the sodic soil in Randomized Complete Block Design with three replications during *kharif* 2018. Phenotypic

(PCV), genotypic (GCV) and environmental (ECV) coefficients of variation for different characters were estimated by formulae suggested by Burton and de Vane (1953). The estimates of heritability in narrow sense ($h^2_{(ns)}$) have been classified by Robinson (1966) into three categories *viz.,* high (> 30%), medium (10-30%) and low (<10%).

Results and Discussion

Analysis of variance

The analysis of variance for different characters of line × tester set 24 parents and their F_1,s under sodic soil are presented in **Table 1.** Highly significant variability was found for all the characters in studied materials. Similar finding has also been reported by earlier researchers (Jayasudha *et al.,* 2009; Rahimi *et al.,* 2010; Sanghera and Hussain 2012; Latha *et al.,* 2013; Kargbo *et al.,* 2019; Sarker *et al.,* 2020 and Kulsum *et al.,* 2022). The analysis of variance revealed that mean squares due to parents *v/s* crosses were highly significant or significant for all the characters except flag leaf area in F_1's. Similar result has also been supported by earlier researchers (Rahimi *et al.,* 2010; Sanghera *et al.,* 2012; Bassuony *et al.,* 2021 and Mazal *et al.,* 2021).

Coefficients of variation

The phenotypic (PCV) and genotypic (GCV) coefficients of variation for the eighteen characters have been presented in **Table 2.** The magnitude of phenotypic coefficient of variation was higher than the corresponding genotypic coefficient of variation for all the traits. The high estimates of phenotypic and genotypic coefficient of variation (> 20%) were estimated for amylose content, grain per panicle, spikelet's per panicle, flag leaf area, grain yield per plant in F_1's. Similar results have also been reported by earlier researcher (Khedikar *et al.,* 2003; Saxena *et al.,* 2005; Singh and Singh, 2005; Dhanwani *et al.,* 2013; Gyawali *et al.,* 2018; Hasan *et al.,* 2020; Chavan *et al.,* 2022).

Estimates of heritability and genetic advance

The estimates heritability in narrow sense and genetic advance in per cent of mean have been presented in **Table 3.** High estimates of heritability in narrow sense were recorded for flag leaf area (94.36), amylose content (89.86), protein content (84.15), 1000-grain weight (76.84), panicle bearing tillers per plant (75.92), spikelets per panicle (66.91), panicle length (56.17), grains per panicle (55.23) in F_1 generation. Similar result has also been reported by earlier research (Sanghera and Hussain. 2012).

High estimates of genetic advance per cent of mean were reported for spikelets/panicle, grain per panicle, amylose content, plant height, flag leaf area and 1000-grain weight in F_1 generation. Similar result has also been reported by earlier researchers (Kargbo *et al.*, 2019, Prasad *et al.,* 2017 and Jaiswal *et al.,* 2020).

Some of the characters *i.e.,* flag leaf area, panicle bearing tiller per plant, panicle length, spikelets per panicle, grain per panicle, 1000-grain weight, amylose content and protein content showed less than unity of average degree of dominance in F_1s, revealing lack of dominance. The predictability ratio was lesser than one for all the characters studied in F_1s and above mention traits *i.e.,* flag leaf area, panicle bearing tiller per plant, panicle length, 1000-grain weight, amylose content and protein content showed close to one predictability ratio, this finding state that these characters was governed by additive gene. The same finding have also been reported by earlier reporters (Awad-Allah *et al.,* 2016; Bassuony and Zsembeli 2021; Abo-Yousef *et al.,* 2022).

Conclusion

From the study, it could be concluded that most of the characters were governed by dominant gene action. The five characters, spikelets/panicle, grain per panicle, amylose content, flag leaf area and 1000-grain weight showed high estimates of narrow sense heritability

Table 1: Analysis of variance for 18 characters of line × tester set of crosses (F_1s) and their parents in rice under sodic soil

Characters	Sources of variation										
	Replica-tions	Treatments	Parents	Parents (Line)	Parents (testers)	Line *vs* testers	Parents *vs* Crosses	Crosses	Lines Effect	Testers Effect	Lines × testers Effect	Error
d.f.	2	86	23	20	2	1	1	62	20	2	40	172
Days to 50% flowering	4.533	23.844**	19.196**	19.411**	3.111	47.056**	55.643**	25.055**	64.550**	1.466	6.488**	3.591
Chlorophyll content	0.124	13.149**	9.791**	8.740**	14.066**	22.281**	46.735**	13.853**	35.210**	11.142*	3.310**	0.244
Leaf nitrogen	0.001	0.019**	0.016**	0.013**	0.001	0.107**	0.023**	0.019**	0.046**	0.005	0.007**	0.001
Leaf temperature	0.128	12.051**	11.205**	3.043**	0.032	196.801**	360.198**	6.749**	12.214**	0.077	4.350**	0.123
Flag leaf area (cm^2)	0.596*	147.160**	134.078**	149.315**	47.452**	2.612**	0.334	154.381**	477.493**	0.715	0.508**	0.158
Plant height (cm)	0.794	415.83**	520.247**	477.477**	583.108**	1249.920**	373.497**	377.788**	1114.465**	84.964*	24.091**	1.9523
Panicle bearing tillers/plant	0.002	13.517**	13.118**	13.428**	2.919**	27.314**	120.576**	11.938**	36.594**	0.021	0.206**	0.091
Panicle length (cm)	0.031	20.710**	25.136**	19.019**	3.969**	189.815**	45.582**	18.667**	56.134**	1.920	0.771**	0.446
Spikelets/panicle	5.107	4078.566**	1259.884**	1190.030**	2192.111**	792.508**	44748.580**	4468.238**	13596.620**	172.577	118.832**	5.561
Grains/panicle	24.969*	3472.527**	1397.688*	1390.316**	2072.444**	195.627**	26821.710**	3865.625**	11463.930**	1881.370**	165.687**	6.810
Spikelet fertility (%)	2.712	131.232**	116.838**	130.307**	19.6612**	41.815**	66.844**	137.610**	247.490**	435.496**	67.776**	3.992
Biological yield/ plant (g)	1.184	140.447**	137.447**	118.549**	387.111**	16.071**	3702.759**	84.104**	205.699**	135.894**	20.716**	2.180
Harvest index (%)	1.191	45.352**	61.207**	64.483**	58.461**	1.172	281.575**	35.660**	55.080**	181.603**	18.653**	2.338
L/B ratio	0.024	0.655**	0.781**	0.638**	2.491**	0.218**	0.106**	0.617**	1.581**	0.757**	0.128**	0.010
1000 -grain weight (g)	1.737*	24.200**	23.901**	26.424**	5.003**	11.241**	23.592**	24.321**	74.567**	0.302	0.398	0.369
Amylose content	0.000	200.271**	186.176**	211.551**	8.976**	33.090**	10.504**	208.561**	646.506**	0.001	0.016	0.001
Protein content (%)	0.001	0.512**	0.4523**	0.517**	0.025**	0.014**	0.315**	0.537**	1.655**	0.004	0.006**	0.001
Grain yield/plant (g)	0.048	33.619**	19.249**	16.884**	51.051**	2.947**	949.83**	24.172**	47.133**	99.290**	8.936**	0.081

,** Significant at 5% and 1% probability levels, respectively.

coupled with high genetic advance as well as less than one average degree of dominance and predictability ratio in F_1 generations. This indicated very clearly that the inheritance of these five characters was governed by additive gene action and the direct selection for these two characters would be rewarding.

Table 2: Estimates of general mean, phenotypic (PCV) and genotypic (GCV) coefficient of variation for 18 characters in rice under sodic soil

S. No.	Characters	General mean ±SE	Coefficient of variation (%)	
			PCV	GCV
1	Days to 50% flowering	84.4944±SE1.0789	3.7800	3.0563
2	Chlorophyll content	13.0219±SE0.2813	16.5523	16.1190
3	Leaf nitrogen	0.5931±SE0.0143	13.7167	13.0572
4	Leaf temperature	35.0979±SE0.2004	5.8070	5.7211
5	Flag leaf area (cm^2)	32.7261±SE0.2258	21.3384	21.3045
6	Plant height (cm)	114.3304±SE0.7990	10.5977	10.5276
7	Panicle bearing tillers/plant	10.9906±SE0.1714	19.2656	19.0731
8	Panicle length (cm)	24.5035±SE0.3789	11.0447	10.7112
9	Spikelets/panicle	157.4007±SE1.3502	23.2804	23.2324
10	Grains/panicle	132.7453±SE1.6431	25.5728	25.4818
11	Spikelet fertility (%)	84.1179±SE1.2496	8.1508	7.7292
12	Biological yield/plant (g)	40.4981±SE0.8486	17.0131	16.6170
13	Harvest index (%)	39.1072±SE0.8772	10.3499	9.5840
14	L/B ratio	2.9280±SE0.0558	16.0935	15.7477
15	1000-grain weight (g)	24.4255±SE0.3451	11.7572	11.4968
16	Amylose content	18.8346±SE0.0155	43.0035	43.0033
17	Protein content (%)	6.2306±SE0.0199	6.5868	6.5632
18	Grain yield/plant (g)	15.8858±SE0.1621	20.9624	20.8868

Table 3: Heritability in narrow sense and genetic advance in per cent of mean for 18 characters in rice under sodic soil

Characters	Heritability ($h^2_{(ns)}$%)	Genetic advance in per cent of mean	Average degree of dominance $\sqrt{ó^2 s/2ó^2 g}$	Predictability ratio $2ó^2 g/2ó^2 g + ó^2 s)$
Days to 50% flowering	13.6550	0.4452	1.6804	0.2615
Chlorophyll content	14.9678	0.3512	2.2939	0.1597
Leaf nitrogen	9.4691	0.0097	2.9593	0.1025
Leaf temperature	2.9568	0.0745	5.6473	0.0304
Flag leaf area (cm^2)	94.3605	3.3689	0.2031	0.9604
Plant height (cm)	44.7904	3.5190	1.0643	0.4689
Panicle bearing tillers/plant	75.9264	0.8344	0.4202	0.8499
Panicle length (cm)	56.1769	0.8865	0.5741	0.7521
Spikelets/panicle	66.9151	15.0828	0.6865	0.6797
Grains/panicle	55.2367	12.6391	0.8815	0.5627
Spikelet fertility (%)	5.3870	0.5423	4.0656	0.0570
Biological yield/plant (g)	14.4625	0.8465	2.3004	0.1589
Harvest index (%)	4.7966	0.2525	4.1666	0.0545
L/B ratio	17.3950	0.0815	2.0960	0.1854
1000-grain weight (g)	76.8403	1.1987	0.1496	0.9781
Amylose content	89.8609	4.0346	0.0365	0.9987
Protein content (%)	84.1591	0.1871	0.3903	0.8678
Grain yield/plant (g)	8.6103	0.3202	3.2431	0.0868

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Evaluation of Rice Varieties Under Different Crop Management Options in Rainfed and Drought Prone Ecology of Jharkhand

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Abstract

Rice is the life and livelihood of Indians and the fact is more appropriate to the eastern part of the country. Rainfed and drought prone upland rice contributes a significant part of the total rice cultivation not only in India but also at the global level. However, the productivity is very low as compared to other rice-ecosystems. Hybrids were released from many institutions having several advantages and limitations. Comparative evaluation of rice hybrids and high yielding varieties (HYVs) under transplanting and direct seeding conditions is necessary to obtain a comparative picture. A field trial was conducted for three consecutive years to compare HYVs and popular hybrids under integrated crop management in drought prone rainfed ecology. Results of the experiment revealed that higher number of tillers were noted under wet-direct seeding, whereas increased application of fertilizer dose did not influence tillering under both direct seeding (DSR) and transplanting methods of crop establishment. Number of panicles per unit area also showed similar trend as tiller number and it was found that number of panicles were more in DSR as compared to transplanted rice. Grain yield between the transplanted and DSR is comparable, however, reduction in yield was higher in case of hybrids when switched from transplanted to DSR as compared to HYVs. Hence, it can be concluded that, in the drought prone rainfed areas HYVs should be preferred for cultivation over hybrids under DSR as there is diminishing scope of transplanted rice cultivation.

Keywords*:* Rainfed upland rice, drought prone, wet-direct seeding, transplanting, crop management, HYVs and hybrid

Introduction

Achieving higher productivity and increasing input use efficiency remain the major challenges experienced by researchers and farmers worldwide and it is the crucial option for increasing productivity and profitability in a sustainable manner for meeting food demand and alleviation of poverty. Rice is the staple food of about half of the world's population mainly in southeast, east, and south Asia and in some countries of Africa and tropical South America. In India, rice covers about 44 million hectares of area with an average production of 120 million tonnes and a productivity of 2.7 tonnes per hectare. (GoI, 2022). Considering the increasing population and the demand for rice, it is estimated that in 2030 and 2050 the requirement would be 137 and 197 million tonnes, to feed around 1.51 and 1.65 billion people, respectively (Pathak *et al.,* 2020). India must have to increase its rice productivity by 3% per annum to sustain the present food self-sufficiency and to fulfil future food demand (Thiyagarajan and Selvaraju, 2001). Rice is grown in diverse ecologies from submerged lowland in Assam to the drought prone upland conditions of Chotanagpur plateau and from hilly regions of Himalaya to the coastal saline regions of Kerala. Rainfed upland rice accounts for 11% of total rice area in India (4.8 Mha), located mainly in Eastern part of the country *i.e.,* Bihar, Chhattisgarh, Jharkhand, Odisha, UP and West Bengal (Pathak *et al*., 2020) and it is the prime contributor of livelihood security of the people in this region. In a suitable eco-region mapping for different crops, it was also found that eastern and northeastern states of the country come under suitable to very suitable category for growing rice (Pathak *et al.,* 2020).

Transplanting is the common method of crop establishment in rice and 77% of rice crop in the world is established through this method (Rao *et al*., 2007). In India also barring rainfed upland and some deep-water areas, rice is mostly transplanted in all other ecosystems. But this method of crop establishment consumes huge quantity of water either through rain or irrigation and is highly labour intensive and requires about 30 persons/ha/day (IRRI 2007). In the recent years, there is a trend of labour migration from low-income rural areas to high income urban/ industrial areas that led to huge shortage of labour in agricultural sector and as a result, labour-intensive work like transplanting of rice is adversely affected. Among different agricultural operations, transplanted rice is one of the major sources of greenhouse gas emission contributing 11% of the global total anthropogenic methane emission leading to global warming effect (Stocker *et al*., 2013). With the increasing problem of transplanting operations in rice cultivation and to reduce the cost of cultivation in an environment friendly manner there is a growing interest to replace it with other suitable methods. Different alternative crop establishment methods such as dry-direct sowing of rice (D-DSR), wet direct sowing (Wet DSR), aerobic rice etc have emerged to address several issues related to rice production *viz.* water and labour scarcity, improving the economic gain from rice cultivation etc. Aerobic rice is growing rice like any other upland crop under non-puddled, non-flooded and non-saturated soil conditions that require considerably less water than conventional puddled (transplanted) rice. Direct seeded rice (DSR) in wet (puddled) condition results in reduced use of labour, less consumption of water and early crop maturation of 1 to 2 weeks earlier when compare to the conventional transplanted rice (Weerakoon *et al*., 2011; Mishra *et al*., 2017; Saha *et al*., 2020). However, DSR has several limitations such as inconsistent plant population, injudicious use of fertilizer, water stress and presence of weeds in the field that often restrict realization of crop yield (Shultana *et al*., 2016). To improve the productivity and production in rainfed drought prone systems, a combination of improved varieties as well as integrated crop management practices are necessary. It was observed that, many farmers practice injudicious application of fertilizers which promotes higher losses in soil or environment that leads to low nutrient use efficiency. Fertilizers use efficiency (especially N) is very low in rice (approx. <40%) due to several losses (Cassman *et al*., 2002). Beside this, performance of different crop establishment methods also varies throughout the agroecological regions with different crop management options. Hence, there is scope for comparative evaluation of different establishment methods and crop management options together (Alam *et al*., 2020). Current situation demands an economically viable crop establishment method while growing different varieties to enhance the productivity as well as net return. Limited information is available on fertilizer management options under wet-DSR system. Moreover, DSR is an emerging production system which is less labour intensive that may reduce the cost of production. Hence, information on effect of fertilizer and different rice varieties in DSR may be helpful to identify suitable crop management options to achieve higher production and to reduce cost of cultivation. Therefore, the present study was undertaken to evaluate suitable varieties and fertilizer management options to obtain higher grain yield under wet DSR and to compare its relative advantage over transplanted rice.

Materials and Methods

Experimental details

To achieve the objectives, a field trial was initiated in *kharif* (wet season) of 2016 and continued for three consecutive years to compare high yielding varieties (HYVs) and popular hybrids under integrated crop management (fertilizer application rates and crop establishment methods) at research farm of CRURRS (ICAR-NRRI), Hazaribag. Combination of two crop establishment methods *viz.,* 1) Transplanting and 2) Wet direct Seeding (DSR); and two fertilizer management schedule *viz.,* 1) N_{80}:P_{40}:K_{30} and 2) N_{120}:P_{60}:K_{30} comprised the main plot treatments while four high yielding varieties (Hazaridhan, Sadabahar, Sahbhagidhan and DRR Dhan 44) and two hybrids (PAC 801 and PA 6444 Gold) formed the subplot treatments. The experiment was carried out under shallow lowland field having clay loam soil texture. The weather condition during the crop growth period is shown in **Figure 1.**

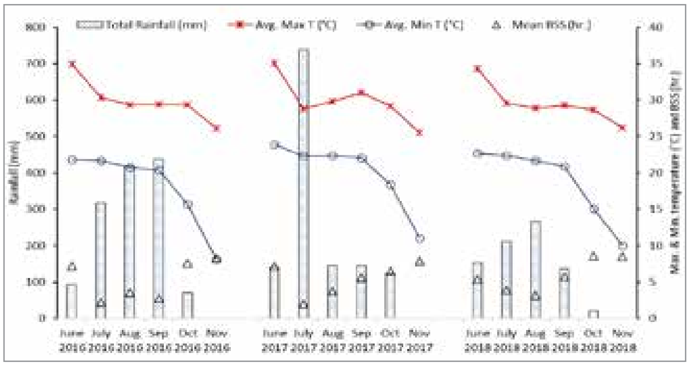

Figure 1: Weather condition during crop growth period

Table 1: Duration and special features of the rice varieties used in the study

Varieties	Duration (days)	Special Feature
Hazaridhan	115-120	Long slender grain, resistant to blast, moderately resistant to bacterial leaf blight, stem borer
Sadabahar	105	Long bold grain, moderately resistant to sheath blight
Sahbhagidhan	105-110	Long-bold grains; resistant to blast, and moderately resistant to brown spot, sheath rot, stem borer and leaf folder
DRR Dhan 44	115-120	Long slender grains, resistant to blast, moderate resistant to bacterial leaf blight and plant hoppers
PAC 801	120-125	Hybrid, long slender grains
PA 6444 Gold	135	Hybrid, resistant to bacterial leaf blight

Field and crop management

The field was prepared with two passes by a power tiller followed by two ladderings before sowing or transplanting. Twenty-four to thirty days old seedlings were transplanted in the main field at a spacing of 20 cm ×10 cm; maintaining two to three seedlings at each hill in conventional transplanting. In direct seeding, 2-3 sprouted seeds were dibbled manually at 20 cm × 10 cm spacing in puddled field with negligible or no standing water on surface. The nursery for transplanting and main field sowing in direct sowing was done at the same time for providing uniform growth. Fertilizers were applied as per the treatments through urea, DAP (di-ammmonium phosphate) and MOP (muriate of potash) in both transplanting and DSR. Alternate wetting and drying were followed for managing water requirement of the crop. Others management practices were followed throughout the experiment as per requirement.

Data collection and analysis

After harvesting rice plants were separated into straw (including rachis) and spikelets by hand threshing and then the grain yield, straw yield, panicle weight, grains per panicle and 1000-grain weight (test weight) were recorded. The data pertaining to treatment effects on different parameters were tested by two-way analysis of variance (ANOVA), and treatment means were compared using least significant difference (LSD) tests at 0.05 level of significance ($p \leq 0.05$).

Results and Discussion

During the three consecutive years of study, it was observed that the number of days required for 50% flowering varied significantly due to interaction between varieties, methods of crop establishment as well as fertilizer application rates. On an average it was observed that, varieties took 7-10 days more to flower (50% flowering) under TPR compared to wet-DSR. Varieties also showed substantial variations among themselves in number of days taken to 50% flowering as illustrated in **Figure 2.**

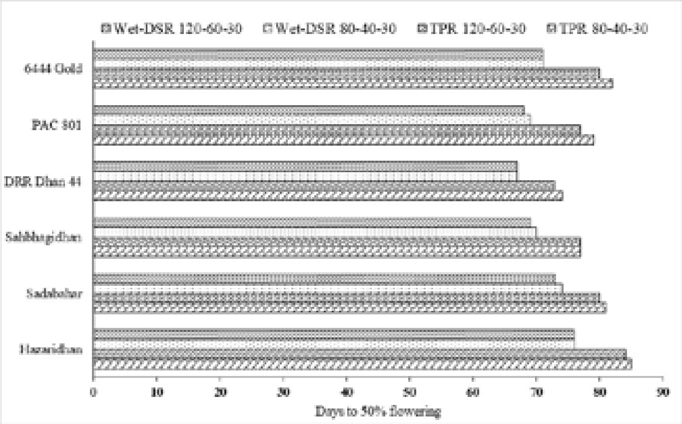

Figure 2: Effect of crop establishment, fertilizer application and varieties on 50% flowering

Effects of crop management options and varieties are found to be significant on different growth and yield attributes as shown in **Table 2.** Higher number of tillers was noted under DSR method, whereas increased application of fertilizer dose did not influence tillering under both DSR and TPR methods of crop establishment. Number of panicles per unit area also showed similar trend as tiller number and it was found that number of panicles were more in DSR as compared to transplanting. Higher tiller number in DSR compared to transplanted rice was also observed in other studies (Mai *et al.*, 2021). Xu *et al.*, (2019) also reported positive response to direct rice seeding in terms of panicle number. In contrast to tiller and panicle number, it was found that, under TPR, panicles were heavier and number of spikelets per panicle was also more as compared to DSR method and increased rate of fertilizer also resulted in heavier panicles with more grains per panicle. Among the varieties, hybrids were found with heavier panicles and more spikelets per panicle as compared to HYVs. Crop establishment method and fertilizer application (integrated crop management options) failed to influence test weight; however, varieties are found to be significantly differed in their test weights.

Effect of crop management options and varieties are significant on the grain yield, and it was found that, wet-DSR method produced numerically less yield (not significant in most of the cases) as compared to transplanted condition. The yield under wet DSR is comparable to transplanted method as there was very less change (mean change of approx. 0.5 t/ha) due to switching from DSR to TPR over three years of experimentation **(Table 2).** Other researchers also reported comparable result in rice grain yield under wet and dry direct sowing in comparison to transplanted rice (Kukal and Aggarwal, 2002; Saha *et al*, 2020). Among the varieties, hybrids produced more yield as compared to HYVs in some instances, however, the trend is not similar throughout the year and establishment methods and yield are comparable in most of the cases **(Table 3).**

Interactive effect of integrative crop management options and varieties are also significant, and on an average, it was found that grain yield reduction of 17.7 per cent in hybrids and 5.0 per cent in the HYVs

Table 2: Effect of crop management (crop establishment methods and fertilizer application) and varieties on yield and yield attributes of rice

Treatments	Tillers/m^2 (no.)			Panicles/m^2 (no.)			Panicle wt. (g)			Spikelets/panicle (no.)			1000- grain wt. (g)			Grain yield (t/ha)		
	2016	2017	2018	**2016**	**2017**	**2018**	2016	2017	2018	**2016**	**2017**	**2018**	2016	2017	2018	**2016**	**2017**	**2018**
Establishment method × Fertilizer																		
TPR 80-40-30	167	236	201	153	208	178	4.67	4.30	4.02	209	137	145	24.9	24.9	24.4	5.69	5.27	4.77
TPR 120-60-30	155	227	205	142	203	184	5.00	4.27	4.16	215	139	152	25.1	25.3	25.4	5.61	5.54	4.89
Wet-DSR 80-40-30	250	266	255	234	229	227	3.25	4.14	3.25	127	129	103	25.7	26.1	24.2	4.99	4.79	4.22
Wet-DSR 120-60-30	231	246	257	209	215	232	3.68	4.18	3.45	135	127	112	25.3	25.9	24.8	5.60	5.15	3.98
CD (0.05)	*42*	*30*	*36*	*39*	*16*	*28*	*0.58*	*ns*	*0.32*	*31*	*ns*	*25*	*ns*	*ns*	*0.4*	*0.69*	*0.57*	*0.62*
Varieties																		
Hazaridhan	207	238	228	195	213	200	4.28	4.20	3.78	147	116	113	28.1	27.8	27.3	5.52	5.32	4.57
Sadabahar	256	275	274	236	250	248	3.28	3.97	3.15	117	109	106	24.9	25.6	24.6	4.83	4.67	3.88
Sahbhagidhan	218	235	236	188	211	210	3.65	4.29	3.49	156	129	117	24.3	25.8	24.3	5.53	5.32	4.55
DRR Dhan 44	184	228	214	161	198	188	4.32	4.37	3.87	202	148	140	24.9	26.4	25.0	5.42	5.04	4.31
PAC 801	178	237	214	166	207	196	4.69	4.40	4.07	192	150	136	25.7	25.3	24.8	5.83	5.43	4.77
PA 6444 Gold	177	253	212	163	220	186	4.69	4.17	3.95	231	144	153	23.3	23.2	22.6	5.72	5.35	4.71
CD (0.05)	*25*	*18*	*28*	*24*	*20*	*18*	*0.61*	*0.27*	*0.42*	*25*	*14*	*16*	*1.5*	*0.8*	*1.1*	*0.65*	*0.42*	*0.58*

Table 3: Interaction effect of crop management and varieties on grain yield of rice

Rice variety	2016				2017				2018			
	T1	T2	T3	T4	**T1**	**T2**	**T3**	**T4**	T1	T2	T3	T4
Hazaridhan	5.91	5.92	4.60	5.64	5.53	5.69	4.79	5.26	5.07	5.12	4.02	4.08
Sadabahar	4.48	4.73	4.78	5.32	4.40	4.85	4.54	4.90	3.58	4.18	4.01	3.76
Sahbhagidhan	5.18	5.37	5.74	5.83	5.47	5.66	4.91	5.22	4.64	4.78	4.66	4.10
DRR Dhan 44	5.34	5.61	5.05	5.69	5.06	5.19	4.82	5.10	4.50	4.64	4.19	3.89
PAC 801	6.86	6.02	4.87	5.57	5.60	5.91	4.90	5.30	5.45	5.28	4.24	4.12
PA 6444 Gold	6.39	6.03	4.91	5.53	5.55	5.96	4.79	5.10	5.39	5.34	4.20	3.92
CD 5%	*1.59*				*0.94*				*0.86*			

Note- T1: *TPR 80-40-30, T2: TPR 120-60-30, T3: Wet-DSR 80-40-30, T4: Wet-DSR 120-60-30*

was noted because of switching of crop establishment method from TPR to DSR. However, between the two fertilizer doses, remarkable response of HYVs was noted under DSR at high dose of fertilizer application. Hybrids used in this study were originally bred for conventional transplanting that might be a reason for less response of hybrids in wet-direct seeding. A higher number of panicles in DSR compared to TPR might have compensated for less test weight and number of grains per panicle (Yadav *et al.*, 2021).

Conclusions

From the above finding it was observed that, though the number of grains per panicle was lower in DSR, the increased tiller number compensated the same which turned into comparable grain yield between the transplanted and direct seeding. However, reduction in yield is higher in case of hybrids when shifted from transplanted to DSR as compared to HYVs. Rice varieties/hybrids bred for transplanted condition should not be used for DSR without judging their potential to perform in direct seeded methods. Hence, it can be concluded that in the drought prone rainfed areas HYVs should be preferred for cultivation under DSR over hybrids as there is diminishing scope of transplanted rice.

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RESEARCH ARTICLE **https://doi.org/10.58297/USZC7294**

Genotypic Variation in Photosynthetic Traits, Grain Yield and Nitrogen Use Efficiency in Rice (*Oryza sativa* L.) Under Differential Nitrogen Levels

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Abstract

Nitrogen (N) is one of the yield limiting nutrients for rice. Unwarranted usage of N fertilizer to achieve higher crop returns is affecting environment and increasing the cost of cultivation. A field experiment was conducted under two differential N experimental plots (N-Low and N-Rec) to evaluate the effect of N on photosynthesis, grain yield and nitrogen use efficiency (NUE) of six rice genotypes belonging to three diverse groups. At N-Rec, Kolajoha3 exhibited highest mean SCMR value (43.2), flag leaf length (39.0 cm), flag leaf width (1.77 cm), flag leaf area (53.8 cm^2), photosynthetic rate (19.50 µmol CO_2 m^{-2} s$^{-1)}$, stomatal conductance (0.38 mol [H_2O] m^{-2} s$^{-1)}$, transpiration rate (10.72 mmol [H_2O] m^{-2} s$^{-1).}$ IC463254 recorded highest mean grain yield (621.5 g m^{-2}), total dry matter (1302.5 g m^{-2}), harvest index (47.7%), grain N uptake (84.4 kg ha$^{-1)}$ and nitrogen use efficiency (18.2). Significant reduction in growth, photosynthetic rate and yield of rice occurred under N-Low compared with N-Rec. In comparison N-Rec, Kolajoha3 exhibited least mean reduction in plant height (10.68%), photosynthetic rate (14.96%), productive tiller number (35.40%), grain yield (50.63%), straw yield (24.83%), total dry matter (36.03%), agronomic efficiency (14.6%) and NUE (26.21%) under N-Low, while IC463254 exhibited least mean reduction in SCMR value (14.11%) and flag leaf width (23.66%).

Keywords: Rice, nitrogen, photosynthetic rate, grain yield, NUE.

Introduction

Rice is a staple cereal crop, cultivated in ~167 Mha with a production of 770 million tons and productivity of 4.10 t ha^{-1}. An increase of 2% - 3% in annual rice production has to be promised to ensure the self-sufficiency with the available resources (Haque and Haque 2016). In the scenario of global climate change, agriculture segment witnesses the snag to attain marked crop returns. Influence of high-temperature episodes, unexpected weather events, increased CO_2 concentrations and non-CO_2 Green House Gas (CH_4 and N_2O) emissions on the global food security is being realized world over. Reduction of greenhouse gases based on IPCC recommendations is crucial to emphasize the future food security, planning and its implementation. Applying excessive nitrogen (N) fertilizer doses to the agricultural lands increases the concentration of NO_3-N and NH_4-N in ground water and has negative impact on environment and soil health (Savci 2012). High quantity of N fertilizer usage rises the input cost to the farmers and effects the environment adversely. In particular, N fertilizer import, and subsidy outgo has an impact on nation's economy as well. To achieve two-fold raise in the aggregate agricultural yield since 1960 to 1995, seven folds of higher N fertilizer applied to farmlands (Tilman *et al*., 2002). Considering this perspective, Climate Resilient Agriculture (CRA) is an innovative to precisely solve the problem through potent mitigation practices like increasing NUE in crop plants besides sustainably increasing the crop yields.

Nitrogen plays a significant part in photosynthetic activity of rice leaves as it is the primary constituent of proteins which are in turn constituents of protoplasm, chloroplasts, phyto-hormones, and enzymes (Murata and Osada, 1959). Increased N fertilizer usage contributes to enhanced yield. Nitrogen deficiency in rice fields leads to increase in stomatal resistance which is the critical step in carbon dioxide diffusion during leaf photosynthesis (Oritani *et al*., 1979; Makino *et al*., 1983; Weng and Chen, 1987). More than 90% of crop biomass is derived from assimilates of photosynthesis. According to Long *et al*., (2006) there is a close relationship between enhanced photosynthesis, biomass, and yield; this suggests that increasing photosynthesis increases yield, if other genetic factors are not altered.

Although, N is essential to rice plant metabolism, all the rice genotypes do not need same N fertilizer doses. Every genotype has possessed best N application rate which depends on its Nitrogen Use Efficiency (NUE). NUE can be defined as the capability of a genotype to absorb and mount up the adequate nitrogen to raise and make over to better grain yield per unit of available N (native N + supplied N) in the soil (Mi *et al*., 2007 and Hirel *et al.,* 2021). Only 33% of NUE was noticed globally for cereal crops and the rest 67% is lost into environment worth INR 72,000 crore per annum (Abrol *et al*., 2007). According to Mahajan *et al*., (2010), Basmati varieties do not bear high N fertilizer doses to enhance yields; high N application may cause for susceptibility to lodging, disease prone conditions, and insect pest attacks. Vijayalakshmi *et al*., (2015a and 2015b) was also observed that an aromatic rice genotype, Basmati 370 has shown tolerance and performed well under 'N' stress conditions. Thus, there is a necessity to enhance NUE in rice, that future rice breeding programmes should be in such a way that rice genotypes exhibit high NUE as a natural instinct. There is a prerequisite to be aware of the photosynthetic activity in developing cultivars at limiting soil-N levels (Abrol *et al*., 2008). Thus, rice genotypes with high NUE, optimum photosynthetic rate and sustainable grain yield under N stress conditions were considered in this study.

Materials and Methods

Six rice genotypes *viz.,* Basmati370 and Kolajoha3 (aromatic), IC463222 and IC463254 (germplasm) and Giza178 and Zardrome (ACC32379) (IRHTN) were selected based on earlier studies (Rao *et al.,* 2018). Field experiments were conducted during *kharif 2020*, *rabi 2021* and *kharif 2021* at Indian Institute of Rice Research, Hyderabad, India (17.530 19' N, 78.270 29' E and 542.7 MSL). Two separate plots were maintained with zero N fertilizer application (N-Low) and recommended N (N-Rec) since 2010 (Vijayalakshmi *et al.,* 2015a; Swamy *et al.,* 2016; Vishnukiran *et al.,* 2020). Nitrogen fertilizer @ 100 kg ha^{-1} was supplied in the form of urea in three equal split applications to the N-Rec treatment (at basal, active tillering and panicle initiation stages). Phosphorus (@ 40 kg ha^{-1}), potassium (@ 40 kg ha^{-1}) and zinc (@ 25 kg ha^{-1}) were applied to both plots.

Soil samples were collected from experimental plots prior to experiment to determine the preliminary soil properties. Samples were collected from four different areas of experimental plot and the mixed composite was used to determine N content by following semi micro Kjeldahl method (Kjeldahl, 1883). The soil characteristics during three successive seasons for N-Rec treatment plot: soil pH 7.29, 7.39, 7.42; electrical conductivity (EC) 0.24, 0.28, 0.27 dS m^{-1}; organic carbon content 0.69%, 0.72%, 0.72%; available nitrogen (N) 220, 255, 252 kg ha^{-1}; available phosphorus (P_2O_5) 60, 63, 61 kg ha^{-1}; available potassium (K_2O) 682, 705, 789 kg ha^{-1}; and for N-Low treatment plot: soil pH 7.20, 7.42, 7.46; electrical conductivity (EC) 0.22, 0.26, 0.29 dS m^{-1}; organic carbon content 0.58%, 0.66%, 0.66%; available nitrogen (N) 202, 243, 233 kg ha^{-1}; available phosphorus (P_2O_5) 56, 52, 50 kg ha^{-1}; available potassium (K_2O) 628, 692, 721 kg ha^{-1}.

The experiment was laid out in split plot design with two N levels (N-Rec and N-Low) as main plots and six genotypes as subplots and replicated thrice. Rice seeds were sown as nursery and 30 days old seedlings were transplanted in square meter area with one seedling per hill at a spacing of 10 × 20 cm. Recommended package of rice crop production and protection practices were followed (www.rkmp.co.in).

Agro-morphological parameters, grain yield and NUE were studied for two consecutive seasons and during third season in addition to above mentioned traits, flag leaf photosynthetic traits were also studied. Flag leaf traits and SCMR values were measured at reproductive stage. Agro-morphological, yield and yield related attributes were recorded at physiological maturity. In situ leaf chlorophyll content (SCMR values) was noted down by using Konica Minolta Corporation's Chlorophyll SPAD-502 plus, (USA). A portable photosynthesis measuring system, LI6400XT (LI-COR Environmental, USA) connected to leaf chamber fluorimeter (6400-40, LI-COR, USA) was used to assess the leaf photosynthetic characteristics of flag leaf between 10.00-13.00 h. At this moment leaf temperature was maintained at 30 °C, which is equal to the ambient temperature prevailing at the time of measurements and PAR was maintained at 1200 μ mol (photon) m^{-2}s^{-1}. Measurements were made at ambient CO_2 levels (400 ± 6 ppm). Plants from each replicate were cut at ground level and were threshed manually. Moisture content of grain was adjusted to 14% before determining the total grain weight. Straw samples were dried at 70 °C to take straw weight. Nitrogen content in grain and straw samples was analysed in Kjeldahl method (Kjeldahl, 1883). Agronomic Efficiency (AE) and Physiological efficiency (PE) was calculated as per formula given by Dobermann (2007). Nitrogen use efficiency (NUE) was calculated as described in Huang *et al*., (2018). Data analysis was done using open software R language with *agricolae* package (Mendiburu and Yaseen 2021).

Results and Discussion

Plant height

Nitrogen application has significantly influenced the plant height **(Table 1)**. Maximum mean plant height (100.8 cm) was recorded with N-Rec whereas N-Low recorded minimum (79.9 cm). Significant differences were noticed among the genotypes for plant height. At N-Rec, Basmati370 (155.3 cm and 135.6 cm) during *kharif-2020* and *kharif-2021*, Zardrome (125.7 cm) during *rabi-2021* has showed significantly higher plant height compared to other genotypes, while lowest plant height was recorded in IC463222 (74.7 cm and 77.9 cm) during *kharif-2020* and *kharif-2021*, Kolajoha3 (71.0 cm) during *rabi-2021*. In comparison with N-Rec, plant height has decreased significantly under N-Low in all three seasons **(Figure 1)**. Kolajoha3 has showed the least reduction in plant height (10.65%, 6.57% and 14.13%) while highest reduction was noticed in Basmati370 (30.04%), Zardrome (27.32%) and IC463254 (35.57%) during *kharif-2020*, *rabi-2021* and *kharif-2021*. Results for plant height were supported by the findings of Zhang *et al*., (2020), who reported remarkable improvements in plant height with increased N application. Similar results have also been demonstrated by Jahan *et al*., (2022), who described that an increase in N supply to rice genotypes caused a significant increase in the height of rice plants.

SPAD Chlorophyll Meter Readings (SCMR)

SCMR value has increased significantly with nitrogen application **(Table 1).** N-Low has showed lowest mean SCMR value (31.7) whereas highest value was recorded with N-Rec (38.1). SCMR value has differed significantly among the genotypes. At N-Rec, Kolajoha3 (44.4, 44.2 and 41.0) has showed significantly higher SCMR value compared to other genotypes, while lowest value was recorded in Zardrome (32.9, 36.0 and 34.4) during *kharif-2020*, *rabi-2021* and *kharif-2021*. In comparison with N-Rec, SCMR value has decreased significantly under N-Low in all three seasons **(Figure 1).** Basmati370 (11.26% and 10.24%) during *kharif-2020* and *rabi-2021*, IC463254 (12.05%) during *kharif-2021* has showed the least reduction in SCMR value while highest reduction was noticed in Giza178 (27.43%), IC463222 (19.79%) and Basmati370 (25.10%) during *kharif-2020*, *rabi-2021* and *kharif-2021*. The linear relationships for chlorophyll content and N application rate have been explained by Abunyewa *et al.,* (2016).

Flag leaf traits

Flag leaf length was significantly increased by nitrogen application **(Table 1).** Maximum mean flag leaf length was recorded with N-Rec (31.1 cm) while N-Low (21.8 cm) has exhibited the minimum length. Significant differences were noticed among the genotypes for flag leaf length. Kolajoha3 has showed higher flag leaf length (42.6 cm, 30 cm and 44.3 cm), while lowest length was noticed in IC463254 (28 cm), Giza178 (19.5 cm) and Zardrome (29.6 cm) in *kharif-2020*, *rabi-2021* and *kharif-2021* at N-Rec. Significant reduction in flag leaf length was observed with N-Low compared to N-Rec in all three seasons. In *kharif-2020* and *kharif-2021*, Kolajoha3 (50.19% and 49.62%) has showed higher reduction in flag leaf length while least reduction was noticed in Zardrome (11.56% and 9.59%). In *rabi-2021*, Basmati370 (46.56%) has recorded higher reduction while IC463254 (15.36%) and Giza178 (15.37%) has exhibited least reduction.

Nitrogen application has significantly increased the flag leaf width **(Table 1).** N-Rec (1.37 cm) has exhibited highest mean flag leaf width while lowest width was recorded with N-Low (0.95 cm). The tested genotypes differed significantly for flag leaf width. Kolajoha3 has showed higher flag leaf width (2.13 cm, 1.21 cm and 1.99 cm), while lowest width was noticed in Giza178 (1.32 cm), Zardrome (0.86 cm) and Basmati370 (1.26 cm) in *kharif-2020*, *rabi-2021* and *kharif-2021* at N-Rec. In comparison with N-Rec, flag leaf width has decreased significantly under N-Low in all three seasons. Giza178 (25.51%), IC463254 (8.55%) and Basmati370 (21.96%) has exhibited least reduction in flag leaf width while highest reduction was noticed in Kolajoha3 (44.53%, 50.41% and 45.30%) in *kharif-2020*, *rabi-2021* and *kharif-2021*.

Significantly highest mean flag leaf area was recorded with N-Rec (33.2 cm^2) while N-Low (15.7 cm^2) has exhibited the least area. Flag leaf area has differed significantly among the genotypes. At N-Rec, Kolajoha3 has showed higher flag leaf area (68.4 cm^2, 27.2 cm^2 and 66.1 cm^2), while lowest area was noticed in IC463254 (29.4 cm^2), Zardrome (15 cm^2 and 30.2 cm^2) in *kharif-2020*, *rabi-2021* and *kharif-2021*. Significant reduction in flag leaf area was observed with N-Low compared to N-Rec in all three seasons. Kolajoha3 (72.44%, 62.63% and 72.46%) has showed highest reduction in flag leaf area while least reduction was noticed in Zardrome (36.85%), IC463254 (22.6%) and Zardrome (30.16%) in *kharif-2020*, *rabi-2021* and *kharif-2021*.

Table 1: Effect of nitrogen application on agro-morphological traits, grain yield and NUE in six rice genotypes

Treat	Entry	Plant height (cm)				SCMR value				Flag leaf length (cm)				Flag leaf width (cm)				Flag leaf area (cm²)			
		S1	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**
N - Low	BASMATI 370	108.7	87.7	104.7	100.3	36.1	32.4	28.0	32.2	22.6	15.5	23.3	20.5	0.91	0.83	0.98	0.91	15.4	9.7	17.1	14.1
	GIZA 178	80.7	73.0	83.2	79.0	27.2	34.5	29.1	30.2	24.9	16.5	27.2	22.9	0.98	0.81	1.02	0.94	18.4	10.0	20.7	16.3
	IC-463222	58.0	69.3	56.7	61.3	27.8	30.6	30.7	29.7	20.5	18.0	21.2	19.9	0.93	1.00	0.97	0.97	14.4	13.5	15.4	14.4
	IC-463254	79.8	71.0	68.0	72.9	34.1	32.9	34.5	33.8	22.9	19.9	23.3	22.1	0.95	1.03	1.00	1.00	16.4	15.4	17.6	16.5
	KOLA JOHA 3	72.7	66.3	72.9	70.6	37.5	36.5	31.3	35.1	21.2	22.7	22.3	22.1	1.18	0.60	1.09	0.96	18.9	10.2	18.2	15.7
	ZARDROME	99.0	91.3	95.3	95.2	27.8	29.4	29.8	29.0	25.2	18.1	26.7	23.3	1.11	0.70	1.05	0.95	20.9	9.5	21.1	17.2
N-Low - Mean		**83.1**	**76.4**	**80.1**	**79.9**	**31.7**	**32.7**	**30.6**	**31.7**	**22.9**	**18.5**	**24.0**	**21.8**	**1.01**	**0.83**	**1.02**	**0.95**	**17.4**	**11.4**	**18.4**	**15.7**
N - Rec	BASMATI 370	155.3	100.3	135.6	130.4	40.7	36.1	37.4	38.1	31.8	29.0	32.7	31.1	1.32	1.02	1.26	1.20	31.5	22.3	30.9	28.2
	GIZA 178	97.7	80.3	105.9	94.6	37.5	40.6	35.0	37.7	31.8	19.5	33.3	28.2	1.32	1.11	1.33	1.25	31.5	16.2	33.3	27.0
	IC-463222	74.7	75.3	77.9	76.0	33.6	38.1	36.1	35.9	35.9	29.9	36.2	34.0	1.50	1.20	1.64	1.45	40.4	27.1	44.4	37.3
	IC-463254	99.7	89.0	105.6	98.1	40.2	38.7	39.2	39.4	28.0	23.5	30.0	27.2	1.40	1.13	1.39	1.31	29.4	19.9	31.1	26.8
	KOLA JOHA 3	81.3	71.0	84.9	79.1	44.4	44.2	41.0	43.2	42.6	30.0	44.3	39.0	2.13	1.20	1.99	1.77	68.4	26.9	66.1	53.8
	ZARDROME	129.7	125.7	124.2	126.5	32.9	36.0	34.4	34.4	28.5	23.3	29.6	27.1	1.55	0.86	1.36	1.26	33.1	15.0	30.2	26.1
N-Rec - Mean		**106.4**	**90.3**	**105.7**	**100.8**	**38.2**	**39.0**	**37.2**	**38.1**	**33.1**	**25.9**	**34.3**	**31.1**	**1.54**	**1.09**	**1.49**	**1.37**	**39.0**	**21.2**	**39.3**	**33.2**
LSD (T)		1.80*				1.51**				0.58*				0.056*				1.98*			
LSD (S × T)		4.74**				ns				1.52**				0.14**				5.21**			
LSD (E)		5.07**				1.04*				0.95**				ns				1.58*			
LSD (S × E)		8.78**				2.41**				1.66**				0.11**				3.66**			
LSD (T × E)		5.39*				ns				1.35**				0.093**				2.98**			
LSD (S × T × E)		12.41**				2.57*				2.34**				0.12*				5.17**			
CV (T)%		4.25				6.09				4.66				10.22				17.24			
CV (R)%		6.32				4.51				4.08				6.41				9.74			

Treat	Entry	Productive tiller number m^{-2}				Grain yield (g m^{-2})				TDM (g m^{-2})				HI (%)				Nitrogen Use Efficiency			
		S1	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**
N - Low	Basmati370	176.7	283.3	196.1	218.7	220.5	117.3	214.5	184.1	549.7	399.7	569.4	506.3	40.0	29.2	37.5	35.6	10.9	9.2	4.8	8.3
	Giza178	223.3	250.0	248.9	240.7	247.8	196.0	254.2	232.6	723.2	523.0	716.6	654.2	34.2	37.5	35.5	35.8	12.3	10.9	8.1	10.4
	IC-463222	210.0	316.7	233.3	253.3	238.2	221.7	186.7	215.5	566.6	611.3	532.2	570.0	42.0	36.2	35.1	37.8	11.8	8.0	9.1	9.6
	IC-463254	360.0	266.7	300.6	309.1	305.8	280.7	289.0	291.8	780.0	693.2	690.9	721.4	39.2	40.5	41.9	40.5	15.1	12.4	11.6	13.0
	KolaJoha3	173.3	183.3	227.2	194.6	88.5	244.7	94.0	142.4	285.2	648.0	341.5	424.9	30.9	37.8	27.7	32.1	4.4	4.0	10.1	6.2
	Zardrome	193.3	220.0	165.3	192.9	183.8	242.0	251.7	225.8	396.2	575.7	692.5	554.8	46.2	42.1	36.3	41.5	9.1	10.8	10.0	10.0
N-Low - Mean		**222.8**	**253.3**	**228.6**	**234.9**	**214.1**	**217.1**	**215.0**	**215.4**	**550.1**	**575.1**	**590.5**	**571.9**	**38.8**	**37.2**	**35.7**	**37.2**	**10.6**	**9.2**	**8.9**	**9.6**
N - Rec	Basmati370	286.7	416.7	396.7	366.7	601.8	413.2	578.7	531.2	1383.0	885.7	1276.8	1181.8	43.5	46.6	45.3	45.2	18.8	16.4	11.6	15.6
	Giza178	416.7	500.0	418.1	444.9	581.7	423.9	478.3	494.6	1350.0	986.5	1082.6	1139.7	43.1	43.0	44.2	43.4	18.2	13.6	11.9	14.6
	IC-463222	480.0	536.7	472.2	496.3	645.1	415.2	461.7	507.3	1327.7	993.2	961.0	1094.0	48.5	41.8	48.0	46.1	20.2	13.1	11.7	15.0
	IC-463254	503.3	466.7	513.9	494.6	671.6	656.2	536.7	621.5	1435.7	1338.5	1133.4	1302.5	46.8	49.0	47.4	47.7	21.0	15.2	18.5	18.2
	KolaJoha3	246.7	296.7	360.6	301.3	201.0	420.8	243.3	288.4	540.5	843.0	609.2	664.2	37.2	49.9	39.9	42.3	6.3	6.9	11.9	8.3
	Zardrome	266.7	366.7	311.4	314.9	548.6	429.9	531.3	503.3	1186.9	951.3	1178.0	1105.4	46.3	45.3	45.2	45.6	17.1	15.1	12.1	14.8
N-Rec - Mean		**366.7**	**430.6**	**412.1**	**403.1**	**541.6**	**459.9**	**471.7**	**491.1**	**1204.0**	**999.7**	**1040.1**	**1081.3**	**44.2**	**45.9**	**45.0**	**45.1**	**16.9**	**13.4**	**13.0**	**14.4**
LSD (T)		44.23**				27.68**				7.40*				1.64*							
LSD (S × T)		ns				47.94**				19.42**				ns							
LSD (E)		62.46**				19.69*				34.68*				ns							
LSD (S × E)		ns				45.35**				79.90**				3.93**							
LSD (T × E)		88.34**				27.84*				49.05*				ns							
LSD (S × T × E)		ns				64.14**				113.0**				5.56**							
CV (T)%		19.43				10.98				1.9				8.51							
CV (R)%		22.08				8.36				6.29				6.22							

Treat	Entry	Grain N uptake (Kg N ha^{-1})				Straw N uptake (Kg N ha^{-1})				Agronomic efficiency (kg grain kg^{-1} N)				Physiological efficiency (kg kg^{-1})			
		S1	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**
N - Low	Basmati370	20.0	10.7	20.3	17.0	13.3	11.0	16.9	13.7	-	-	-	-	-	-	-	-
	Giza178	26.8	21.6	29.4	25.9	18.2	13.5	18.4	16.7	-	-	-	-	-	-	-	-
	IC-463222	26.5	24.6	19.7	23.6	10.4	13.6	11.1	11.7	-	-	-	-	-	-	-	-
	IC-463254	32.4	29.8	31.1	31.1	18.7	17.5	16.6	17.6	-	-	-	-	-	-	-	-
	KolaJoha3	8.3	22.9	8.6	13.3	9.1	17.3	12.6	13.0	-	-	-	-	-	-	-	-
	Zardrome	19.0	25.1	26.6	23.6	8.6	14.4	18.6	13.9	-	-	-	-	-	-	-	-
N-Low - Mean		**22.2**	**22.5**	**22.6**	**22.4**	**13.0**	**14.5**	**15.7**	**14.4**	-	-	-	-	-	-	-	-
N - Rec	Basmati370	58.9	40.5	70.4	56.6	41.2	24.9	41.7	35.9	38.1	29.6	36.4	34.7	56.9	49.3	67.8	58.0
	Giza178	70.7	53.1	61.3	61.7	33.1	30.2	31.1	31.5	33.4	22.8	22.4	26.2	56.8	51.0	47.6	51.8
	IC-463222	85.3	54.8	58.4	66.1	27.9	27.6	21.6	25.7	40.7	19.3	27.5	29.2	53.3	56.4	43.9	51.2
	IC-463254	91.4	89.2	72.5	84.4	32.8	33.1	31.8	32.6	36.6	37.5	24.8	33.0	49.9	43.4	50.2	47.8
	KolaJoha3	23.2	47.9	27.0	32.7	19.7	21.8	22.2	21.2	11.2	17.6	14.9	14.6	44.1	53.4	59.3	52.2
	Zardrome	68.4	50.5	61.4	60.1	32.3	28.7	36.2	32.4	36.5	18.8	28.0	27.7	49.9	53.4	47.4	50.2
N-Rec - Mean		**66.3**	**56.0**	**58.5**	**60.3**	**31.2**	**27.7**	**30.8**	**29.9**	**32.8**	**24.3**	**25.7**	**27.6**	**51.8**	**51.1**	**52.7**	**51.9**
LSD (T)		3.49**				1.80**				-				-			
LSD (S × T)		6.05**				2.06*				-				-			
LSD (E)		2.37*				ns				3.68*				ns			
LSD (S × E)		5.46**				4.64**				8.59**				13.73**			
LSD (T × E)		3.35*				2.85*				-				-			
LSD (S × T × E)		7.72**				4.94*				-				-			
CV (T)%		11.85				11.44				-				-			
CV (R) %		8.59				13.65				13.89				11.78			

S1 - Kharif 2020; S2 – Rabi 2021; S3 – Kharif 2021; T – Treatment; S – Season; E – Entry; R - Residual

Increase in length and width of flag leaf with increased application of nitrogen was observed in both field and pot experiments and is attributed to enhanced photosynthetic activity with increased nitrogen content of plant (Manzoor *et al*., 2006; Bahmaniar *et al*., 2007; Kumar *et al*., 2008). The results obtained in present study were in accordance with Wang *et al*., (2006), who reported that increased nitrogen application has significantly increased the leaf area in rice and stated that nitrogen plays a very significant role in cell division which in turn is very essential for the increase in leaf area.

Flag leaf gas exchange traits

Data on flag leaf gas exchange traits is provided in **Table 2.** Significantly higher mean photosynthetic rate was recorded at N-Rec (15.55 µ mol CO_2 m^{-2} s^{-1}) compared with N-Low (12.11 µ mol CO_2 m^{-2} s^{-1}). Photosynthetic rate has differed significantly among the genotypes. Kolajoha3 (18.04 µ mol CO_2 m^{-2} s^{-1}) has exhibited significantly highest mean photosynthetic rate whereas Zardrome (11.57 µ mol CO_2 m^{-2} s^{-1}) showed least value. Photosynthetic rate has decreased significantly under N-Low compared to N-Rec in all the genotypes. Kolajoha3 (14.96%) has exhibited least reduction in photosynthetic rate while highest reduction was noticed in Basmati370 (32.82%). Stomatal conductance has increased significantly with N-Rec (0.30 mol [H_2O] m^{-2} s^{-1}) compared to N-Low (0.23 mol [H_2O] m^{-2} s^{-1}). Significant differences were observed among the genotypes for stomatal conductance. Kolajoha3 (0.32 mol [H_2O] m^{-2} s^{-1}) has recorded maximum stomatal conductance while minimum value was noticed in Zardrome (0.18 mol [H_2O] m^{-2} s^{-1}). Significant reduction in stomatal conductance of all the genotypes was observed with N-Low compared to N-Rec. Basmati 370 (15.89%) has exhibited least reduction in stomatal conductance whereas Kolajoha3 (32.23%) has showed highest reduction. Significant interaction was noticed between N treatments and genotypes. Maximum stomatal conductance was observed in Kolajoha3 at N-Rec (0.38 mol [H_2O] m^{-2} s^{-1}) whereas Zardrome at N-Low (0.16 mol [H_2O] m^{-2} s^{-1}) has recorded minimum value.

N-Rec (275 ppm) has showed significantly higher mean internal CO_2 concentration compared to N-Low (262 ppm). Genotypes has differed significantly for internal CO_2 concentration. Kolajoha3 (258 ppm) has recorded lowest mean internal CO_2 concentration while highest value was noticed in Giza178 (277 ppm). Mean transpiration rate has increased significantly with N-Rec (8.07 m mol [H_2O] m^{-2} s^{-1}) compared to N-Low (6.00 m mol [H_2O] m^{-2} s^{-1}). Significant differences were noticed among the genotypes for transpiration rate. Mean maximum transpiration rate was observed in Kolajoha3 (8.77 m mol [H_2O] m^{-2} s^{-1}) whereas Zardrome (5.51 m mol [H_2O] m^{-2} s^{-1}) has exhibited minimum value. Transpiration rate of all the genotypes has reduced significantly with N-Low compared to N-Rec. Giza178 (14.41%) has showed least reduction in transpiration rate while highest reduction was noticed in Kolajoha3 (36.52%). Significant interaction was observed between treatments and genotypes for transpiration rate. Maximum transpiration rate was observed in Kolajoha3 with N-Rec (10.72 m mol [H_2O] m^{-2} s^{-1}) whereas minimum value was noticed in Zardrome with N-Low (4.70 m mol [H_2O] m^{-2} s^{-1}).

Several studies have reported that N deficiency decreased photosynthetic rate in crop leaves, while sufficient N supply extended the longevity of functional leaves, hence, the photosynthetic capacity and grain yield improved. Similarly, in this study, photosynthetic rate increased with the nitrogen application. The results obtained in current study correspond to the reports for rice by Huang *et al*., (2004), who reported a significant reduction in photosynthetic rate and stomatal conductance (g_s) under low N supply.

Table 2: Effect of nitrogen application on leaf photosynthetic traits in six rice genotypes at 50% anthesis stage

Entry/Treat	Photosynthetic rate (μ mol CO_2 m^{-2} s^{-1})			Stomatal conductance (mol [H_2O] m^{-2} s^{-1})			Internal CO_2 concentration (ppm)			Transpiration rate (m mol [H_2O] m^{-2} s^{-1})		
	N-Low	N-Rec	Mean	N-Low	N-Rec	Mean	N-Low	N-Rec	Mean	N-Low	N-Rec	Mean
Basmati370	10.55	15.70	13.13	0.23	0.28	0.25	273	271	272	5.45	7.45	6.45
Giza178	10.18	14.42	12.30	0.27	0.36	0.31	286	268	277	6.78	7.92	7.35
IC-463222	13.35	15.80	14.57	0.23	0.30	0.27	253	285	269	5.75	8.18	6.97
IC-463254	12.03	14.76	13.39	0.23	0.31	0.27	263	281	272	6.53	7.80	7.16
KolaJoha3	16.58	19.50	18.04	0.26	0.38	0.32	240	275	258	6.81	10.72	8.77
Zardrome	10.00	13.14	11.57	0.16	0.20	0.18	256	271	264	4.70	6.32	5.51
Mean	**12.11**	**15.55**	**13.83**	**0.23**	**0.30**	**0.27**	**262**	**275**	**269**	**6.00**	**8.07**	**7.03**
LSD (T)	2.03*			0.049**			11.92*			1.21**		
LSD (E)	1.76**			0.030**			9.41**			0.73**		
LSD (T × E)	ns			0.042**			13.30**			1.04**		
CV (T) %	10.23			5.54			3.09			5.22		
CV (R) %	7.77			6.83			2.13			6.38		

T-Treatment; E-Entry; R-Residual

Yield and Yield attributes

Significant increase in number of productive tillers per m^2 was observed with nitrogen application **(Table 1).** N-Rec has recorded highest mean productive tillers (403.1) while lowest number (234.9) was observed in N-Low. Genotypes has differed significantly for productive tiller number. At N-Rec, IC463254 (503.3 and 513.9) during *kharif-2020* and *kharif-2021*, IC463222 (536.7) during *rabi-2021* has exhibited higher number of productive tillers while lowest number was noticed in Kolajoha3 (246.7 and 296.7) during *kharif-2020* and *rabi-2021*, Zardrome (311.4) during *kharif-2021*. In comparison with N-Rec, productive tiller number has decreased significantly under N-Low in all three seasons. Zardrome (27.50%), Basmati370 (32.00%) and Kolajoha3 (36.98%) has exhibited least reduction in productive tiller number while highest reduction was noticed in IC463222 (56.25%), Giza178 (50.00%) and Basmati370 (50.81%) in *kharif-2020*, *rabi-2021* and *kharif-2021*.

Grain yield was significantly influenced by nitrogen application. Highest mean grain yield was recorded with N-Rec (491.1 g m^{-2}) whereas N-Low (215.4 g m^{-2}) has recorded the least. Significant differences were noticed among the genotypes for grain yield. At N-Rec, IC463254 (671.6 and 656.2 g m^{-2}) during *kharif-2020* and *rabi-2021*, Basmati370 (578.7 g m^{-2}) during *kharif-2021* has recorded higher grain yield, while lowest grain yield was noticed in Kolajoha3 (201.0 and 243.3 g m^{-2}) during *kharif-2020* and *kharif-2021*, Basmati370 (413.2 g m^{-2}) during *rabi-2021*. Significant reduction in grain yield was observed with N-Low compared with N-Rec in all three seasons **(Figure 1).** Zardrome (66.50%) during *kharif-2020*, Basmati370 (71.61% and 62.93%) during *rabi-2021* and *kharif-2021* has exhibited highest reduction in grain yield while least reduction was noticed in IC463254 (54.46% and 46.15%) during *kharif-2020* and *kharif-2021*, Kolajoha3 (41.86%) during *rabi-2021*.

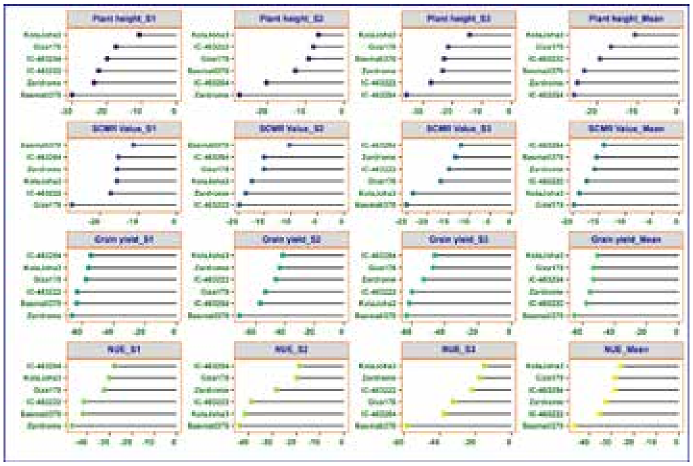

Figure 1: Per cent reduction in plant height, SCMR Value, grain yield and NUE of rice genotypes under N-Low compared with N-Rec

Nitrogen application has significantly influenced the total dry matter. N-Rec (1081.3 g m^{-2}) has exhibited the highest mean total dry matter while least value was recorded with N-Low (571.9 g m^{-2}). Genotypes has differed significantly for total dry matter. IC463254 (1435.7 and 1338.5 g m^{-2}) during *kharif-2020* and *rabi-2021*, Basmati370 (1276.8 g m^{-2}) during *kharif-2021* has recorded significantly higher total dry matter compared to other genotypes, while lowest was recorded in Kolajoha3 (540.5, 843.0 and 609.2 g m^{-2}) during *kharif-2020*, *rabi-2021* and *kharif-2021* at N-Rec. In comparison with N-Rec, total dry matter has decreased significantly under N-Low in all three seasons. Zardrome (66.62%) during *kharif-2020*, Basmati370 (54.87% and 55.40%) during *rabi-2021* and *kharif-2021* has exhibited the highest reduction in total dry matter while least reduction was noticed in IC463254 (45.67%), Kolajoha3 (23.13%) and Giza178 (33.81%) during *kharif-2020*, *rabi-2021* and *kharif-2021*.

Harvest index has increased significantly with Nitrogen application. Highest mean harvest index was observed with N-Rec (45.1%) whereas N-Low (37.2%) has recorded the least. At N-Rec, IC463222 (48.5 and 48.0%) during *kharif-2020* and *kharif-2021*, Kolajoha3 (49.9%) during *rabi-2021* has recorded highest harvest index while least harvest index was observed in Kolajoha3 (37.2 and 39.9%) during *kharif-2020* and *kharif-2021*, IC463222 (41.8%) during *rabi-2021*. Harvest index has decreased significantly with N-Low compared to N-Rec in all three seasons. Least reduction in harvest index was noticed in Zardrome (0.16% and 7.03%) during *kharif-2020* and *rabi-2021*, IC463254 (11.62%) during *kharif-2021* while highest reduction was observed in Giza178 (20.56%), Basmati370 (37.36%) and Kolajoha3 (30.70%) during *kharif-2020*, *rabi-2021* and *kharif-2021*.

Jahan *et al*., (2022) observed that N fertilization increased the number of tillers m^{-2}, which resulted due to the increased N availability for cell division which supports results obtained in present investigation. Srikanth *et al*., (2022) also indicated that suitable dosage of N fertilizer is a key factor to increase rice grain yield. The dry matter production of rice plants is a vitally important factor that determines the formation of rice grain yield (Ye *et al*., 2013). Dry matter production is the result of the accumulation and translocation of photosynthates in different plant organs, which is significantly affected by nitrogen management (Deng *et al*., 2015; Peng *et al*., 2007; Qiao *et al*., 2013). Optimal nitrogen application amounts and rational N application timing would be beneficial to improve rice population quality, and increasing dry matter accumulation and grain yield.

Nitrogen uptake and Nitrogen Use Efficiency

Grain N uptake has increased significantly with N application. N-Rec (60.3 kg ha^{-1}) has recorded highest mean grain N uptake whereas N-Low (22.4 kg ha^{-1}) has recorded the least. Significant differences were noticed among the genotypes for grain N uptake. At N-Rec, IC463254 (91.4, 89.2 and 72.5 kg ha^{-1}) has recorded highest grain N uptake during *kharif-2020*, *rabi-2021* and *kharif-2021* while least uptake was observed in

Kolajoha3 (23.2 and 27.0 kg ha^{-1}) during *kharif-2020* and *kharif-2021*, Basmati370 (40.5 kg ha^{-1}) during *rabi-2021*. In comparison with N-Rec, grain N uptake has decreased significantly under N-Low in all three seasons. Zardrome (72.15%) during *kharif-2020*, Basmati 370 (73.61% and 71.12%) during *rabi-2021* and *kharif-2021* has exhibited the highest reduction in grain N uptake while least reduction was noticed in Giza178 (62.04% and 52.04%) during *kharif-2020* and *kharif-2021*, Zardrome (50.20%) during *rabi-2021*.

Nitrogen application has significantly increased the straw N uptake. Highest mean straw N uptake was observed with N-Rec (29.9 kg ha^{-1}) whereas N-Low (14.4 kg ha^{-1}) has recorded the least. At N-Rec, Basmati370 (41.2 and 41.7 kg ha^{-1}) during *kharif-2020* and *kharif-2021*, IC463254 (33.1 kg ha^{-1}) during *rabi-2021* has showed highest straw N uptake while lowest uptake was recorded in Kolajoha3 (19.7 and 21.8 kg ha^{-1}) during *kharif-2020* and *rabi-2021*, IC463222 (21.6 kg ha^{-1}) during *kharif-2021*. Straw N uptake has decreased significantly with N-Low compared to N-Rec in all three seasons. Highest reduction was observed in Zardrome (73.45%) during *kharif-2020*, Basmati370 (55.88% and 59.41%) during *rabi-2021* and *kharif-2021* while IC463254 (43.13%) during *kharif-2020*, Kolajoha3 (20.77%) during *rabi-2021* and Giza178 (40.95%) during *kharif-2021* has exhibited least reduction in straw N uptake.

Agronomic efficiency has differed significantly among the genotypes **(Table 1).** IC463222 (40.7 kg grain kg^{-1} N), IC463254 (37.5 kg grain kg^{-1} N) and Basmati370 (36.4 kg grain kg^{-1} N) has exhibited highest agronomic efficiency, whereas Kolajoha3 (11.2 kg grain kg^{-1} N, 17.6 kg grain kg^{-1} N and 14.9 kg grain kg^{-1} N) has exhibited least agronomic efficiency during *kharif-2020*, *rabi-2021* and *kharif-2021*. No significant differences were noticed among the genotypes for physiological efficiency. Kolajoha3 (44.1 kg kg^{-1}), IC463254 (43.4 kg kg^{-1}) and IC463222 (43.9 kg kg^{-1}) has recorded least physiological efficiency during *kharif-2020*, *rabi-2021* and *kharif-2021*, while highest physiological efficiency was noticed in Basmati370 (56.9 kg kg^{-1}) and Giza178 (56.8 kg kg^{-1}) during *kharif-2020*, IC463222 (56.4 kg kg^{-1}) during *rabi-2021* and Basmati370 (67.8 kg kg^{-1}) during *kharif-2021*.

NUE has increased significantly with nitrogen application. N-Rec has showed significantly higher mean NUE (14.4) whereas N-Low has recorded the lowest (9.6). Significant differences were noticed among the genotypes for NUE. At N-Rec, IC463254 (21.0 and 18.5) during *kharif-2020* and *kharif-2021*, Basmati 370 (16.4) during *rabi-2021* has recorded higher NUE while lowest value was noticed in Kolajoha3 (6.3 and 6.9) during *kharif-2020* and *rabi-2021*, Basmati370 (11.6) during *kharif-2021*. NUE was reduced significantly under N-Low compared to N-Rec in all three seasons **(Figure 1).** IC463254 (27.86% and 18.65%) during *kharif-2020* and *rabi-2021*, Kolajoha3 (15.06%) during *kharif-2021* has showed least reduction while highest reduction was observed in Zardrome (46.93%) during *kharif-2020*, Basmati 370 (44.00% and 58.52%) during *rabi-2021* and *kharif-2021*.

NUE is largely influenced by grain yield, N fertilizer input and N uptake by the plant (Qiao *et al*., 2012). As to the present experiment, the increase in N supply has been reported to increase grain and straw N concentration, and grain and straw N uptake for rice (Yesuf and Balcha 2014). Under optimum management practices agronomic efficiency should be above 25 kg grain kg^{-1} N (Dobermann 2005). In the present study, all the genotypes except Kolajoha3 (14.6 kg grain kg^{-1} N) have showed mean agronomic efficiency above the value suggested by Dobermann. Many scientists have reported variations in NUE of different rice genotypes. These variations may be attributed due to genetic factors, biochemical and physiological processes such as translocation, assimilation, and N remobilization (Fageria and Baligar 2003).

Conclusion

In conclusion, at N-Rec, Kolajoha3 has exhibited highest mean SCMR value (43.2), flag leaf length (39.0 cm), flag leaf width (1.77 cm), flag leaf area (53.8 cm^2), photosynthetic rate (19.50 μ mol CO_2 m^{-2} $s^{-1),}$ stomatal conductance (0.38 mol [H_2O] m^{-2} $s^{-1),}$ transpiration rate (10.72 m mol [H_2O] m^{-2} $s^{-1),}$ and IC463254 has recorded highest mean grain yield (621.5 g m^{-2}), total dry matter (1302.5 g m^{-2}), harvest index (47.7%), grain N uptake (84.4 kg $ha^{-1)}$ and NUE (18.2). Kolajoha3 has exhibited least mean reduction in plant height (10.68%), photosynthetic rate (14.96%), productive tiller number (35.40%), grain yield (50.63%), straw yield (24.83%), total dry matter (36.03%), agronomic efficiency (14.6%) and NUE (26.21%), and IC463254 has exhibited least mean reduction in SCMR value (14.11%) and flag leaf width (23.66%). Hence, Kolajoha3 and IC463254 can be further utilized in breeding programmes for developing nitrogen use efficient rice cultivars.

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Competing interests

Authors have declared that no competing interests exist.

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Assimilate Partitioning and Photosynthetic Parameters of Rice (*Oryza sativa* L.) in Response to Salicylic Acid Application

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Abstract

Salicylic acid (SA), a signaling molecule is known to affect various physiological processes like growth and development, photosynthesis, absorption and translocation of assimilates etc. Therefore, an experiment was conducted to study the effect of salicylic acid on assimilate partitioning and yield of rice. The experiment comprised of 14 treatments replicated thrice in Randomized Complete Block Design (RCBD). Foliar application of SA @ 50, 100, 150 & 200 µg ml^{-1} was done at boot leaf stage (BL), one week after boot leaf stage (1WABL) and at BL + 1WABL. Treatment of water spray and unsprayed (control) were also included. Findings reveal that application of 100 µg ml^{-1} SA at BL + 1WABL resulted in the highest grain yield, which was statistically similar to 150 µg ml^{-1} SA at BL + 1WABL. The higher productivity under respective treatments can be ascribed to higher crop growth rate, relative growth rate, net assimilation rate and improvement in partitioning of dry matter from vegetative parts to grains due to improved vascularization. Also there was improvement in photosynthetic efficiency in terms of total chlorophyll content; carotenoid content and Hill reaction activity under SA treated plots. Thus, the productivity enhancement in rice can be achieved through 2 foliar sprays of salicylic acid @ 100 µg ml^{-1} each at boot leaf stage + one week after boot leaf stage.

Keywords: Dry matter partitioning, photosynthetic efficiency, rice, salicylic acid, yield

Introduction

Rice (*Oryza sativa* L.) belonging to family *Poaceae* is commonly cultivated as an annual plant. In tropical Asia, rice is consumed by 90% population (Bandumula 2017). India is world's second largest rice producing country after China. Amongst the various factors responsible for low yield of rice, poor grain filling is the most important one. The grain filling may be influenced by number of factors such as environmental conditions, hormonal balance, nutrient supply, water supply through effect on photosynthetic rate, leaf senescence or altered source-sink ratio etc. A balance between source and sink largely determines the grain filling. Although the sink capacity of large panicle rice is also huge but poor assimilate partitioning and export of sucrose content may lead to poor inferior spikelet filling, low seed setting rate and reduced yield. Srivastava *et al.,* (2017) reported that grain weight is reduced due to decrease in mobilization of reserve pre-anthesis assimilates leading to decrease in grain filling. Interruption in photosystem II is observed due to alterations in thylakoid membrane. Thus, negative influence on photosynthetic activity. Moreover, it leads to excessive production of ROS, which results in disturbed integrity of membrane and also may lead to death of the cell. Zhang *et al*., (2019) opined that variation in grain development between spikelets in a panicle is greatly influenced by phytohormones. Assimilates stored in the sheath and stem before heading and those produced after heading contribute to grain filling. Carbohydrates in the form of sucrose are translocated from source tissues to the sink (grain) and a number of enzymes catalyse the conversion of these assimilates to starch. Inadequate supply of carbohydrate causes the slow grain filling and low grain weight of inferior spikelets. During early grain filling, hormone levels play an essential role in the grain development. Fu *et al*., (2011) observed the effect of temperature on grain filling of rice and reported that temperature may affect grain filling in inferior spikelets. Nazar *et al*., (2017) reported that under environmental extremes salicylic acid enhances heat tolerance capacity of plants. To cope with the adverse effects of various stresses, plant growth regulators and antioxidant compounds have been used extensively (Iqbal *et al*., 2013). Exogenous application of SA improved the growth and biomass of heat tolerant as well as sensitive genotypes of rice. Physiological and biochemical processes are adversely affected under extreme temperature conditions which result in reduction. Salicylic acid protect the membranes and enzymes against heat-induced ROS-mediated degradation, thus increasing the crop productivity. The present study was thus planned with the objective to investigate the effect of salicylic acid on photosynthetic parameters and on mobilization of assimilates in rice.

Materials and Methods

Experiment was conducted during *kharif* 2019 at Research Farm and Laboratory of department of Botany, Punjab Agricultural University, Ludhiana, India [30°56’ N latitude; 75°52’ E longitude; 247 m altitude] located in the Western Indo-Gangetic Plains (WIGPs). Climate of experimental site is characterized as subtropical, semi–arid with an annual rainfall of 733 mm, out of which about 80% is received during June to September. The data on rainfall, sunshine hours, maximum and minimum temperatures were measured at agro-meteorological observatory of Punjab Agricultural University, Ludhiana, situated at 200 meters away from experimental site **(Table 1)**. The soil of the experimental field was sandy-loamy in texture, high in available-P and available-K but low in available N and soil organic carbon (SOC) status. The electrical conductivity and pH of the soil were within normal range.

Table 1: Mean monthly meteorological data during crop growth season (*Kharif* 2019)

Month	Temperature (ºC)			Rainfall (Mm)	Sun-shine Hours
	Maximum	Mini-mum	Mean		
	2019	2019	2019	2019	2019
June	40.4	26.8	33.6	29.9	305.4
July	34.0	26.7	30.3	218.4	129.8
August	33.8	26.7	30.3	331.4	200.4
September	33.1	25.5	29.3	264.8	184.0
October	30.6	18.4	24.5	0.0	197.6
Mean/Total	34.4	24.8	29.6	844.5	1017.2

Experiment comprising 14 treatments was laid in Randomized Complete Block Design (RCBD) with three replications. The treatments included foliar application of Salicylic acid (SA) @ 50, 100, 150 & 200 µg ml1 at boot leaf stage (BL), one week after boot leaf stage (1WABL) and at BL + 1WABL. Treatment of water spray and unsprayed (control) were also kept. The sowing of short duration variety ‘PR 126’ was done during last week of May and was transplanted during last week of June using 30 days old seedlings. Crop was transplanted with a spacing 15 cm x 20 cm and size of plot was 2.2 x 3.5 metre. All other production and protection technologies were followed as per recommendations of Punjab Agricultural University, Ludhiana (Anonymous, 2019). Recommended dose of fertilizer (N @ 105 kg/ha and $ZnSo_4$ (21%) @ 25 kg/ha) was applied to the crop. Nitrogen was applied in the form of urea in three equal splits at 7, 21 and 35 days after transplanting (DAT). Whole of $ZnSo_4$ was applied as basal. Owing to sufficient level of available P and K, these nutrients were not applied to the experiments crop.

Total chlorophyll content, carotenoid content and Hill reaction activity was measured from randomly chosen leaves from each plot and calculated by using the equation suggested by Hiscox and Israelstam (1979) for chlorophyll and carotenoid content and Hill reaction activity was calculated by using the equation given by Cherry (1973). For recording dry matter partitioning, five plants were cut at ground level from each plot and were separated into different parts (leaf, stem, grains, chaff) and then oven dried at 60-65 ºC to a constant weight. Dry matter remobilization efficiency (%) and dry matter conversion rate (%) was calculated by using the formulae suggested by Ntanos *et al.*, (2002) and Xiong *et al.*, (2013). The crop growth rate (CGR), Relative growth rate (RGR) and Net assimilation rate (NAR) were calculated as suggested by Watson (1958), Radford (1967) and Vernon and Allison (1963), respectively. For recording grain yield, the grains obtained after threshing net plots were sun dried, winnowed, cleaned and weighed on an electronic balance. For valid comparison of different treatments, moisture in grains was estimated using moisture meter. Grain yield was measured after reducing moisture content to 14% moisture using digital moisture meter (Kett's RICETER J Handheld grain moisture meter) and expressed as q ha^{-1}. Data were subjected to analysis of variance (ANOVA) using Proc GLM procedure of SAS software (SAS 9.3.) as per RCBD. The multiple comparisons among treatment means were carried out by Tukey's test ($p \leq 0.05$).

Results and Discussion

Photosynthetic parameters

SA treatments caused an increase in total chlorophyll and carotenoid content as compared to control **(Figure 1)**. At anthesis stage, the highest total chlorophyll and carotenoid content was recorded in leaves of plants treated with 100 µg ml^{-1} SA at BL + 1WABL. A decrease in total chlorophyll content was recorded at physiological maturity stage. However, at this stage also 100 µg ml^{-1} SA at BL + 1WABL showed maximum total chlorophyll content (2.31 mg g^{-1} fresh weight) as compared to 1.44 mg g^{-1} fresh weight in unsprayed control. Application of SA also caused an increase in Hill reaction activity at both the stages as compared to control (unsprayed).

Figure 1: Effect of different concentrations of salicylic acid on photosynthetic parameters

At anthesis stage plants treated with 100 µg ml^{-1} SA at BL + 1WABL showed the highest Hill reaction activity (0.44 Δ O.D. mg^{-1} chl h^{-1}). At maturity stage also, same treatment resulted in the highest Hill reaction activity. It was least in control plants (0.15 Δ O.D. mg^{-1} chl h^{-1}). SA application improved the carotenoid content in leaves. Muthulakshmi and Linga Kumar (2016) also observed improved chlorophyll and carotenoid content in SA treated mungbean plants.

Anatomy of peduncle

Plates 1 show the transverse sections of peduncle in control (unsprayed), water sprayed and SA treated plants. The sections were hand-cut and observed under Leica Bright Field Research Microscope at 4x magnification. A variation in number of vascular bundles was observed in all the treatments as compared to control. The peduncle of unsprayed control plants showed least number of vascular bundles (12). Application of 50 µg ml^{-1} SA at boot leaf stage caused an increase in number of vascular bundles (14) in the peduncle. The number of vascular bundles in plants treated with 100 µg ml^{-1} SA at boot leaf stage was 17 while those treated with 150 and 200 µg ml^{-1} SA had 16 and 13 vascular bundles, respectively, in their peduncles. The plants treated with 50, 100, 150 and 200 µg ml^{-1} SA at one week after boot leaf stage had 13, 16, 15 and 14 vascular bundles, respectively, in their peduncles. The number of vascular bundles in peduncles of plants treated with 50, 100, 150 and 200 µg ml^{-1} SA at boot leaf + one week after boot leaf stage were 13, 19, 17 and 16, respectively. Plants treated with 100 µg ml^{-1} SA at boot leaf + one week after boot leaf stage showed maximum number of vascular bundles in their peduncles. The increase in number of vascular bundles led to an increase in area of conducting tissues which might be responsible for translocation of more assimilates to the grains.

Dry matter partitioning, growth analysis and grain yield

Data presented in **Table 2** reveals significant influence of SA application on dry matter partitioning of rice. It is evident that application of 100 µg ml^{-1} SA at BL + 1WABL resulted in the highest values of dry matter accumulation (DMA) in leaves, stem and panicle (at anthesis stage) compared to control (unsprayed), which was onpar with 150 µg ml^{-1} SA at BL + 1WABL. Application of 100 µg ml^{-1} SA at BL + 1WABL resulted in 35.4, 34.15, 13.5 and 65.6% enhancement in DMA in leaves, stem, chaff and grains over control respectively at physiological maturity stage. Although water sprayed plots showed improvement in DMA by panicle at anthesis stage and by chaff at physiological maturity but differences in DMA by other plant parts could not reach the level of significance amongst these two treatments **(Table 2).** Our results are supported by the observations recorded by Parveen *et al*., (2020) and Sha *et al*., (2019).

Data in **Figure 2** shows that dry matter remobilization efficiency also increased following SA application as compared to control (Unsprayed). Plants treated with 100 µg ml^{-1} SA at BL + 1WABL had maximum dry matter remobilization efficiency (40.2%) which was followed by 150 µg ml^{-1} SA treated plants (38.8%), whereas, control (unsprayed) and water spray treatments registered the least dry matter remobilization efficiency (30.9 and 31.9%).

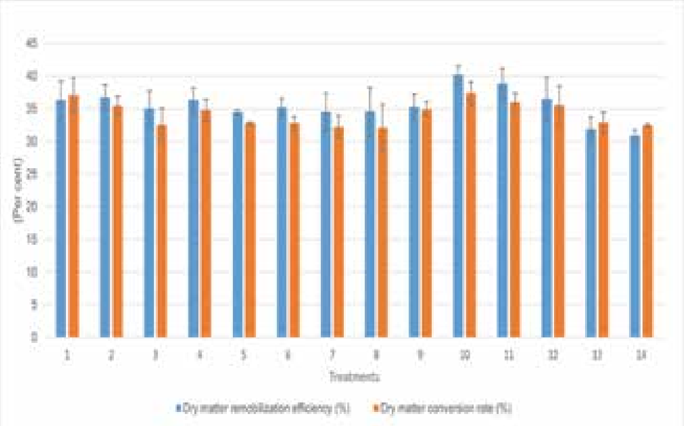


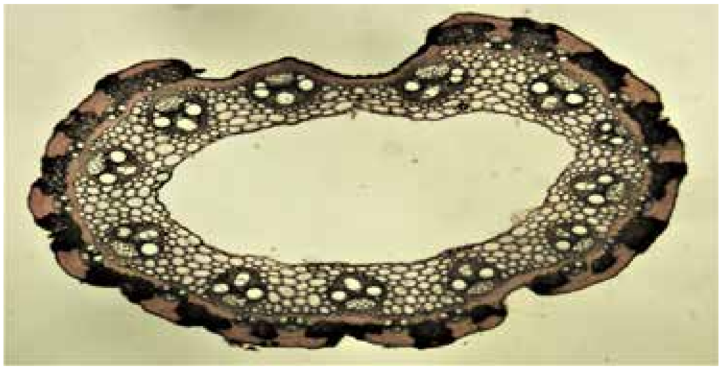
Figure 2: Effect of different concentrations of salicylic acid on dry matter remobilization efficiency (%) and dry matter conversion rate (%)

In general, dry matter remobilization efficiency ranged between 30.9 to 40.2% among different treatments. Increase in dry matter remobilization efficiency in plants treated with 100 µg ml^{-1} SA was due to increase assimilates translocation. Dry matter conversion rate was in the range of 32.5% to 37.3% and the trend was similar to that observed for dry matter remobilization efficiency. **Figure 3** depicts growth analysis (CGR, RGR and NAR) from vegetative to anthesis stage and anthesis to physiological maturity stage as affected by SA application. SA treated plants maintained higher CGR as compared to control (water sprayed and unsprayed). During vegetative to anthesis stage, the highest CGR, RGR and NAR was registered under 100 µg ml^{-1} SA at BL + 1WABL. As crop advanced to physiological maturity stage, there was decline in CGR, RGR and NAR but SA treated crop maintained higher values of these indices as compared to control. Foliar application of SA increased CGR, RGR and NAR in maize which is corroborated by the findings of Amin *et al*., (2013). The treatment of water spray although recorded numerical increment in grain yield over control (unsprayed) but difference was statistically not significant. Data further brings out that the highest grain yield was recorded under the treatment of 100 µg ml^{-1} SA at BL + 1WABL due to better yield attributes under this treatment. The former treatment was statically similar to the treatment of 150 µg ml^{-1} SA at BL + 1WABL. Both these treatments excelled over the control (unsprayed) by a respective margin of 14.6% and 13.5% **(Table 2)**. Increase in grain yield in SA treated plants might be due to role of SA in mobilization of assimilates from source to developing sink on account of increased vascularization **(Plate 1)**. Saranraj (2014) also reported an increase in grain yield following SA application. Similar results were obtained by Jatana *et al*., (2020) and Parveen *et al*., (2020).

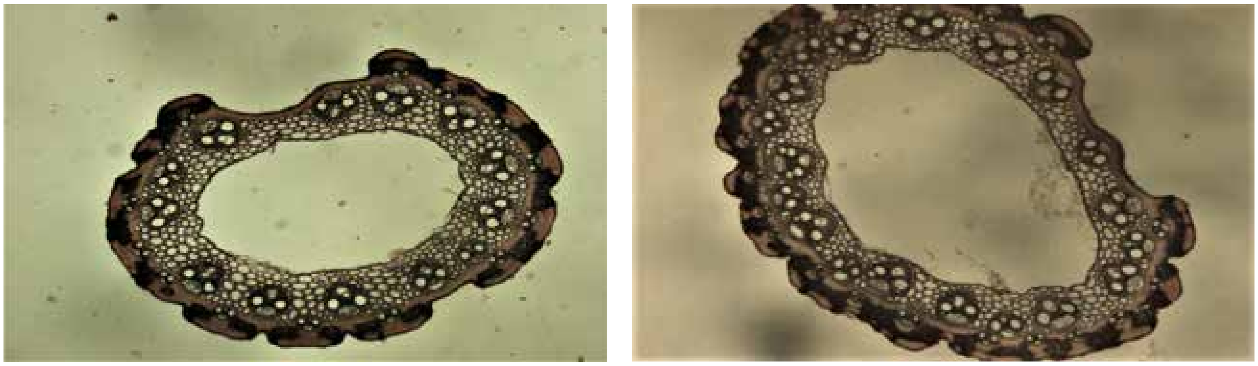
Table 2: Effect of different concentrations of salicylic acid on periodic dry matter partitioning (g plant^{-1}) and grain yield of rice

Treatments	Anthesis Stage			Physiological Maturity				Grain yield (q ha^{-1})
	Leaves	Stem	Panicle	Leaves	Stem	Chaff	Grains	
50 µg ml^{-1} SA at BL	14.88^{c} ± 0.50	10.29^{c-e} ± 0.19	11.98^{hi} ± 0.01	10.83^{de} ± 0.20	9.11^{c-e} ± 0.09	7.33^{de} ± 0.07	26.57^{e} ± 0.18	74.8^{de} ± 0.35
100 µg ml^{-1} SA at BL	16.68^{ab} ±0.24	11.80^{a-c} ± 0.13	13.32^{d-f} ± 0.09	12.96^{ab} ± 0.27	9.71^{a-e} ± 0.23	7.90^{a-c} ± 0.01	31.65^{cd} ± 0.12	78.0^{b-d} ± 0.53
150 µg ml^{-1} SA at BL	16.84^{ab} ± 0.07	11.86^{ab} ± 0.65	13.64^{c-e} ± 0.17	13.41^{ab} ± 0.19	9.94^{a-d} ± 0.16	8.00^{ab} ± 0.01	33.79^{bc} ± 0.58	79.3^{a-d} ± 0.73
200 µg ml^{-1} SA at BL	16.65^{ab} ± 0.09	11.05^{b-d} ± 0.19	13.29^{d-f} ± 0.15	12.94^{ab} ± 0.09	9.34^{b-e} ± 0.27	7.80^{bc} ± 0.02	31.38^{d} ± 0.06	78.0^{b-d} ± 1.16
50 µg ml^{-1} SA at 1WABL	15.08^{c} ± 0.06	10.42^{b-e} ± 0.28	12.40^{gh} ± 0.04	11.84^{cd} ± 0.15	9.14^{c-e} ± 0.08	7.21^{e} ± 0.01	29.61^{d} ± 0.58	76.0^{c-e} ± 0.75
100 µg ml^{-1} SA at 1WABL	17.37^{ab} ± 0.04	11.93^{ab} ± 0.15	13.94^{b-d} ± 0.04	13.63^{ab} ± 0.24	10.20^{a-c} ± 0.37	8.16^{a} ± 0.03	34.28^{b} ± 0.58	79.8^{a-c} ± 0.81
150 µg ml^{-1} SA at 1WABL	17.40^{ab} ± 0.23	11.94^{ab} ± 0.56	14.30^{bc} ± 0.21	13.74^{ab} ± 0.16	10.57^{a-c} ± 0.34	8.17^{a} ± 0.05	34.62^{b} ± 0.58	80.2^{a-c} ± 1.05
200 µg ml^{-1} SA at 1WABL	16.72^{ab} ± 0.16	11.83^{a-c} ± 0.44	13.41^{de} ± 0.23	13.29^{ab} ± 0.22	9.94^{a-d} ± 0.14	7.96^{a-c} ± 0.01	33.61^{bc} ± 0.58	78.5^{a-d} ± 1.50
50 µg ml^{-1} SA at BL + 1WABL	16.34^{b} ± 0.32	10.88^{b-d} ± 0.07	12.52^{f-h} ± 0.10	12.81^{c} ± 0.27	9.27^{c-e} ± 0.69	7.30^{de} ± 0.01	29.64^{d} ± 0.06	76.5^{c-e} ± 1.26
100 µg ml^{-1} SA at b BL + 1WABL	17.78^{a} ± 0.19	13.25^{a} ± 0.20	15.32^{a} ± 0.10	13.89^{a} ± 0.06	11.00^{a} ± 0.02	8.17^{a} ± 0.12	38.50^{a} ± 0.61	83.1^{a} ± 1.56
150 µg ml^{-1} SA at BL + 1WABL	17.72^{a} ± 0.10	12.66^{a} ± 0.14	14.53^{ab} ± 0.10	13.79^{ab} ± 0.25	10.94^{ab} ± 0.23	7.63^{cd} ± 0.06	35.65^{b} ± 0.07	82.3^{ab} ± 1.72
200 µg ml^{-1} SA at BL + 1WABL	16.39^{b} ± 0.19	10.95^{b-d} ± 0.17	13.01^{e-g} ± 0.19	12.89^{ab} ± 0.09	9.29^{c-e} ± 0.62	7.40^{de} ± 0.01	30.40^{d} ± 0.58	77.0^{c-e} ± 1.74
Water sprayed	14.10^{d} ± 0.10	10.19^{de} ± 0.14	11.46^{i} ± 0.27	10.56^{e} ± 0.29	8.41^{de} ± 0.08	8.15^{a} ± 0.13	24.71^{f} ± 0.18	74.5^{de} ± 1.00
Control (Unsprayed)	13.67^{d} ± 0.31	9.20^{e} ± 0.05	10.72^{j} ± 0.20	10.26^{e} ± 0.05	8.20^{e} ± 0.16	7.20^{e} ± 0.12	23.25^{f} ± 0.21	72.5^{e} ± 0.85

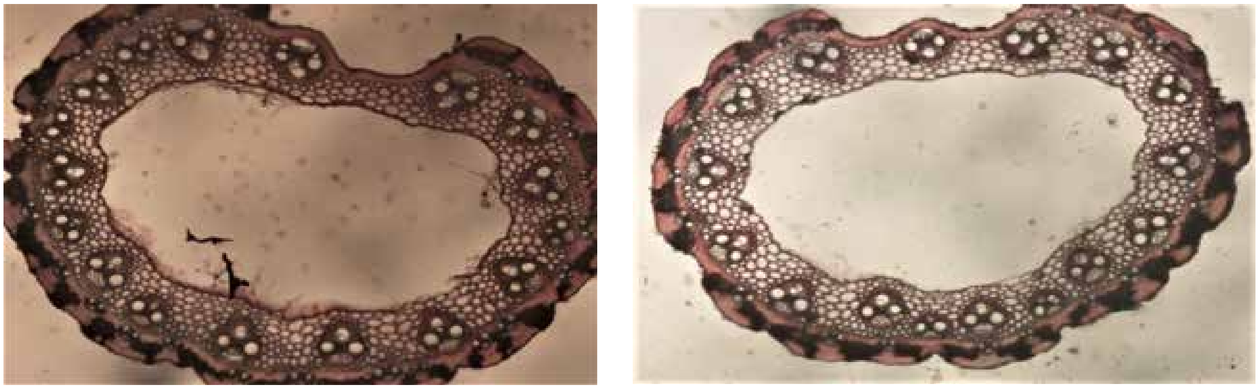
Means in the same column followed by different letters are significantly different at $p<0.05$.



(a) Control (no spray)



(b) 50 µg ml^{-1} SA at boot leaf+ one week after boot leaf stage (c) 100 µg ml^{-1} SA at boot leaf+ one week after boot leaf stage



(d) 150 µg ml^{-1} SA at boot leaf+one week after boot leaf stage (e) 200 µg ml^{-1} SA at boot leaf+ one week after boot leaf stage

Plate 1: Variation in number of vascular bundles in peduncle of plants under different treatments

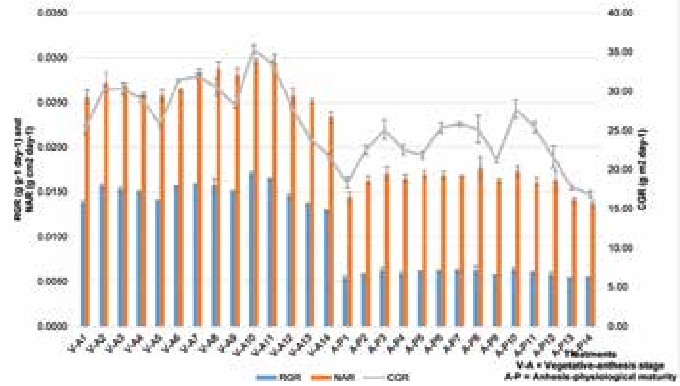


Figure 3: Effect of different concentrations of salicylic acid on crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR)

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Water Productivity, Economic Viability and Yield of Rice under Different Rice Establishment Methods

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Abstract

A field experiment was conducted during the *kharif* (2013*)* at Tamil Nadu Rice Research Institute (TRRI), Aduthurai to evaluate the productivity and input usage of different rice establishment methods *viz*., wet direct seeding using drum seeder, dry direct seeding using tractor operated seed drill, and conventional transplanting. Data reveal that dry seeding using a tractor drawn seed drill utilized a lower seed rate of 30 kg/ha compared to wet seeding (37.5 kg/ha) and transplanted rice (60 kg/ha). The plant height and plant population did not exhibit significant variations across the different establishment methods. However, yield attributes like ear bearing tillers (396/m^2) and filled grains (137/panicle) were significantly higher in transplanted rice. Nonetheless, dry seeded rice recorded a grain yield of 6040 kg/ha which was only 5.5% lower than that of transplanted rice. Notably, dry seeding conserved 32.6% of irrigation water and reduced labour requirement by 48.9% compared to transplanted rice. Moreover, dry seeded rice exhibited higher water productivity (6.40 kg/ha/mm) and a higher benefit cost ratio (2.66) as compared to other establishment methods. Therefore, considering the existing water crisis and labour shortage, the adoption of dry seeding for rice cultivation holds promise as a viable solution for farmers. This method not only addresses the challenges posed by limited water availability and the scarcity of labour but also maintains satisfactory levels of productivity.

Keywords: Dry seeded rice, wet seeded rice, transplanted rice, productivity, input use, economics

Introduction

The Cauvery delta region often referred to as the “Rice bowl of South India” is renowned for its extensive rice cultivation. However, rice production in this region faces several challenges, including water scarcity, labour shortage and rising labour costs (Surendran *et al.,* 2021). Furthermore, the impact of climate change exacerbates the water availability issues for irrigated agriculture, particularly in rice cultivation (Vijayakumar *et al*., 2021). In the Cauvery Delta Zone, the cultivation of *kharif* rice (May/June to September/October) heavily Threlies on irrigation from the Cauvery river water supplied by the Mettur Dam, groundwater sources, and supplemented by rainfall during South West monsoon. Unfortunately, there has been a rise in the occurrence of problems such as failure of monsoon rains in catchment areas, uncertainties surrounding the release of canal water and untimely water supply in the past decade. These prevailing challenges have led farmers in the region to seek alternate rice establishment methods that require less input and lower cultivation costs (Subramanian *et al*., 2021).

The alternate rice establishment methods are crucial to address various challenges and enhance the efficiency of rice cultivation. Transplanting rice is known to be labour-intensive, and the scarcity of skilled laborers represents a significant constraint (Vijayakumar *et al*., 2018). By embracing alternate approaches such as drip irrigation, direct seeding or dry seeding, the reliance on manual labour can be reduced significantly (Subramanian *et al*., 2023). Moreover, these methods offer advantages such as time savings, cost reduction, and enhanced water management, thereby promoting the economic viability and environmental sustainability of rice production (Vijayakumar *et al*., 2022). Furthermore, alternate establishment methods provide the flexibility to adapt to evolving climate conditions and help overcome the limitations associated with traditional transplanting practices. Consequently, their implementation is deemed essential for augmenting the overall productivity and resilience of rice production systems (Mallareddy *et al*., 2023).

Dry seeded rice (DSR) has emerged as an attractive option for farmers to mitigate water scarcity and eliminate the labour-intensive processes such as nursery preparation and maintenance, pulling out and transport of seedlings to main field, and transplanting (Yadav *et al*., 2014). DSR, with its lower water requirement for crop establishment due to absence of puddling, offers a potential solution. Direct seeding of rice during the *kharif* season in the Cauvery Delta Zone holds promise in ensuring a timely harvest before the onset of the monsoon. This method allows rice to be advanced by 7-10 days, as it eliminates the transplanting methods. However, with the declining water availability for rice cultivation and the increasing demand for rice, it is crucial to thoroughly study the advantages and disadvantages of DSR and promote its adoption among rice growers (Vijayakumar *et al*., 2019). Therefore, this field experiment aims to critically evaluate various rice establishment methods in the Cauvery Delta Zone and propose new approaches to address these challenges effectively.

Materials and Methods

A field experiment was conducted during the *kharif* season (June-September) at Tamil Nadu Rice Research Institute (TRRI), Aduthurai, located in the Cauvery Delta Zone of Tamil Nadu, India. The geographical coordinates of the institute are 11^{o} N and latitude 79.3^{o} E longitude with an altitude of 19.4 m above MSL. The experimental field had alluvial clay soil with a pH of 7.7 and an electrical conductivity (EC) of 0.3 dS/m. The available nitrogen, phosphorus, and potassium contents of the soil were medium, high, and low, respectively. The experiment field was ploughed twice using a cultivator, followed by a rotovator to create a suitable seedbed for the rice crop. The experiment was laid out in a Randomized Block Design with seven replications. The treatments consisted of three rice establishment methods *viz.,* dry seeding, wet seeding and conventional transplanted rice. In the transplanted rice treatment, 22 days old seedlings were planted at a spacing of 20 x 10 cm in puddled and levelled field. The variety ADT 45 was used in this experiment.

A pre-emergence application of butachlor at a rate of 1 kg a.i/ha was applied three days after transplanting (DAT). For the dry seeding method, a tractor drawn seed drill was used to sow the seeds in well prepared dry soil. Irrigation was immediately provided after sowing, and a pre-emergence application of pendimethalin @ 1 kg a.i/ha was sprayed on the 3rdday after sowing (DAS). In the wet seeding method, the field was first puddle and then levelled, followed by seeding using a drum seeder. A pre-emergence application of Pretilachlorat a rate of 0.45 kg a.i/ha was applied at 5 DAS. Irrigation was applied to a depth of 5 cm after the disappearance of ponded water. Gap filling and thinning was done on 20 DAS in both wet and dry direct seeding. A recommended dose of fertilizer at 150:50:50 kg NPK/ha was applied in all the establishment methods. Nitrogen at 150 kg/ha through urea and K through Muriate of potash were applied in 4 equal splits from basal, active tillering, panicle initiation and heading stages in the transplanted rice method. Whereas, in wet and dry direct seeded rice, the N and K was given in 4 splits from 14 DAS, active tillering, panicle initiation and heading stages.

Various observations were recorded, including plant population, plant height and yield parameters such as ear bearing tillers, filled grains per panicle, as well as grain and straw yield. Labour used for various operations *viz.,* land preparation, sowing, nursery management, thinning and gap filling, transplanting, irrigation and weeding were recorded for different production systems. Similarly, seed rate used for different cropping system is also noted. The quantity of irrigation water applied to each crop establishment method was recorded using a water meter installed at the delivery point of every plot. The rainfall received during the cropping season (459.6 mm) was measured using an automatic rain gauge installed near the experimental field. Water productivity was worked out by dividing the grain yield by the total water used for the crop. Economic analysis was worked out based on the prevailing market price and net return was calculated by deducting the costs of cultivation from the gross return. The benefit cost ratio (BCR) was worked out by dividing the gross returns (Rs/ha) by the cost of cultivation (Rs/ha).

To determine if there were significant differences between the treatments, the data obtained from the study were analyzed statistically using the procedures suggested by Gomez and Gomez (1984). Significant differences between treatments were determined using critical differences calculated at a five per cent probability level.

Results and Discussion

Growth and yield parameters

Plant height and plant population did not show significant variation among the different rice establishment methods. However, transplanted rice exhibited slightly higher values compared to other methods. The better distribution of rainfall, amounting 459.6 mm, throughout the cropping period may have contributed to the similar growth of rice under different establishment methods. On the other hand, transplanted rice demonstrated significantly higher yield attributes such as ear bearing tillers (396/m^2) and filled grains per panicle (137/panicle), in comparison to wet seeding (**Table 1**). While dry direct seeded rice recorded the lowest number of productive tillers (368/m^2) and filled grains (123 grains/panicle) and it remained statistically at par with wet direct seeding method. The practice of transplanting rice seedlings in puddled soil condition might have favoured better nutrient availability and uptake, leading to increased photosynthesis, improved source-sink relationship (Midya *et al.,* 2021) and ultimately higher yield attributes. Furthermore, flooding the rice fields after successful establishment can alleviate nutrient deficiencies such as Fe and Zn and control soil-borne diseases (ex. nematodes) and weeds, thereby promoting better performance of rice crop (Kumar and Ladha, 2011).

Grain yield and water productivity

Transplanted rice exhibited significantly higher grain yield (6391 kg/ha) and straw yield (11100 kg/ha) compared to wet seeded rice, but it showed comparable yield with dry direct seeded rice (**Table 1**). The grain yield of dry seeded rice was 6040 kg/ha, which was 5.5% lower than that of transplanted rice. This reduction can be attributed to the reduced availability of soil nutrients, particularly N, Fe, and Zn in direct seeded rice (Kumar and Ladha, 2011). Similarly, wet seeded rice registered 8.2% less grain yield than transplanted rice. Contrary to our finding, Singh *et al.*, (2005) reported that, in North India, direct seeded rice produced comparable grain yield and higher net profit compared to transplanted rice.

In terms of water productivity (WP), dry seeded rice exhibited the highest value (6.40 kg/ha/mm), followed by transplanted rice (5.42 kg/ha/mm) and wet seeded rice (5.39 kg/ha/mm). The higher water productivity of dry seeded rice can be attributed to its minimal water usage combined with higher grain yield. Research by Soriano *et al.,* (2018) also reported significantly higher WP in dry direct seeded rice compared to transplanted-flooded rice.

Table 1: Growth and yield parameters and grain yield of rice under different rice establishment methods

Rice establishment methods	Plant height (cm)	Plant population (No./m^2)	Productive tillers (No./m^2)	Filled grains (No./Panicle)	Grain yield (kg/ha)	Straw yield (kg/ha)
Transplanted rice	102.7	48.3	396	137	6391	11100
Wet seeded rice	99.7	46.6	356	126	5932	9560
Dry seeded rice	100.2	48.0	368	123	6040	10508
CD (P=0.05)	NS	NS	30.7	8.4	354.6	854

Inputs saving

Among the different methods of rice cultivations, dry seeding demonstrated superiority in terms of input saving compared to other methods. The use of a tractor drawn seed drill in dry seeding allowed for a lower seed rate of 30 kg/ha, whereas wet seeding required 37.5 kg/ha and transplanted rice necessitated 60 kg/ha (**Table 2**). Dry seeded rice also required the minimum irrigation water, utilizing 485 mm, followed by wet seeding with 641 mm, and transplanted rice with 720 mm. In terms of total water usage, transplanted rice utilized the highest amount of water (1179.6 mm), followed by wet seeding (1100.6 mm) and dry seeding (944.6 mm). Dry seeded rice registered a significant irrigation water saving (32.6%) as compared to transplanted rice. With respect to labour requirements, it was found that dry seeding require less labour (60 man-days/ha), followed by wet seeding (90 man-days/ha) and transplanted rice (117.5 man-days/ha). Dry seeded rice resulted in a substantial labour saving (48.9%) compared to transplanted rice. Within the direct seeding methods, dry seeding showed superiority in terms of seed, water and labour saving over wet seeding. DSR has been shown to reduce total labour requirements by 11% to 66%, depending on the season, location, and type of DSR, when compared with transplanted rice. It also saved 35–57% water compared to continuously flooded rice (Sharma *et al.*, 2002).

Table 2: Seed rate, water use, water productivity, labour use and economics of rice under different rice establishment methods

Particulars	**Transplanted rice**	**Wet seeded rice**	**Dry seeded rice**
Seed rate (kg/ha)	60	37.5	30
Irrigation quantity (mm)	720	641	485
Irrigation water saving (%)	-	11.0	32.6
Total water used (mm)	1179.6	1100.6	944.6
Water productivity (kg/ha/mm)	5.42	5.39	6.40
Labour use (man days/ha)	117.5	90	60
Labour saving (%)	-	23.4	48.9
Cost of cultivation (Rs./ha)	38000	35645	33485
Net returns (Rs./ha)	56183	51031	55543
Benefit cost ratio	2.48	2.43	2.66

Note: Rainfall during cropping period: 459.6 mm

Economics

Transplanted rice incurred a higher cost of cultivation (Rs. 38000 /ha) but also resulted in higher net returns (Rs. 56183/ha) compared to direct seeding method (**Table 2**). The increased cost of cultivation in transplanted rice was primarily due to higher input and labour usage. On the other hand, dry seeded rice exhibited a lower cost of cultivation (Rs. 33485/ha) and a higher benefit cost ratio (2.66) compared to the other methods. The use of fewer inputs and reduced labour under dry seeding contributed to the higher benefit cost ratio. Direct seeding of rice offers several advantages, including labour savings, ease of operation, reduced drudgery, early crop maturity (7–10 days), lower water requirements, higher tolerance to water deficit, higher yield, low production cost, increased profitability, improved soil physical conditions for subsequent crops and reduced methane emission (Kumar and Ladha, 2011).

Conclusion

Based on the findings of this field experiment and taking into account the current challenges of water and labour scarcity in the Cauvery Delta Zone, it can be concluded that dry direct seeding of rice using a tractor drawn seed drill, can be considered as an alternative rice establishment method to replace the existing practice of transplanted rice during the *kharif* season. Dry seeding offers several advantages in terms of input savings, reduced water requirements, lower labour demands, and similar grain yield compared to transplanted rice. Implementing dry direct seeding as an alternative method can help farmers overcome the challenges posed by water and labour availability while maintaining productivity levels. It is important to provide proper training and extension services to farmers to ensure the successful adoption of this method.

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SHORT COMMUNICATION https://doi.org/10.58297/KCIX9658

DRRH-4 (IET 27937) - World's First Public Bred Aerobic Rice Hybrid

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Abstract

DRRH-4 [IET 27937 (IIRRH-124)], is an aerobic rice hybrid developed from APMS-6A / AR 9-18 cross. It was evaluated in AICRIP multi-location aerobic rice trials during wet seasons of 2018 to 2021. DRRH-4 consistently out-performed the check varieties in Punjab, Odisha, Chhattisgarh, Tripura and Gujarat states with a mean grain yield 5030 kg/ha, which is 32%, 28%, 22% and 11% higher than national check, zonal, local and hybrid checks, respectively. In addition, it exhibited moderate resistance to leaf blast, neck blast, gall midge, rice stem borer, and whorl maggot. DRRH-4 has early duration of 120 days (seed to seed) and possess desirable grain and cooking quality parameters. It was released for cultivation in aerobic ecosystems of Punjab, Odisha, Chhattisgarh, Tripura and Gujarat states through Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 4065(E) dt. 31st Aug., 2022 [CG-DL-E-31082022-238490].

Keywords: Aerobic rice hybrid, grain yield, cooking quality.

Introduction

Hybrid rice is cultivated in more than 350,000 hectares and it is anticipated to cross >4 million hectares. However, in scenario of changing climate, over 80% released rice hybrids are reported to be sensitive to abiotic stresses like high-temperature and drought stress. In this context, aerobic rice is the need of the hour for substantial and stabilized crop returns. Indian Institute of Rice Research (ICAR-IIRR) has initiated the development of rice hybrids suitable for aerobic cultivation and a promising cross combination, APMS-6A / AR 9-18 (IIRRH-124) was identified. The promising hybrid, IIRRH-124 was identified and nominated in AICRIP Aerobic rice trail-2018. Subsequently, the entry performed well all the four years and released as a direct seeded aerobic rice hybrid,DRRH-4 through Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 4065(E) dt. 31st Aug 2022 [CG-DL-E-31082022-238490] suitable for cultivation in Punjab, Odisha, Chhattisgarh, Tripura and Gujarat states. The overall mean grain yield of DRRH-4 was 5030 kg/ha, which is 32%, 28%, 22% and 11% higher than National, Zonal, Local and Hybrid checks, respectively. The mean grain yield in Zone II was 4989 kg/ha, which was 26%, 40%, 25% and 10% higher than National, Zonal, Local and Hybrid checks, respectively. The mean grain yield in Odisha state was 5579 kg/ha, which was 46%, 28%, 58% and 15% higher than National, Zonal, Local and Hybrid checks, respectively. The weighted mean grain yield was 5910 kg/ha in Zone-IV and this was 30% higher than the national check. In Chhattisgarh state, the weighted grain yield mean was 5039 kg/ha and out yielded the national, regional, local and hybrid checks by 52%, 28%, 16% and 9%, respectively. The mean grain yield in Zone VI was 4854 kg/ha, which was 26%, 23%, 29% and 13% higher than National check, Zonal, Local and Hybrid checks, respectively. In Gujarat state of Zone VI, the weighted mean grain yield was 5710 kg/ha and out yielded the national, regional, local and hybrid checks by 34%, 25%, 40% and 15%. The weighted mean grain yield was 5306 kg/ha in Punjab, Odisha, Tripura Chhattisgarh and Gujarat, which was 14% higher than the best check **(Table 1).**

Table 1: Yield performance of DRRH-4 in Punjab, Odisha, Tripura, Chhattisgarh and Gujarat states

Zone / State	Mean Grain Yield (Kg. ha^{-1})	Superiority over checks			
		National Check (%)	Zonal Check (%)	Local Check (%)	Hybrid Check (%)
Zone-II	4989	26	40	25	10
Zone-III	5579	46	28	58	15
Zone-IV	5910	30	27	5	10
Zone-V	4958	46	25	19	10
Zone-VI	4854	26	23	29	13
Overall	5030	32	28	22	11

It exhibited moderate resistance to Leaf blast, Neck blast, Gall midge, Rice stem borer and Whorl Maggot. It has good hulling (79.2%), milling (71.3%) and head rice recovery (62.8%) in comparison with the checks and qualifying varieties. It possesses intermediate amylose content (24.6%), medium alkali spreading value (4.0), gel consistency (30 mm), long bold (LB) grain type (KL-6.5 mm; KB- 2.4 mm) and other desirable grain and cooking quality parameters **(Figure 1A and 1B).** DRRH-4 is highly suitable for dry direct seeded aerobic conditions with intermittent irrigation. Dry direct seeding is preferable during the second week of June to second week of July (with the onset of rain or with pre-sowing irrigation). Immediately after sowing, life-saving irrigation should be ensured for uniform germination and crop establishment. Weed management is a big menace in aerobic rice. To resolve this, apply Pendimethalin herbicide @1 kg per hectare at field capacity moisture within 3 days of sowing. Further, it is recommended to apply Post Emergence, broad spectrum systemic herbicide like Bispyribac Sodium 10% SC (Nominigold) @50ml per hectare at field capacity moisture within 5-15 days of sowing. One intermittent weeding is recommended (two if more weeds) during crop growth period. Need based irrigation should be followed upto physiological maturity. The DRRH-4 has an advantage of 10-15 days (115-120 seed to seed duration) in comparison with transplanted rice and can yield up to 5.5-6.0 t/ha subject to use under area of adoption and recommended climate conditions and adoption of package of practices. It is suitable for direct seeding of both early *kharif* (wet)and *rabi* (dry) seasons.

Figure 1A: Field view of DRRH-4

Figure 1B: Paddy, Brown rice and Polished rice of DRRH-4

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DRR Dhan 64 - (IET 28358) - First Nitrogen Use Efficient, Early Transplanted Rice Variety

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Abstract

DRR Dhan 64 [IET 28358 (RP 5599-212-56-3-1)], an early transplanted rice variety was developed from MTU-1010/KMR-3R cross. It was evaluated in AICRIP multi-location ETP trials during wet seasons of 2019 to 2021. DRR Dhan 64 consistently out-performed the check varieties in Eastern Zone (Zone III) with a mean grain yield 5330 kg/ha, which is 8%, 28% and 12% higher than National check, Zonal and Local checks, respectively. In addition, it exhibited moderate resistance to Leaf blast and Neck blast; and also resistant to gall midge and rice thrips; and moderately resistant to planthoppers and whorl maggot. DRR Dhan 64 has early duration of 115-120 days (seed to seed) and possesses desirable grain and cooking quality parameters. It was released for cultivation in aerobic ecosystems of Bihar and West Bengal (Zone III) states through Central Sub-committee on Crop Standards, Notification and Release ofVarieties for Agricultural Crops vide S.O. 4065(E) dt. 31stAug 2022 [CG-DL-E-31082022-238490].

Keywords: Irrigated rice, grain yield, cooking quality

Introduction

Rice (*Oryza sativa* L.) is cultivated in <22 million hectares under irrigated ecology which accounts approximately 50% of the total area under rice production in India. In view of developing differential nitrogen use efficiency and its response to low nitrogen uptake with earliness, efforts started in 2011 with crossing of MTU-1010/KMR-3R. The segregating populations were evaluated in low nitrogen (0, 20, 40 and RDN) under station trials. The promising line, RP 5599-212-56-3-1was identified and nominated in AICRIP ETP trial-2019. Subsequently, the entry performed well in all the three years and released as early transplanted and first Nitrogen use efficient rice variety - DRR Dhan 64 through Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 4065(E) dt. 31stAug 2022 [CG-DL-E-31082022-238490] suitable for cultivation in Bihar and West Bengal States of eastern zone (Zone III). The overall mean grain yield of DRR Dhan 64 in Zone III was 5330 kg/ha, which is 8, 28 and 12% higher than National check, Zonal and Local checks, respectively. The weighted mean grain yield was 5382 kg/ha in Bihar and this was 8%, 37% and 18% higher than National check, Zonal and Local checks, respectively. In West Bengal state, the weighted grain yield mean was 5266 kg/ha and out yielded the national, regional and local checks by 7, 18 and 6%, respectively **(Table 1).**

Table 1: Yield performance of DRR Dhan 64 in Zone III

Zone / State	Mean Grain Yield (Kg. ha^{-1})	Superiority over checks		
		National Check (%)	Zonal Check (%)	Local Check (%)
Z-III	5254	7	34	9
Bihar	5382	8	37	18
West Bengal	5266	7	18	6

It exhibited resistance to major insect pests and diseases such as leaf blast, neck blast, gall midge and rice thrips; moderate resistance to plant hoppers and whorl maggot. It has good hulling (80.2%), milling (72.2%) and head rice recovery (66.8%) in comparison with the checks and qualifying varieties. It possesses intermediate amylose content (22.5 %), gel consistency (62 mm), Long Slender (LS) grain type (KL- 6.36 mm; KB- 2.07 mm) andother desirable grain and cooking quality parameters **(Figure 1A and 1B).**

The variety DRR Dhan 64 is highly suitable for cultivation under irrigated (E TP) growing regions (Bihar, and West Bengal). Sowing is preferably to be done during the second week of June to second week of July. Weed management is a big menace and to resolve this, apply any one of the pre-emergence herbicides on 3rd or 4th day after sowing to control weeds in the lowland nursery. Keep a thin film of water and allow it to disappear. Avoid drainage of water. This will control germinating weeds. One intermittent weeding is recommended (two if more weeds) during crop growth period. The DRR Dhan 64 has an advantage of 10-15 days (115-120 seed to seed duration) in comparison with other transplanted rice and can yield up to 5-5.5t/ha subject to use under area of adoption and recommended climate conditions and adoption of package of practices. It is suitable for irrigated ecosystems of both early *kharif* (wet) and *rabi* (dry) seasons.

Figure 1A: Field view of DRR Dhan 64

Figure 1B: Paddy, Brown rice and Polished rice of DRR Dhan 64

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NLR 3186: A Long Duration Blast Resistant Rice Culture Suitable for Irrigated Ecology of Andhra Pradesh

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Abstract

The culture NLR 3186 was derived from a cross of NLR 28523 / Secandro Brazelio (5720-11-1-3-1) through Pedigree method of breeding at Agricultural Research Station, Nellore. It recorded an average yield increase of 19.97% over the check NLR 33892 in the station trials. In Multi Location Trial conducted for 2 years, it recorded 11.26% increase over the checks used for testing MTU 1061.I n 3 years of minikit testing the entry NLR 186 recorded 8.3% higher grain yield than the check varieties tested. In AICRIP trial during 2012-13, it recorded on par with the national check MTU 7029 (4249 kg/ha). It has non-lodging nature, high yielding, nitrogen responsive, with medium green foliage, low shattering and complete exertion of panicle. It was tolerant to leaf blast, neck blast and sheath rot. It has good cooking and chemical quality as it exhibits intermediate and desired values of ASV, gel consistency, good linear elongation ratio and amylase content. It also possesses good head rice recovery with translucent grains which is very much desired for marketing.

Keywords: Rice, blast, long duration, irrigated ecology.

Introduction

Rice is the staple food of millions and it has the ability to adopt to diverse agro-climatic conditions throughout the world. In India, rice occupies an area of about 44 million ha whereas in Andhra Pradesh it occupies 25 lakh hectares in *kharif* and *rabi* seasons. Nellore is one of the most important rice growing district in Andhra Pradesh where rice crop has been cultivated for three seasons *viz.,* early *kharif* (April-August), late *kharif* (August-January) and *rabi* (November-March) depending on the availability of irrigation water for rice cultivation. In early *kharif* season, short duration (120-125 days), in late *kharif*, long duration (150 days) and in *rabi* medium duration (130-135 days) varieties are generally cultivated in this area. *Molagolukulu* rice is the traditional rice cultivated in Nellore, Prakasam, Chittoor, Guntur and parts of Kadapa districts of Andhra Pradesh state. Generally *Molagolukulu* varieties are of long duration, tall statured, lodging prone, dark glumed grain, thick panicle and the grains are arranged in thread like manner on the rachis of the panicle. These varieties are suitable to plant even under aged nursery conditions (40-50 days aged seedlings) but having good cooking and keeping quality of cooked rice and good elongation of cooked rice grain. The cooked rice does not spoil even 20 hours after cooking. Due to irregularities in monsoon pattern, the area has drastically come down to 30,000 ha for these varieties. In spite of that, the single cropped area grown with rice crop is mostly occupied by *Molagolukulu* varieties in this area. At agricultural Research station, Nellore more than 10 improved *Molagolukulu* rice varieties were released for cultivation long back. During 2006, NLR 33892 (Parthiva) variety was developed and released, which is a high yielding and blast tolerant, with thick panicles but under high nitrogen application it is prone to lodging. Because of health consciousness among the public, the demand is increasing again for *Molagolukulu* rice varieties. In view of the above, at Agriculture Research station, Nellore, NLR 3186 culture was developed to overcome the above said difficulties in *Molagolukulu* rice cultivation and as an alternative to NLR 33892 rice variety.

Materials and Methods

NLR 3186 rice culture was developed at ARS, Nellore, ANGRAU by following pedigree method of breeding. This culture is a derivative of NLR 28523 x Secandro Brazelio. This is a long duration culture and the growing season was August month. It was tested for yield and its attributes at station level yield trails from 2009-10 to 2011-12. The culture was tested in multilocation testing in ANGRAU during 2012-13 and in 2017-18 under late maturity group trial. NLR 3186 was tested in AICRIP testing during 2012 *kharif* season as IET 23660 in locations across the country. It was tested for pest and diseases in AICRIP under NSN 2 nursery. It was tested in farmer's fields under minikit testing from 2017-18 to 2019-20 for three years in 168, 168 and 143 locations throughout the state in comparison with the various checks which are ruling in that particular area. The data on quality parameters in comparison with the checks were conducted ta RARS, Maruteru during 2017-18. It was deposited as an indigenous rice culture and IC number was got for further reference. The DNA finger printing data was generated by using different markers at RARS, Maruteru, ANGRAU.

Results and Discussion

The hybridization between NLR 28523 x Secandro Brazelio was attempted during 2003. The best progeny was identified during F6 generation. Later on yield trials were conducted at station level for 3 consecutive years from 2009-10 to 2011-12 and it recorded an average grain yield of 7272 kg/ha as against the check NLR 33892 (6030 kg/ha) which is 19.97% increase over the check. It was tested in multilocation testing during 2012 in 11 centres against the check MTU 7029 where it recorded an average grain yield of 6029 kg/ha which is 9.57% increase over the common check (5502 kg/ha) variety used. In the year 2017, again it was tested in MLT in 9 centres against MTU 1061 (common check) where it recorded 7346kg/ha which is 13.26% superior over the check (6485 kg/ha) used.

The performance of any culture is proven when it is tested under large scale area in the farmers field. The culture was tested for three consecutive years from 2017-18, 2018-19 and 2019-20 under minikit testing in 168, 168 and 143 farmers fields, respectively. In minikit trials the culture was tested against respective rice varieties grown in that particular area in different districts of Andhra Pradesh where it recorded an average grain yield of 6443 kg/ha as against the check 5950 kg/ha which is 8.3% increase over the check. The overall mean of the culture was 6815 kg/ha. (**Table 1**).

During 2013 *kharif* season NLR3186 was nominated and tested as IET23660 along with 63 entries under IVT-L trial in 9 centres all over India under AICRIP testing along with three checks (National, Regional and Local Checks). It recorded an average grain yield of 4249 kg/ha with the highest yield of 5093 kg/ha at Raipur centre. NLR3186 recorded an increased grain yield of 33% over the National Check at Bhubaneswar, 37.5% at Cuttack, 9% at Sharoli, 23.65% at Karnataka

Table 1: Yield performance of NLR 3186 at station, multilocation trials and at farmers' fields in Andhra Pradesh state

S. No.	Name of the Trial	Year and season of testing	Grain yield (Kg/ha)			Percentage increase over check
			NLR 3186	Name of the Check	Check yield	
1	OVT-L	2009-10 *Kharif*	8886	NLR 33892	6434	38.11
2	PVT-L	2010-11 *kharif*	6221	NLR 33892	5860	6.1
3	AVT –L	2011-12 *Kharif*	6709	NLR 33892	5796	15.7
4	MLT-I year	2012-13 - 11 locations	6029	MTU 7029 (Common check)	5502	9.57
5	MLT-II yr	2017-18 9 locations	7346	MTU 1061 (common check)	6485	13.26
6	Minikit trials at farmers fields	2017-18 (168 locations)	6373	NLR 33892/MTU 1061/ RGL 2537/BPT 5204	5828	9 .35
7		2018-19 (168 locations)	6372	NLR 33892/MTU 1061/ RGL 2537/BPT 5204/MTU 7029	5865	8.64
8		2019-20 (143 locations)	6585	NLR 33892/ MTU 1061/ RGL 2537/ BPT 5204/ MTU 7029	6158	6.93
		Average	6815		5991	13.45

b: Ancillary parameters

Name of the trial	Year and season of testing	Days to 50% flowering		Plant height (cm)		Panicle length (cm)		EBTS/m^2	
		NLR 3186	Check NLR 33892	NLR 3186	Check NLR 33892	NLR 3186	Check NLR 33892	NLR 3186	Check NLR 33892
OVT-L	2009-10 *Kharif*	127	120	109.1	123.6	24.8	24.5	420	405
PVT-L	2010-11 *kharif*	124	124	96.5	107.3	24.5	24.3	495	424
AVT –L	2011-12 *Kharif*	122	125	109.2	118.6	24.8	24.3	568	524
	Average	124	123	105	117	25	24	494	451

- *The entry recorded 150-155 days duration for maturity.*

and 10.72% at Karaikal. On an average it recorded at par yield with national check Swarna. Except Nawagam centre, NLR 3186 surpassed the yield of Swarna (National Check) in the AICRIP testing. **(Table 2)** (ICAR-IIRR Annual Progress Report 2013, Vol. I, Page Nos. 1.215-1.226)

Table 2: Centre wise Performance of NLR 3186 (IET 23660) in All India Coordinated trials. Grain yield (Kg/ha) in IVT- (Late) *kharif*-2013

IET 23660 (NLR 3186) Grain Yield (Kg/ha)				
Place	**NLR 3186**	**National Check (Swarna)**	**Regional Check (Samba Mahsuri)**	**Local check**
Bhubaneswar	4138	3103	4138	4138
Cuttack	**4432**	3222	3524	4181
Chinsura	**3526**	4915	4434	5769
Raipur	5093	5489	4828	3042
Sharoli	4354	3993	4618	4347
Nawagam	2392	7562	7022	4398
Nellore	**4368**	4342	3414	3896
Karnataka	4772	3859	3589	5318
Karaikal	**5536**	5000	3732	6161
Overall Mean	**4249**	**4249**	**4393**	**4717**
DFF (days)	125	114	112	115
EBTs/Sq.m (No.)	271	288	293	282

Disease and Pest reaction

The culture was tested for various diseases at Agricultural research station, Nellore from 2010 to 2013 and it showed prominent tolerant reaction to leaf blast disease **(Table 3a and 3b).** In AICRIP testing during 2013 it was tested in NSN 2 nursery, where it was found tolerant for both leaf and neck blast diseases **(Table 4a and 4b).**

Table 3a: Reaction of NLR 3186 to different diseases at A. R. S, Nellore

Year	Genotype	Leaf Blast	Neck blast	Bacterial Blight	Sheath rot
2009-10	NLR 3186	0	-	-	-
	NLR 33892©	4	-	-	-
2010-11	NLR 3186	1	-	-	-
	NLR 33892©	5	-	-	-
2011-12	NLR 3186	0	-	-	-
	NLR 33892©	6	-	-	-
2012-13	NLR 3186	1	7	5	5
	NLR 33892©	1	1	6	3
2013-14	NLR 3186	4	3	5	1
	NLR 33892©	5	3	5	3
	SI	1.6	5	5	3
In the station screening trials it was found tolerant to leaf blast.					

Table 3b: Reaction of NLR 3186 to insect pests at ARS, Nellore

Year	Variety	30DT (% damage)		
		Gall Midge	Dead Hearts	Leaf Folder
2009-10	NLR 3186	0	3.5	5.6
	TN 1	4.5	19.5	12.5
2010-11	NLR 3186	0	7.92	6.21
	TN 1	3.0	17.5	22.5
2011-12	NLR 3186	1.0	5.75	4.35
	TN 1	5.0	21.75	24.5

Table 4a: Reaction of NLR 3186 to Leaf blast at AICRIP testing during 2013

S. No.	Place	Blast disease score		
		Leaf Blast	Swarna	HR 12
		NLR 3186	National yield Check	National Susceptible check
1	Barapani	5	-	9
2	ICAR-IIRR	3	9	9
3	Lenova	4	8	9
4	Nellore	5	4	8
5	Almora	3	5	9
6	Gaghraghat	5	5	4
7	Ranchi	4	5	7
8	Varanasi	4	6	5
9	Mandya	2	6	4
10	Malan	1	5	8
11	Hazaribhag	3	3	5
12	Rewa	3	4	5
13	Coimbatore	4	5	4
14	Warangal	5	3	4
15	Jagdalpur	2	2	2
16	Pattambi	4	4	4
17	Maruteru	3	4	7
18	Rajendranagar	3	1	5
19	Karjat	3	5	3
20	Ponnampet	0	1	8
21	Gangavathi	2	2	2
	SI	3.1	4.3	5.5

- ***DS: Damage Score***

Table 4b: Reaction of NLR 3186 (IET23660) against insect pests in *kharif* 2013 (DRR Screening nurseries)

Place	Entry	BPH (DS)	WBPH (DS)	Green Leaf Hopper (DS)	Gall Midge Biotype 1% DP	Stem borer		Leaf Folder
						Dead hearts % DH	White ears % WE	% DL
ICAR-IIRR	TE	2.8	8.3		38.5			
	NC	9.0	7.2		-			
Ludhiana	TE	9.0				3.0 (65 DAT)		28.9 (65 DAT)
	NC	9.0				2.6		29.4
Gangavathi	TE	26.4 (62 DAT)	25.7				4.6 (Pre harvest)	10.7 (62 DAT)
	NC	5.6	5.8				0.9	3.6
Chinsura	TE					19.256 (DAT)	11.1 (93DAT)	
	NC					3.5	0.0	
SBP	TE					10.7 (50 DAT)		
	NC					5.3		
Rajendranagar	TE						1.1 (123 DAT)	
	NC						8.0	
Jagdalpur	TE			19	5.8 (50 DAT)			2.1 (50 DAT)
	NC			8	25.2			6.3
Bharapani	TE				80 (50 DAT)			
	NC				15			

Table 5: Response of NLR 3186 to Nitrogen fertilizer at A.R.S, Nellore

	2016		2017		2018		Mean	
	NLR 3186	**BPT 5204**	**NLR 3186**	**BPT 5204**	**NLR 3186**	**BPT 5204**	**NLR 3186**	**BPT 5204**
N 40	5187	4622	5284	4860	4676	4298	5049	4593
N 80	5288	5269	5559	5414	5541	5343	5463	5342
N 120	5517	5269	5330	5447	5660	4865	5502	5194
N 160	5624	5300	5739	5433	5096	4672	5486	5135
Mean	5404	5115	5478	5289	5243	4794	5375	5066

Summary: Among the four levels of nitrogen tested here, NLR 3186 responds even up to 160 kg N. the optimum dosage is 80 kg/ha.

According to Nagendra Reddy *et al*., (2016), in a study conducted on antibiosis and resistance mechanisms of resistance to BPH, the culture NLR 3186 (IET 23660) recorded resistant reaction against BPH (2 score) (TN1 susceptible check score:9, Resistant check PTB score: 2.1), low fecundity of BPH, low % of nymphal survival, longer nymphal duration, low growth of nymphs and less gain in body weight of BPH was observed when compared with the susceptible check TN 1.

Agronomic evaluation

The culture NLR 3186 was tested at four different nitrogen levels for three consecutive years from 2016-2018 where it recorded 5342 kg/ha at 80kg nitrogen application per hectare. It responds even up to 160 kg N but the optimum dosage is 80 kg/ha (**Table 5**).

Morphological features

The morphological features of the cultures are given in the **Table 6**. The culture flowered 120 days after sowing and it grows up to a height of 90-100 cm and bearing 12-15 tillers per plant. The panicle length is 25cm and the grains are in golden brown and having dark coloured furrows on the glumes. Short awns were present on the top grains in the panicle. The leaves were erect and showing delayed senescence at the time of maturity. Each panicle was fully exerted from the boot leaf and comprises 220 grains per panicle. The harvest index ranges from 60-65%. **(Table 6).**

Table 6: Description of NLR 3186

S. No.	Trait / Character	Description
1.	Plant height	90-100 cm
2.	Habit	Erect
3.	Days to 50% flowering	120-125 days
4.	Lodging	Non lodging
5.	Leaf blade colour	Medium Green
6.	Basal leaf sheath colour	Medium Green
7.	Leaf angle	Erect
8.	Flag leaf angle	Erect
9.	Leaf length	32 cm (medium)
10.	Leaf width	1.4 cm (medium)
11.	Leaf blade pubescence	Strong
12.	Ligule colour	White
13.	Ligule shape	Split
14.	Ligule length	3.2 mm
15.	Auricle colour	Pale green
16.	Collar colour	Pale green
17.	Culm angle	Erect
18.	Flag leaf angle	Erect
19.	Culm internode colour	Green
20.	Panicle length	25 cm
21.	Panicle type	Compact
22.	Panicle exertion	Well exerted
23.	Awns	Present on the top portion of the panicle
24.	Apiculus colour	Straw
25.	Stigma colour	White
26.	Lemma palea colour	Straw
27.	Lemma palea pubescence	Hairs on upper portion
28.	Seed coat colour (bran)	Dark brown
29.	Sterile lemma colour	Straw
30.	Senescence	Late
31.	Grain type	Medium slender
32.	Grain length (mm)	8.2
33.	Grain breadth (mm)	2.6
34.	Kernel length (mm)	5.52
35.	Kernel Breadth (mm)	1.82
36.	L/B ratio	2.98
37.	Hulling (%)	76.8
38.	Milling (%)	67.52
39.	Head Rice Recovery	65.64
40.	1000 grain weight	23.16g
41.	Chalkiness	Absent
42.	Gelatinization temperature	Intermediate
43.	Kernel elongation ratio	1.82
44.	Keeping quality	Good
45.	Grain shattering	<2%
46.	Flowering duration (days)	8-10
47.	Dormancy (weeks)	-
48.	Harvest index	60-65
49.	Filled grains/panicle	210-225
50.	Tillering ability	Moderate (7-14)
51.	Distinguishing characters	Compact, erect, Non-lodging, high yielding, dwarf with medium green foliage, dark brown glumed grains, medium slender, translucent grain with high grain number per panicle.

Quality features

After grain yield, second most important thing to consider is quality which includes physical, milling, cooking and chemical quality parameters. The culture NLR 3186 is a medium slender culture with a grain length of 8.2mm, width 2.6 mm and the kernel length of 5.5 mm, breadth 1.82 whereas the kernel L/b ratio was 2.98. The head rice recovery of the culture is 65% and it is acceptable recovery from the millers point of view. Absence of grain chalkiness and good kernel elongation ratio of 1.82 and volume expansion of 3.3 shows the good sign for cooking quality of the rice. The grain size belongs to medium slender group and the amylose content (24) and gel consistency (25 mm) are also under desirable limits (**Table 7**). In the organoleptic test conducted by the group of people and it was found to that the rice was flaky, non-sticky and good compatibility with curries while eating *i.e.,* good relishability.

Table 7: Grain quality data of NLR 3186

S. No.	Character	NLR 3186	BPT 5204	NLR 33892
1.	Grain type	Medium slender	Medium slender	Medium slender
2.	Kernel length (mm)	5.52	4.98	5.5
3.	Kernel Breadth (mm)	1.85	1.85	2.3
4.	L/B ratio	2.98	2.69	2.39
5.	Hulling %	76.80	75.67	77.6
6.	Milling %	67.52	67.21	73.6
7.	Head Rice Recovery	65.64	63.37	61.6
8.	Test Weight (gm)	23.16	14.2	18.2
9.	Rice Grain Type	Medium slender	Medium slender	Medium slender
10.	Grain Chalkiness	VOC	VOC	VOC
11.	Amylose content	24.2	23.4	25
12.	Alkali spreading value	5.0	4.0	3.0
13.	Water uptake	167.5	130	175
14.	Volume expansion ratio	3.3	3.3	3.5
15.	Kernal elongation ratio	1.82	1.74	1.8
16.	Gel consistency	25	24	24
17.	Aroma	NS	NS	NS

In view of the above it was concluded that the culture NLR 3186 possess good yielding ability at station level and also at framers fields, good milling and cooking quality traits along with blast resistance, suitable to sow from July to September month. Even under delayed transplanting conditions (aged seedlings) it was found to be suitable to cultivate in the irrigated rice ecology of Andhra Pradesh state.

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KAU Pournami (MO 23): A High Yielding Red Rice Variety

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Abstract

KAU Pournami (MO 23; KAUM 109-1-2-1; IET 23739) is a high yielding photo-insensitive, medium duration, medium-bold red rice variety with an average productivity of 7000-7500 kg ha^{-1}, released from Kerala Agricultural University. It is developed from the cross between NHTA 8 and Aruna (MO 8). It has got high milling quality in terms of Head Rice Recovery and better cooking quality compared to the popular variety Uma. It is moderately tolerant to sheath blight, sheath rot, BPH and gall midge. The variety was notified by the Government of India during 2021.

Keywords: KAU Pournami, red rice variety

Introduction

Rice is the staple food of Kerala, a southern state of Indian sub-continent. Rice agro-ecosystems of Kerala is hot spot for pests and diseases due to the high temperature, rainfall and humidity prevailing during the cropping period. The variety development programme was started at Rice Research Station, Moncompu to evolve a high yielding rice variety with biotic stress tolerance. Hybridisation work was initiated between high yielding locally adapted varieties *viz.,* Uma, Pavithra, Panchami, Bhadra, Asha, Aruna and Jyothi with identified donor parents for biotic stress tolerance *viz.,* NHTA 8, Triguna, TN 1, Phalguna, GM 8 and Bhumansa. Pedigree selection method was followed, and genotypes were selected based on biotic stress tolerance and important yield attributing traits.

The cultures after attaining uniformity were advanced to Initial Evaluation Trial (IET) followed by Preliminary Yield Trial (PYT) and Comparative Yield Trial (CYT). Among the advanced culture's KAUM109-1-2-1 **(Figure 1)** was identified as promising one with respect to yield as well as tolerance to biotic stresses and was forwarded to multi-location and adaptive research trials (ART). It is a medium duration, semi-dwarf, photo-insensitive culture, which is suitable to both *kharif* and *rabi* seasons. The mean grain yield of KAUM109-1-2-1 at different yield trial is given in **Table 1.**

Figure 1: Field view of KAU Pournami (MO 23) rice variety

Table 1: Mean grain yield (kg ha^{-1}) obtained for KAUM 109-1-2-1 in different yield trials

Variety	PYT	CYT	ART
KAUM 109-1-2-1	**5278^{a}**	**5957^{a}**	**7419^{a}**
Jyothi	3505^{b}	3667^{b}	5700^{b}
Uma	5244^{a}	5433^{a}	8090^{a}
C.D @ p=0.05	750	708	816

Multi-location trial of the selected culture (IET 23739) was conducted as part of the All India Coordinated Rice Improvement Programme (AICRIP) by including it in Initial Variety Trial-Irrigated Mid-Early (IVT-IME) during *kharif* 2013 and Advanced Variety Trial-1-Irrigated Mid-Early (AVT-1-IME) of AICRIP during *kharif* 2014. It ranked seventh in the IVT-IME and showed superior performance of 16.4%, 6.1% and 10.4% over the national, regional, and local checks respectively in eastern region. In AVT-1-IME it ranked first in Kerala. Adaptive research trial (ART) of the culture was conducted in 6 locations and the results showed on par yield for KAUM 109-1-2-1 with Uma, and superior yield compared to Jyothi. The yield at different ART locations ranged between 6750 kg ha^{-1} to 8625 kg ha^{-1} with an average productivity of 7419 kg ha^{-1}. Results of station trials, multi-locational trials and ART proved the superiority and suitability of KAUM 109-1-2-1 as a new high yielding rice variety.

Reaction to pests and disease were scored in the National Screening Nursery 1 (NSN 1) of AICRIP **(Table 2)** and field of RRS Moncompu, following standard Evaluation System of Rice (IRRI, 2013). KAUM 109-1-2-1 showed moderate tolerance to major diseases *viz.,* sheath rot, blast, brown spot and RTD and pests *viz.,* BPH, stem borer, leaf folder and gall midge. Grain and cooking quality were analyzed in the laboratory of ICAR-IIRR and RRS Moncompu based on standard laboratory procedures. Grain type of KAUM 109-1-2-1 is medium bold with red kernel **(Figure 2).** It has high milling recovery (76%) and HRR (60%). Eating quality of the variety is desirable with intermediate amylose content and medium gel consistency **(Table 3).** The grain quality is better compared to the popular rice variety Uma.

Figure 2: Grains of rice variety KAU Pournami (MO 23)

Table 2: Reaction of KAUM 109-1-2-1 to Diseases and pests in AICRIP (NSN 1) during *kharif* 2014

Variety	Score (0-9)								Damage (%)		
	Sh.B	SR	LB	NB	BLB	BS	RTD	BPH	SB	LF	GM
KAUM 109-1-2-1	**5.4**	**4.3**	**4.8**	**3.7**	**5.8**	**3.7**	**5.0**	**4.2**	**6.4**	**9.3**	**4.0**
TN 1	6.7	5.2	4.7	5.3	6.2	3.7	6.0	7.6	11.3	12.5	7.9

Sh. B: Sheath blight; SR: Sheath rot; LB: Leaf blast; NB: Neck blast; BLB: Bacterial leaf blight; BS: Brown spot; RTD: Rice tungro disease; BPH: Brown plant hopper; SB: Stem borer; LF: Leaf folder; GM: Gall midge *(Source: AICRIP Progress Report 2014)*

Table 3: Grain quality parameters of KAUM 109-1-2-1

Variety	GL (mm)	GW (mm)	L/B ratio	AC (%)	GC (mm)	Hulling %	Milling %	HRR
KAUM 109-1-2-1	**7.00**	**3.00**	**2.33**	**24.80**	**47.00**	**80.00**	**76.00**	**60.00**
Uma	6.08	2.60	2.30	22.26	28.00	81.50	76.00	54.00

KAUM 109-1-2-1 (IET 23739) was approved for release as rice variety ‘KAU Pournami (MO 23)’ in the 27th state seed sub-committee meeting of government of Kerala. KAU Pournami was notified *vide* the Gazatte of India notification number S.O 2775 dated 28th July, 2021 and recommended for cultivation in the state of Kerala.

INTERNATIONAL CONFERENCE - ICSCI 2022

System of Crop Intensification for Climate-Smart Livelihood and Nutritional Security

Recommendations of ICSCI 2022

The International Conference – ICSCI 2022 was organized in hybrid mode during 12-14, December 2022, at ICAR-Indian Institute of Rice Research, Hyderabad. The funding partners included the Indian Council of Agricultural Research (ICAR), International Rice Research Institute (IRRI), PJTSAU, National Bank for Agriculture and Rural Development (NABARD), Agriculture and Processed Food Products Export Authority (APEDA), Basmati Export Development Foundation (BEDF), India. NGOs and Networks like Watershed Support Services and Activities Network (WASSAN), Professional Assistance for Development Action (PRADAN), People's Science Institute (PSI), National Consortium on SRI (NCS), SRI-Rice, GIZ, RoundGlass contributed as knowledge partners.

A total of 309 delegates from 16 Countries, *i.e.,* USA, UK, Philippines, G NGOs and Networks like Watershed Support Services and Activities Network (WASSAN), Professional Assistance for Development Action (PRADAN), People's Science Institute (PSI), National Consortium on SRI (NCS), SRI-Rice, RoundGlass contributed as knowledge partners. Germany, Italy, New Zealand, Netherlands, Japan, Iran, Nepal, Bangladesh, Vietnam, Tanzania, and India participated in the ICSCI-2022. Additionally, 150 farmers also participated in the ICSCI 2022. The technical sessions of the conference were organized in seven thematic sessions, *viz.,*

Theme 1: Current Status of System of Crop Intensification (SCI) in India and rest of the world;

Theme 2: Breeding Cultivars, Land Races, Ideotypes, Management Practices, Pest and Disease Dynamics of SCI;

Theme 3: Resource use and Conservation in SCI (Natural Farming, Organic Farming, Conservation Agriculture, *etc.*), Climate Resilience and Ecosystem Protection;

Theme 4: Agro-Industries/Mechanization for Scaling up SCI; Theme 5: SCI Adoption and their Socio-Economic Impacts including Gender, Labour and Institutional Dynamics;

Theme 6: Policy needs at State, National and International levels for scaling up SCI; and

Theme 7: Learning Experiences & Success stories of SCI: Farmer and Scientist Interaction & Export Potential of Rice and Strengthening FPOs.

A special interaction session was organised to share the experiences of the Farmers and FPO's on 13th December on adoption of the SCI practices across the country.

In these sessions, 10 keynote and 55 lead lectures, in addition to several flash talks were delivered by eminent speakers from across the world.

The recommendations that emerged from the deliberations of the ICSCI-2022 are given below:

Researchable Issues

The transition towards a more socio-economically and environmentally sustainable agricultural production should be based on scientifically proven approaches and techniques. Bridging diverse research areas should be a prerogative for a holistic approach that considers the transition of environmental, agronomic, social, and economic aspects. There is an emergent need to shift from a cropping system approach to a farming system approach.

- Constituents of the National Agricultural Research and Extension System (NARES), *viz.,* the State Agricultural Universities (SAUs) and ICAR institutes in partnership with CSOs and farmers' groups/federations could lead the transition of the Indian agricultural sector towards a more socio-economically and environmentally sustainable production system. An inclusive, coordinated, and concerted approach is necessary to enable constructive dialogues among the sector's stakeholders, to understand the interdependence among them, and empower actors to think systemically and act locally. More importantly, the cropping system should include nutrition crops millets (SRI- Anna - millets) pulses, and other crops beneficial to human and soil health.

- Emphasis should be given to system approaches for climate-smart, carbon-negative regenerative agriculture, by upscaling climate-resilient agricultural practices. System of Rice Intensification (SRI) and System of Crop Intensification (SCI), Conservation Agriculture (CA) and Natural Farming (NF) management practices should be prioritized for sustaining and increasing productivity in the scenario of a rapidly changing climate, thus boosting crop resilience against extreme weather events.

- Research projects for mapping specific challenges for upscaling SRI/SCI should be developed at national and international levels with a focus on increased productivity through reduced inputs, soil health, mitigation of greenhouse gas emissions, restoration of the natural resource base, and the opportunity to incentivize farmers through carbon credits and other financial benefits/instruments.

- Developing appropriate equipment for mechanized SRI/SCI cultivation on small-, medium-, and large-scale should be given importance.

- There is an imminent need to document and analyze data to show environmental (e.g., water, greenhouse gas emissions, carbon credits) and economic benefits (return on investment) of SRI/SCI on a larger scale (e.g., landscape, district, state or regional level) to generate evidence to galvanize policy makers' support.

- Need to design context-related and effective soil and water management strategies and water footprint concepts for the promotion of water-saving technologies such as SRI, SCI, Direct Seeded Rice (DSR), and alternate wetting and drying (AWD) methods. Developing drought-smart future ready rice and other crops would contribute to reducing the water consumption for rice production. Equally, there is a need to unlock the potential of rainfed farming systems for climate-smart rice production.

- Region-specific genotypes suitable for SRI/SCI and DSR and location-specific modifications of SCI technology should be developed on prioritized. Emphasis should be on further research in SAUs and ICAR institutes to increase the productivity of all the major crops in an environmentally and economically sustainable manner.

- High throughput and precise phenotyping for ear and kernel traits, heat, and drought tolerance of various crop plants should be given more emphasis. Two-line rice hybrid breeding should be given more importance in the future.

- Research on bio-inputs (including seeds, bio-fertilizers, bio-pesticides, plant nutrition products, and microbial consortia) should be encouraged for regenerative and bio-SRI/SCI.

Policy Issues

Supportive and conducive policies are a prerogative for the successful dissemination and adoption of sustainable agricultural practices and they are key for an effective transition towards more socio-economically and environmentally sustainable agricultural production.

- Facilitate communication between researchers and policymakers for a more informed definition of the policy requirements to boost the dissemination of scientifically-proven solutions. Participatory Action Research should be emphasized for a faster and more effective transfer of knowledge among farmers, researchers, and policymakers.
- Government Policies should be conceptualized for SRI/SCI upgrade in rainfed farming areas to help them meet their production potential and to meet local food and nutritional security requirements. Special policy provisions are to be initiated for the adoption of SCI in uplands, especially in the North East (NE) and hill regions to address problems like soil erosion, expanding population, and human-animal conflicts.
- Government intervention at National and International levels through policy changes to make the SCI practices more farmer-friendly/ accessible to farmers. High investments and innovations in the Trans-disciplinary mode (conversion of the programmes) are to be made in Public Private Partnership (PPP) model.
- Recommend transition to National Consortium on System of Crop Intensification and an institutional framework for SRI cultivation and also as well from SRI 1.0 to “SRI 3.0” (*i.e.* SRI + Conservation and Regenerative Agriculture and Natural Farming).
- Input and other subsidies may be considered at the national level for farmers adopting SRI/SCI methods, as this would help them to transition towards a more sustainable type of farming by accessing the required farming equipment and other related needs.

Extension and Scaling up of SCI

SRI/SCI methods are contributing significantly to saving water, reducing the Global Warming Potential (GWP) of agricultural production, and increasing farmers’ income in India and worldwide. Most of the knowledge sharing of SRI/SCI methods happened through farmer-to-farmer dissemination, but extension workers have a key role in introducing these practices in new areas and work with farmers to design context and location-specific adoption practices. Also, continuous extension activities during the first 3-5 years are often necessary to guarantee a long-term adoption of these practices.

- Strategies should be developed for on-field interactions between scientists and farmers, scientists and policymakers, and scientists and citizens to identify appropriate methodologies for scaling-up of SCI and DSR technologies. Regular field visits by technology developers and extension workers will help to identify the field-level problems in the adoption of SRI/SCI and develop location-specific solutions to tackle the problems
- Carbon-negative villages and districts should be formed to boost the farmer-to-farmer dissemination of knowledge. SRI/SCI and DSR are methods that should be prioritized in water-scarce areas like Punjab and Haryana. These practices need to be adapted to fit the context of every state and district through a concerted and focused approach to dissemination. Strategies for sustainable agriculture should be popularized among farmers like the development of a systems approach, diversification of farming systems, use of green manures, cover crops, *etc.,* and need-based integration of organic + inorganic sources for profitable, yet sustainable farming.

- The collection of data on the environmental (e.g., water, greenhouse gas emissions, soil organic carbon, carbon credits) and economic benefits (return on investment) of SRI/ SCI implemented on a large scale (e.g., landscape, district, or state), would demonstrate the value of such technologies to policymakers to support these initiatives.

- Eco-literacy-related knowledge and critical thinking skills among farmers through Farmer Field School (FFS) and similar participatory approaches, community mobilization, and collective actions leading to FPOs formulation and sustenance should be fostered.

- Promotion of youth farmers through fellowships for mobilizing fellow farmers and extending field support for taking on SCI practices

- Development of IEC materials on SRI/SCI in the form of manuals, poster sets, pamphlets, videos, *etc.,* in local language

- Popularization of SCI practices through government-sponsored programs like MGNREGA, Natural farming, *etc.,* in order to reduce the GWP of agricultural production and support a smooth transition toward sustainable agriculture should be encouraged. Focusing on emerging digital technologies like the Internet of things (IoTs), block chain technology, and the utilization of next-generation modern technologies would allow extension workers to carry out their activities in a cost-effective manner and reach out to more farmers.

- There is an emergent need to regularly conduct training and awareness programs on SRI/SCI, developing interest of the private sector for the production of suitable, customized equipment for SRI/SCI practices, enable marketing channels for SRI and create the right conditions for promoting SRI at national and international levels.

- Mainstreaming agro-ecology education in higher agricultural education institutions to support the transition from chemical-intensive farming to bio-intensive/natural farming should be a priority area.

National and International delegates at the ICSCI -2022

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.
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Book

Subba Rao LV, Shobha Rani N, Chiranjeevi M, Chaitanya U, Sudharshan I, Suneetha K, Jyothi Badri and Dipal R Choudhary 2013 DUS Characterization of Rice Varieties. Directorate of Rice Research, Rajendranagar, Hyderabad-500 030, AP, India. 524 pp

Figures: Photographs and drawings for graphs and charts should be prepared with good contrast of dark and light. Figure caption should be brief specifying the crop or soil, major variables presented and year. Give careful attention to the width of lines and size, and clarity of type and symbols.

Tables: Tables are used for reporting extensive numerical data in an organized manner and statistically analyzed. They should be self explanatory. Prepare tables with the word-processing tables feature and tabs or graphics boxes should not be used. Table head should be brief but complete and self contained. Define all variables and spell out all the abbreviations. An exponential expression (eg. x 10^3) in the unit's line is often needed to keep length of the data reasonably short, and referenced with an explanatory note. Unless otherwise required, two decimal place values are suggested.

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