TRAIT SPECIFIC DONORS FOR RICE IMPROVEMENT: A COMPENDIUM

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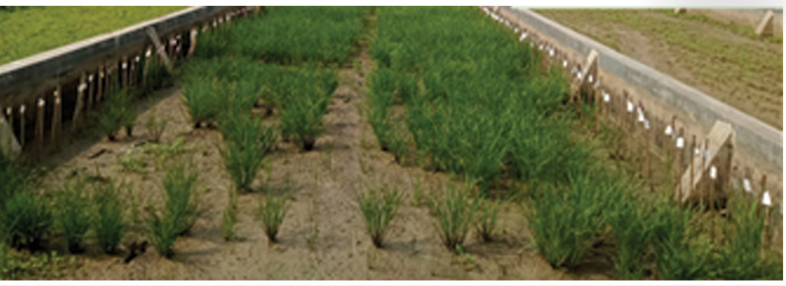

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A Compendium

Edited by

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Preface

Although rice is the staple food for more than two-thirds of the world's population, it is produced under diverse agrosystems, water availability conditions, and resource availability levels. Rice is also affected by various biotic and abiotic stress factors. Due to climate change, the magnitude and complexity of those stresses is gradually increasing. The diversity within this important crop has to be harnessed to improve it for various traits in an environment-specific manner. On the other hand due to its widespread level of consumption in India, this crop is a candidate for achieving food and nutritional security and can combat climate change impact by utilizing the diversity in grain quality traits. ICAR-NRRI is one of the oldest Institute in India and Asia as a whole in rice research and development. Since its inception more than 30000 rice germplasm accessions of cultivated and wild origin were explored, characterized and conserved under various gene bank modules with storage facilities at varying duration. Some of the germplasm resources have been already utilized successfully in rice breeding and NRRI has released till today around 188 high yielding, climate resilient and biofortified rice varieties. However, the huge genetic diversity present among available germplasm is yet to be properly exploited. Moreover, due to excessive selection pressure when creating today's modern or improved rice varieties, the genetic base has naturally been narrowed. Therefore, it has become increasingly important to transfer and pyramid the beneficial alleles from the available germplasm.

A substantial level of variability among rice germplasm for biotic and abiotic stress tolerance, seed properties as well as straw and grain quality has been reported from NRRI in collected cultivated landraces as well as wild accessions. In this present compendium, attempt has been made to review the documents made over the past few decades and compile the information on identified robust donors with desirable traits and making available to the National breeding system for utilising in rice improvement programme. This can be considered as a valuable document where gigantic screening, characterisation and evaluation work done on detection of donors by past and present researchers is considered, scrutinised and finally included based on reproducibility and repeatability of the multiple evaluation data. This is also need of the time as the present rice improvement is focused on backstopping sustainable developmental goals addressing climate resilience and food and nutritional security. This precious compilation will help rice breeder to select and access suitable donors as per the breeding objective and for respective rice ecology and various water and climatic regime having suitable biotic and abiotic stress tolerance at the same time meeting the changing consumers for speciality rice requirement such as medicinal, low GI, biofertified rice and rice for processing industry. In addition, it will also guide for formulation of several projects on basic and strategic research in policies in rice research and development.

Authors

Content

Chapter-1

Drought tolerant germplasm for rice improvement in moisture-stress condition

Koushik Chakraborty, M.J. Baig, Somnath Roy, Nimai Mandal, Padmini Swain

Introduction

Rice is grown in different ecologies covering about 44.0 m ha throughout India. Due to variations in geographic situations and rainfall pattern, the rice experiences different abiotic constraints. Climate change and irregularities in South-west monsoon result in moderate to severe droughts in rain-fed rice growing areas. Water is an important factor in agricultural and food production and yet is a highly limited resource. Water deficit stress causes extensive loss to agricultural production worldwide, thus being a severe threat to sustainable agriculture. Out of 44.0 million ha area under rice in India, drought is one of the major abiotic constraints in around 8.0 million ha of rainfed upland and rainfed lowland situations. About 18% of total rice area of India and 20% of Asia are drought prone. The irregularities in south-west monsoon result in moderate to severe drought in rainfed rice growing areas especially in eastern India. Drought is a multifaceted stress condition with respect to timing and severity, ranging from long drought seasons where rainfall is much lower than demand, short periods without rain where plants depend completely on available soil water (Lafitte et al. 2007). Among the different environmental stresses, drought constitutes an important yield limiting determinant. Food security and prosperity of India is challenged by increasing demand and threatened by declining water availability thereby requiring crop varieties that are highly adapted to dry environments.

Though rice is a water loving plant, it can successfully be grown under upland ecosystem due to its adaptability to low moisture conditions. However, its productivity is much lower than that of irrigated/lowland ecologies. Drought tolerance is a complex trait which depends on a combinatorial interaction of various morphological, biochemical and molecular characters. Therefore, a thorough understanding associated with yield in water stress condition needs attention to facilitate the development of tolerant varieties which can survive and give better yields under drought conditions., Morphological traits *viz*., maintenance of turgor, initiation of leaf rolling, cuticular wax, deep and coarse root with greater xylem vessel radii and lower axial resistance to water flux are indicators of drought tolerance. Most of physiological and metabolic processes are affected by water deficits which include stomatal regulation, photosynthesis, translocation, PSII activity, chlorophyll content, etc. Maintenance of these processes for prolonged period of time under drought is a desired character. Since, ABA is an important component of signalling under drought stress, efficient ABA signalling also ensures tolerance. Biochemical parameters viz., proline and polyamine accumulation in plants increases under drought stress. In addition, a very large number of genes in rice are up- or down-regulated by drought which not only enhances the plant survival in drought conditions but also improves the crop productivity. To facilitate the selection or development of drought tolerant rice varieties, a detailed understanding of the mechanisms that govern the yield of rice under water stress condition is essentially required.

Screening for drought tolerance

To identify rice germplasm lines with built in tolerance to drought at vegetative and reproductive stage, large no. of rice germplasm suitable for upland, lowland, deep water, aromatic rice and fixed lines including wild rice were/are being screened at ICAR-NRRI, Cuttack under field conditions during dry season.

Experimental sites and Soil Properties: Generally, large scale screening experiments are to be conducted under field condition during dry season where interference of rain is negligible during the cropping period. Moreover, as per the availability of controlled facility like Rain out shelter, screening can be done in wet (*kharif*) season. Depending on the soil type the irrigation/stress schedule is to be managed. Before the initiation of experiment information on soil texture type, pH, EC, and available NPK content is to be measured. Soil moisture content at 0.03, 0.05, 0.10, 0.50 and 1.50 MPa (matric potential) to be measured for making a soil moisture release curve. The field should be properly tilled and levelled to avoid variation in soil moisture content within the experiment.

Sowing and Stress Management: Seeds of all the entries are to be seeded directly in dry soil with 4-5 seeds per hill in a spacing of 20 x 10 cm. The line length should be 3 m or 1.5m x 2 lines per genotype. After 15 to 20 days of sowing, it is required for thinning/gap filling to maintain uniform plant population. After germination, plants are allowed to grow with sprinkler irrigation at 3-4 days interval for 25-30 days (4 weeks). Irrigation should be withdrawn for 30 days or beyond till the susceptible check shows permanent wilting and maximum number of lines ???show leaf rolling and tip drying symptoms. Phenotypic observations are to be recorded during the stress period and then the plants should be re-watered for recovery after stress

Looking into vegetative and reproductive stage, the stress is to be imposed at active tillering stage of 4-week crop growth stage and at booting stage respectively. During the period of stress, peizometer (perforated PVC pipes) needs to be fixed for monitoring the ground water table depth on daily basis (for larger plots number of peizometer should be more).

Soil sampling for SMC: Soil moisture should be recorded in periodical interval of 5-7 days at 15 and 30 cm soil depth from the day of suspension of sprinkler irrigation till the susceptible check shows the symptoms of permanent wilting. Soil sample should be collected in a zigzag fashion with the help of auger from the whole field at least from 2 different places in each block. Collected soil samples should be kept in aluminium boxes to record the fresh weight of the soil + box and then the soil to be dried in an oven at 100°C at least for 48 hrs. Then dry weight of soil is to be determined with the box and by deducting the blank box weight the SMC% to be calculated:

$$SMC\ (\%) = \frac{(Soil\ fresh\ weight - oven\ dry\ weight\ of\ soil)}{Soil\ fresh\ weight} \times 100$$

Phenotypic observations

Leaf rolling and death score: Leaf tissues may die (showing desiccation) because of extreme loss of water or heat stress when the leaf temperature rises as a result of inadequate transpirational cooling. All leaves in the canopy should be observed when leaf death is scored. Desiccation may not occur throughout a given leaf in a uniform fashion unless the water deficit is acute. Most typically, it begins at the tip of the leaf, which is usually under greater water deficit than the basal part closer to the stem. Leaf rolling, death and drought score can be recorded as per the following references:

i) Leaf rolling to be recorded in the stressed plots between 12:00 to 14:00h. Visual scales of 0 (no rolling) to 5 (complete rolling) to be used to record leaf rolling (Courtois et al., 2000).

ii) Leaf death score ranges from 0 (no senescence) to 5 (complete leaf drying) to be recorded visually during the morning time, preferably before 10.00AM (Fischer et al., 2003).

iii) Leaf rolling and tip drying (drought score) and recovery data also can be recorded following IRRI SES method, 1 to 9 scales (IRRI, 1996).

Phenotyping for root morphological traits: A dynamic root system is fine-tuned to soil moisture status and is known to regulate the amount of water available to the plant depending on its distribution in the soil. Since root traits are associated with drought tolerance under field condition, germplasm lines differing in their response towards drought can also be evaluated for root traits in PVC pipes under moisture stress at vegetative stage. Among the root morphological traits, maximum root length, root diameter and root: shoot dry weight ratio were found to be associated with drought tolerance in upland conditions.

Table 1. List of selected genotypes with high drought tolerance potential

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Drought score in multiple testing (at <8% SMC)	Mean of values	Standard deviation (SEM)	Reference	Remarks (Tolerant/ MR/R/ etc)
1.	Mahulata	INGR08112 AC-35186 IC-256806	2001-2003; 2018-2020	6	1; 1; 1; 1; 1; 1	1	-	Chakraborty et al. (2023); *CRRI Ann Rep* (2003-04); AICRIP-PHY Report 2019; 2020	Highly tolerant to vegetative stage drought stress and complete submergence up to 14 days
2.	Brahman Nakhi	INGR10150 AC-35678 IC-380753	2007-2009; 2018; 2019	5	1; 1; 1; 1; 1	1	-	Chakraborty et al. (2023); *National Symposium,*	Highly tolerant to vegetative stage drought stress and

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Drought score in multiple testing (at <8% SMC)	Mean of values	Standard deviation (SEM)	Reference	Remarks (Tolerant/ MR/R/ etc)
								NBPGR(2009)	this genotype was used as donor parent for development drought tolerant rice variety Gopinath (CR Dhan 206)
3.	Salkaiin	INGR10151 IC-0256590	2007-2009	3	1; 1; 1	1	-	*NBPGR* (2009)	Highly tolerant to vegetative stage drought stress
4.	CR 143-2-2	INGR17019 IC-0513420	2005-2010	6	1; 1; 0; 1; 1; 0	1	-	Swain et al. (2013) *CRRI Newsletter* pp. 14; Chakraborty et al. (2022) *Plant Biology* 24: 356-366; *CRRI Ann Rep*2005- 06 p. 91-92; *CRRI Ann Rep* 2006- 07 p. 19; *CRRI Ann Rep* 2011-12 p. 22-25	Highly tolerant to vegetative and reproductive stage drought stress. A breeding line from Bala × Lalnakanda 41, this genotype possesses a vigorous root system
5.	Wild rice (*O. nivara*)	INGR21003 IC-330611	2002-2005	3	1; 1; 1	1	-	Patra et al. (2008) *Oryza* 45: 98-102; *CRRI Ann Rep* 2002- 03 pp. 114-115.	A wild rice (*O. nivara*) accession highly tolerant to vegetative stage drought stress
6.	Wild rice (*O. nivara*)	INGR21004 IC-330470	2002-2005	3	1; 1; 1	1	-	Patra et al. (2008) *Oryza* 45: 98-102; *CRRI Ann Rep* 2002- 03 pp. 114-115.	A wild rice (*O. nivara*) accession highly tolerant to vegetative stage drought stress
7.	IRGC-6588	INGR21002 AC-42997	2012-2017	6	1; 1; 1; 1; 1; 1	1	-	Dash et al. (2017); Dash and Swain	Highly tolerant to vegetative

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Drought score in multiple testing (at <8% SMC)	Mean of values	Standard deviation (SEM)	Reference	Remarks (Tolerant/ MR/R/ etc)
		IC-576152						(2015); *CRRI Ann Rep* (2012-13)	stage drought stress with low stomatal density (352.2/mm^2) and high root biomass
8.	Gurum	INGR22110 AC-43037 IC-0645858	2015-16; 2020-21	4	1; 1; 1; 1	1	-	*CRRI Ann Rep* (2015-16); NRRI Ann. Rep. 2020; AICRIP-PHY Rep 2021	Highly tolerant to drought stress with low stomatal density Tolerant to submergence and AG stress.
9.	Dudha Charisda	INGR22109 AC-43025 IC-0645857	2015-16; 2020-21	4	1; 1; 1; 1	1	-	Dash and Swain (2015); NRRI Ann. Rep. 2020; AICRIP-PHY Rep 2021	Highly tolerant to drought stress with high WUE. Tolerant to submergence and AG stress;
10.	Chariesid	INGR22108 AC-43012 IC-0645856	2013-16; 2020	6	1; 3; 3; 1; 3; 3	3	-	Dash and Swain (2015); *CRRI Ann Rep* (2015-16); AICRIP-PHY Rep (2021)	Highly tolerant to vegetative stage drought stress with high WUE and low transpiration rate
11.	Black gora	INGR23004 IC-0640862	2018; 2019; 2021	3	1; 1; 1	1	-	Roy et al. (2023); AICRIP-PHY Rep 2022.	Highly tolerant to drought and AG stress. Additionally, tolerant to submergence and low-P stresses
12.	Dular	INGR22107	2018; 2019; 2021	3	1; 1; 1	1	-	Roy et al. (2023); AICRIP-PHY Rep 2022.	Highly tolerant to drought, submergence and low-P stress along

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Drought score in multiple testing (at <8% SMC)	Mean of values	Standard deviation (SEM)	Reference	Remarks (Tolerant/ MR/R/ etc)
									with high AG potential
13	Parijat		2018; 2019	2	1; 1	1	-	Chakraborty et al. (2023)	Highly tolerant to vegetative and reproductive stage drought stress
14.	IC 516149	IC-516149	2018; 2019	2	3; 3	3	-	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann Rep 2022; AICRIP-PHY Rep 2024	Tolerant to drought, anaerobic germination, and complete submergence up to 14 days
15.	IET 18716	IET-18716	2020; 2021; 2023	2	3; 3	3	-	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann Rep 2022; AICRIP-PHY Rep 2024	Tolerant to vegetative stage drought stress and anaerobic germination
16.	Khandagiri		2020; 2021	2	1; 1	1	-	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann Rep 2022; AICRIP-PHY Rep 2024	Highly tolerant to vegetative stage drought stress and anaerobic germination
17.	Annapurna		2020; 2021	2	3; 3	3	-	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann Rep 2022; AICRIP-PHY Rep 2024	Tolerant to vegetative stage drought stress and anaerobic germination
18.	Sahabhagi Dhan		2020; 2021	2	56; 68	62	6.0	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann Rep 2022; AICRIP-PHY Rep 2024	Highly tolerant to vegetative stage drought stress and anaerobic germination

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Drought score in multiple testing (at <8% SMC)	Mean of values	Standard deviation (SEM)	Reference	Remarks (Tolerant/ MR/R/ etc)
19.	Bhalum-1 (RCRT-2)		2014-16	3	3, 1, 1	1.7	1.2	Anupam et al. (2017)	Tolerant to drought stress
20.	Bhalum-3 (RCRT-1)		2014-16	3	3, 1, 1	1.7	1.2	Anupam et al. (2017)	Tolerant to drought stress
21	RSR2/JLM-9		2020-21	2	3, 3	3	0	Anupam et al. (2022)	Tolerant to drought stress
22	IC 454372	IC-454372	2020-21	2	1, 3	2	1.5	Anupam et al. (2022)	Tolerant to drought stress
23	AUS 449	IRGC 29230	2020-2022	3	1.6, 1.1, 0.8	1.205	0.43	Sar et al., (2022)	Tolerant to drought stress
24	AUS 84	IRGC 28947	2020-2022	3	2.1, 0.7, 1.7	1.501	0.68	Sar et al., (2022)	Tolerant to drought stress
25	BOTESHSHORE	IRGC 53484	2020-2022	3	2.6, 0.8, 1.7	1.622	0.90	Sar et al., (2022)	Tolerant to drought stress
26	Narikel Badi	IRGC 37550	2020-2022	3	0.9, 2.7, 1.4	1.698	0.96	Sar et al., (2022)	Tolerant to drought stress
27	Kortik Kaika	IRGC 31841	2020-2022	3	3.0, 0.9, 1.8	1.914	1.05	Sar et al., (2022)	Tolerant to drought stress
28	Kachilon	IRGC 27555	2020-2022	3	1.8, 1.1, 2.8	1.915	0.89	Sar et al., (2022)	Tolerant to drought stress
29	UPRH 31	IRGC 61503	2020-2022	3	1.7, 1.7, 2.3	1.930	0.31	Sar et al., (2022)	Tolerant to drought stress
30	Mansar Dhan	IRGC 86940	2020-2022	3	1.5, 1.5, 2.9	1.974	0.86	Sar et al., (2022)	Tolerant to drought stress
31	Kalipinch	IRGC 53271	2020-2022	3	1.8, 1.3, 3.6	2.190	1.30	Sar et al., (2022)	Tolerant to drought stress
32	Jasure Aus	IRGC 43860	2020-2022	3	2.2, 1.7, 2.8	2.235	0.56	Sar et al., (2022)	Tolerant to drought stress

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Chapter-2

Rice germplasm tolerant to complete submergence stress

Koushik Chakraborty and Ramani Kumar Sarkar

Introduction

In the era of global climate change, rice cultivation especially in the rain-fed shallow lowland ecology faces multi-facet problems. Erratic rainfall leading to the problem of either water deficit or excess water condition may create a havoc in the near future, although the expected mean annual precipitation may remain the same (Kumar et al. 2011). Such erratic rainfall pattern makes the rice crop vulnerable to germination stage oxygen deficiency (GSOD) or submergence stress depending upon the timing of the natural events. Recent reports suggested more frequent occurrence of such climatic extremities *viz*. prolonged dry spells, heavy precipitation (> 40 mm / day), cyclones etc. in many parts of India, Bangladesh and elsewhere (Samal and Pandey 2005; Ghosh et al. 2012; Sarkar et al. 2012). Submergence is a type of flooding stress defined as a condition, where the entire plant is fully immersed in water (a phenomenon termed as complete submergence) or at least part of the shoot terminal is maintained above the water surface (a phenomenon termed as partial submergence). Under submergence plants face a number of external challenges simultaneously or sequentially results in multiple internal stresses, which affect growth and survival of plants. Submergence substantially reduces the gas diffusion rate in the leaf tissue, restricts oxygen uptake and forces carbon inefficient carbohydrate metabolism *via* an aerobic route (Panda et al. 2017). To add-on the problem turbid floodwaters also reduce light availability, inhibiting underwater photosynthesis and leaf gas exchange (Das et al. 2009). Limitation of efficient gas exchange also restricts transpiration severely, possibly impeding the absorption and transport of nutrients from the soil (Pedersen 1993; Chakraborty et al. 2021).

The Indian cultivar FR13A is the most widely studied and used as a source of submergence tolerance in rice breeding, and a major QTL, designated *SUB1*, was identified that imparts submergence tolerance of this genotype (Xu and Mackill 1996). *SUB1* was subsequently fine-mapped and cloned, and three genes encoding putative ethylene responsive factors (ERF), *Sub1A*, *Sub1B*, and *Sub1C*, were identified with *Sub1A* recognized as the primary determinant of submergence tolerance (Xu et al., 2006). Cloning of *Sub1A* provided opportunities to gain more insight into the molecular mechanisms involved and to unravel the pathways underlying the submergence tolerance conferred by this gene (Fukao and Bailey-Serres, 2008). Moreover, precise gene-based markers were designed for its successful introgression into popular high-yielding rice varieties (Neeraja et al., 2007; Septiningsih et al., 2009). Subsequent testing of the introgression lines in the field showed no apparent effects on agronomic performance, grain yield or quality in the absence of submergence (Sarkar et al., 2009), but with substantial enhancement in survival and yield (by 2-3-fold) after submergence for 12 to17 days (Sarkar et al., 2009). The success of marker added backcrossing / selection and identification of suitable donors tolerant to submergence depends on proper phenotyping. ICAR-National Rice Research Institute (NRRI, erstwhile CRRI) is a pioneer rice research institute of the World. NRRI with great engineering skill constructed field screening facilities for submergence and stagnant flooding in rice as early as in the year 1978-79 (Paul and Bhattacharya, 1980). Simulation of waterlogged situation in normal filed for screening of varieties by engineering skill. The cultivar, FR13A identified by NRRI was the source of widely used *SUB1* gene.

Screening for submergence tolerance

a) *Screening under field conditions:* The mechanisms of survival under flash flooding and stagnant water conditions are different. Plants are raised under direct seeded condition.? Generally, 20-25 days old seedlings are completely submerged under 90–100 cm of water. Plant height is taken before and after submergence to know the elongation ability which may give an idea about the suitability of plants for flash flood or stagnant flood conditions. Keen observation is needed to score the submergence tolerance: the genotype showed greater elongation and pushed their leaf tip above the water surface should be discarded to designate as submergence tolerant cultivar. Finally, number of survived plants of each genotype is counted after 10 days of de-submergence.

   Plant Survival (%) = [(No. of plants/hills survived after 10 days/ No. of plants/hills before imposition of submergence stress) × 100]

   Advantage: Both submergence tolerant and stagnant flooding tolerance screening is possible in a single experiment. Seeds can be harvested from the survived plants. In the same growing season hybridization programme can be initiated with survived plants.

b) *Screening under net house conditions:* Seeds are sown in earthen pots (15 cm height) containing 2 kg of sun-dried soil mixed with farmyard manure (3:1) and inorganic fertilizers as per standard practice. Thinning was done to keep three plants per pot after 10 days of sowing. The 25-day-old seedlings were subjected to submergence stress with 100 cm of standing water in cement tanks (L × B × H: 2 × 1.5 × 1.2). Plant survival count is taken after 10 days of drainage of water. Plant height is taken just before imposition of the stress and immediately after drainage of water from the tanks. This technique saves time and needs limited resources and can be used to distinguish tolerant and susceptible genotypes.

Advantage: Require less area and space.

Disadvantage: Loosing of plant materials suitable for stagnant flooding for medium-depth condition.

Note: Avoiding common pitfalls in submergence screening:

As it is known that quality of floodwater influences the survival of plants, to screen the cultivars we should give our focus on the susceptible cultivars and the quality of floodwater; an assumption can be made so that mortality of the susceptible check may be nearer to the 100%. If the floodwater is clear, then after 7-8 days of complete submergence, one should check the susceptible cultivars. Extreme yellowing of leaves and softening of base is a harbinger of plant death and on that basis, we can take a decision about the total days of submergence. Under clear water, we in general, give submergence stress for 12-15 days depending upon the conditions of susceptible check.

Table 2. List of selected genotypes with high submergence tolerance potential

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Survival (%) in multiple testing (after 14 days)	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
1.	Khadara	INGR8108 AC-36476 IC-283026	2002; 2003; 2004	3	88; 80; 83	83.6	2.3	Panda et al. (2006)	Highly olerant to complete submergence up to 14 days
2.	Atiranga	INGR8109 AC-35584 IC-258997	2004; 2005; 2006	3	98; 92; 95	95	1.7	Panda et al. (2008)	Highly tolerant to complete submergence up to 14 days
3.	Kalaputia	INGR8110 AC-39575 IC-524024	2002-2006	5	95; 98; 92; 90; 96	94.4	1.4	Panda et al. (2006); Panda et al. (2008)	Highly tolerant to complete submergence up to 14 days
4.	Gangasiuli	INGR8111 AC-35157 IC-256777	2004; 2005; 2006	3	70; 78; 73	73.8	2.3	Panda et al. (2008)	Tolerant to complete submergence up to 14 days
5.	Mahulata	INGR8112 AC-35186 IC-256806	2019; 2020; 2021	3	68; 75; 70	71	2.1	AICRIP-PHY Report 2019; 2020; 2021	Tolerant to drought and complete submergence up to 14 days
6.	Kusuma	INGR8113 AC-36517 IC-283068	2004; 2005; 2006	3	62; 66; 69	65.6	2.0	Sarkar et al. (2004); Panda et al. (2008)	Tolerant to complete submergence up to 14 days
7.	Khoda	INGR4001	2004; 2005; 2006	3	90; 85; 92	89	2.1	Panda et al. (2008); Sarkar & Panda (2009)	Highly tolerant to complete submergence up to 14 days
8.	Bhundi	INGR14025 AC-42091	2008-2010	3	79; 88; 90	85.6	3.4	Sarkar &Bhattacharjee (2011)	Highly tolerant to complete submergence

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Survival (%) in multiple testing (after 14 days)	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
		IC-575277							up to 20 days with faster elongation ability
9.	Kalaketaki	INGR14026 AC-42087 IC-0575273	2008-2010; 2018; 2019	5	100; 100; 92; 97; 92	96.3	2.9	Sarkar & Bhattacharjee (2011); NRRI Ann Rep 2018-19; NRRI Ann Rep 2019	Highly tolerant to complete submergence up to 20 days
10.	Andekarma	INGR10148 IC-0256801	2005; 2006	2	100; 95	97.5	2.5	Panda et al. (2007)	Highly tolerant to complete submergence up to 20 days
11.	Champakali	INGR10149 IC-0258830	2005; 2006	2	100; 100	100	0	Panda et al. (2007)	Highly tolerant to complete submergence up to 20 days
12.	Medinapore	INGR10147 IC-0258990	2005; 2006	2	95; 90	92.5	2.5	Panda et al. (2007)	Highly tolerant to complete submergence up to 14 days
13.	Black gora	INGR23004 IC-0640862	2018; 2019; 2020	3	75; 69; 65	69.6	2.9	Roy et al. (2023); AICRIP-PHY Rep 2022.	Tolerant to submergence, drought and low-P stress along with high AG potential
14.	Dular	INGR22107	2018; 2019; 2020	3	89; 80; 83	84	2.64	Roy et al. (2023); AICRIP-PHY Rep 2022.	Highly tolerant to submergence, drought and low-P stress along with high AG potential
15.	CRR751-1-12-B-B	INGR23073 IET-28033	2020; 2021	2	90; 85	87.5	2.5	AICRIP-Varietal Improvement Rep.2020 & 2021.	Highly tolerant to submergence and reproductive stage drought stress with resistance to leaf blast
16.	Gurum	INGR22110 AC-43037 IC-0645858	2020; 2021	2	71; 62	66.5	3.7	NRRI Ann. Rep. 2020; AICRIP-PHY Rep 2021	Tolerant to submergence and AG stress; highly tolerant to drought stress with low stomatal density
17.	Dudha Charisda	INGR22109 AC-43025	2020; 2021	2	84; 72	78	6.0	NRRI Ann. Rep. 2020; AICRIP-	Tolerant to submergence and AG stress;

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Survival (%) in multiple testing (after 14 days)	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
		IC-0645857						PHY Rep 2021	highly tolerant to drought stress with high WUE.
18.	FR13A		2008-2010; 2018-2019	5	100; 95; 98; 96; 92	96.2	1.4	Sarkar & Bhattacharjee (2011); Chakraborty et al. (2021)	Highly tolerant to complete submergence up to 14 days and has high leaf gas film thickness
19.		IC-516366	2019; 2020; 2023	3	100; 100; 92	97.3	2.7	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann Rep 2022; AICRIP-PHY Rep 2023	Highly tolerant to drought and complete submergence up to 14 days
20.	Asina	AC-42088 IC-575274	2008-2010; 2018; 2019	5	100; 100; 98; 100; 95	97.6	1.8	Sarkar & Bhattacharjee (2011); NRRI Ann Rep 2018-19; NRRI Ann Rep 2019	Highly tolerant to complete submergence up to 20 days
21.	IC-516149	IC-516149	2019; 2020; 2023	3	70; 76; 79	75	2.6	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann Rep 2022; AICRIP-PHY Rep 2023	Tolerant to drought and complete submergence up to 14 days and also has high AG potential
22.	AC-38209	AC-38209	2019; 2020; 2023	3	80; 85; 88	84.3	2.3	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann Rep 2022; AICRIP-PHY Rep 2023	Highly tolerant to drought and complete submergence up to 14 days
23.	Gurjari		2019; 2020; 2023	3	85; 91; 82	86	2.7	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann Rep 2022; AICRIP-PHY Rep 2023	Highly tolerant to drought and complete submergence up to 14 days

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Chapter-3

Rice germplasm with salinity tolerance

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Introduction

Several biotic and abiotic factors influence the rice growth and thus affect the productivity in coastal ecology. Owing to the greater frequencies of abiotic stresses in the coastal regions posed by the climate change, higher productivity in rice is in threat (Chattopadhyay et al. 2021). Among many abiotic stresses, salinity is the major constraint which delineate low productivity of rice in the coastal plains. Sensitivity of rice crop to salinity stress varies with their growth stages. Rice is mainly susceptible to salt stress at early vegetative and from the panicle initiation to the grain filling stage. A large number of germplasm lines have been collected along the coastal saline areas in India and evaluated by many researchers. Traditionally, cultivated local rice landraces and cultivars in coastal area show tolerance to salinity at varying level. Pokkali is one of them which was used in detection of the *Saltol*, the most recognized major QTL for seedling stage salt tolerance. As compared to seedling stage, the donors for reproduction stage are rare and marker assisted selection for salt tolerance at flowering stage is rarely used.

Screening for salinity tolerance at seedling stage

The pre-germinated seeds of each genotype on the styrofoam seedling floats kept on plastic trays filled up with the Hoagland or Yoshida nutrient solution (Yoshida et al. 1976). Salinity was raised to 12 dS m^{-1} by adding 6 g NaCl per litre of nutrient solution. When symptoms of salt-stress appeared severe in the susceptible check IR 29, all the genotypes were scored visually in 1 to 9 scale using the modified standard evaluation system (SES) of IRRI (Gregorio et al. 1997). Rice genotypes differ for Na+ and K+ concentration and Na+/K+ ratio in shoot during salt stress. Na+/K+ ratio in shoot is important indicator for salt tolerance at seedling stage.

Screening for salt tolerance at reproductive stage

A unique protocol for evaluation of rice genotypes for salinity tolerance at seedling stage was developed by Chattopadhyay et al. (2018) with the requisite modifications of the standard procedure of Gregorio et al. (1997) to salinize potted plants. For salinization, NaCl was dissolved to tank water to make water EC of 8 dSm^{-1} and salt water was allowed to enter the porous pots to saturate soil. Salt stress was imposed on plants before booting. One perforated pipe (piezometer) was placed inside the soil with its opening outside the soil surface. Water from saturated soil was collected inside this pipe. Regular monitoring of pH and salinity level of water of saturated soil inside this pipe was done using a hand-held EC cum pH meter. Seedlings at the age of 20-25 days were planted in these perforated pots. The level of water in plastic bath was maintained at 2 cm below the soil surface of the perforated pots. One set of potted seedlings was salinized and the other set was allowed to grow in normal condition in the net-house till the grain filling stage. Yield reduction under salt stress at flowering stage??? Is the main indicator of susceptibility. Tolerant genotypes show the reducing yield loss under stress. The following criteria can be set to classify genotypes based on their tolerance to salt stress at flowering stage at EC of 8dSm-1.

Table 3. List of selected genotypes with salinity tolerance potential

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	SES score (1-9 scale) (Na- K ratio)	Mean of values	Standard deviation (SEM)	Reference	Remarks (Tolerant/ MR/R/ etc)
1.	CherayiPokkali (AC 39416A)	INGR No.19004 (IC0413644; AC 39416A)	2011, 2012, 2023	3	3 (0.20)	3	-	NICRA Report (2010-12), Chattopadhyay et al. 2014;	Tolerant to salinity and other abiotic stresses
2.	FL478		2011, 2012	5	3 (0.20)	3	-	Chattopadhyay et al., 2012; CRRI Annual Report	Highly tolerant to salinity at seedling stage

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	SES score (1-9 scale) (Na- K ratio)	Mean of values	Standard deviation (SEM)	Reference	Remarks (Tolerant/ MR/R/ etc)
								2011-12; Chattopadhyay et al., 2014	
3.	Chettivirippu	AC 39389	2011, 2012	3	3 (0.20)	3	-	Chattopadhyay et al., 2012; CRRI Annual Report 2011-12; Chattopadhyay et al. 2014a	Highly tolerant to salinity at seedling stage
4.	Remeni Pokkali	INGR No. 21117 (AC41585)	2009, 2010, 2011, 2012	6	3 (0.21) (0.97)	3	-	NICRA report (2010-12); Chattopadhyay et al. 2014a	Tolerant to seedling and reproductive stage salinity tolerance
5.	FL496		2009, 2010, 2011, 2012	4	3 (0.22) (1.21)	3	-	Chattopadhyay et al. 2014a Chattopadhyay et al. 2014b	Highly tolerant to salinity at seedling stage
6	Patnai	AC 43220	2011, 2012	2	3 (0.22)	3	-	Chattopadhyay et al., 2012; CRRI Annual Report 2011-12;	Tolerant to moderately tolerant to salinity at seedling stage
7	Kamini	INGR No.19033 (AC 44118; IC 599610)	2011, 2012, 2018, 2019	4	3, 5 (0.25)	5	-	NICRA Report (2010-12), Chattopadhyay et al., 2012; CRRI Annual Report 2011-12; Chattopadhyay et al. 2014a; Chakraborty et al. 2020	Tolerant to moderately tolerant to salinity at seedling stage
8	Talmugur	INGR No.19034 (AC 43228; IC 0596460)	2011, 2012	2	3, 5	5	-	NICRA Report (2010-12), Chattopadhyay et al., 2012; CRRI Annual Report 2011-12; Chattopadhyay et al. 2014a	Tolerant to moderately tolerant to salinity at seedling stage
9	Chettivirippu (AC39394)	INGR No.19035 (IC 0599610) AC 39394	2011, 2012	2		3	-	Chattopadhyay et al., 2012; CRRI Annual Report 2011-12; Chattopadhyay et al. 2014a	Tolerant to salinity

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	SES score (1-9 scale) (Na- K ratio)	Mean of values	Standard deviation (SEM)	Reference	Remarks (Tolerant/ MR/R/ etc)
10	SR 26B			2	5 (0.26)	5	-	Chattopadhyay et al. 2014b	Tolerant to salinity
11	Rahspunjar	INGR No. 21116 ((IC-575321; AC 42138)	2009, 2010, 2011	3	5 (0.32) (1.11)	5	-	NICRA Report (2010-12), Chattopadhyay et al. 2014b	Tolerant to salinity and other abiotic stresses
12	Matla		2011, 2012	2	5 (0.33)	5	-	Chattopadhyay et al., 2012; CRRI Annual Report 2011-12;	Moderately tolerant to salinity
13	Marishal		2011, 2012	2	5 (0.33)	5	-	Chattopadhyay et al., 2012; CRRI Annual Report 2011-12;	Moderately tolerant to salinity
14	Rupshal		2011, 2012	2	5 (0.39)	5	-	Chattopadhyay et al., 2012; CRRI Annual Report 2011-12;	Moderately tolerant to salinity
15	Kumrogour	AC43233	2011	1		5	-	Chattopadhyay et al., 2012	Moderately tolerant to salinity at seedling stage
16	Nona Bokra		2009, 2010	2	5 (1.03)	5	-	Chattopadhyay et al. 2014b	Tolerant to salinity
17	Ravana		2010, 2011	2	5	5	-	NICRA Report (2010-12)	Tolerant to salinity
18	Savitri		2009, 2010, 2011, 2012	4	9 (0.69) (2.23)	9	-	Chattopadhyay et al. 2014a, Chattopadhyay et al. 2014b	Susceptible to salinity
19	IR29		2009, 2010, 2011, 2012	4	9 (0.76) (1.66)	9	-	Chattopadhyay et al. 2014a, Chattopadhyay et al. 2014b	Susceptible to salinity, high tissue tolerance
Reproductive stage salinity tolerance									
1	Remeni Pokkali	INGR No. 21117 (AC41585)	2011, 2012, 2014, 2015	3	3	3	-	NICRA report (2010-2012), Chattopadhyay et al., 2013, Chattopadhyay et al. 2020, Chattopadhyay et al. 2018	Tolerant to seedling stage and moderately tolerant to reproductive stage salinity tolerance
2	Chettivirippu (AC39394)	INGR No.19035 (IC 0599610)	2011, 2012, 2014,	3	5	5	-	NICRA report (2010-2012), Chattopadhyay et	Tolerant to seedling stage and

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	SES score (1-9 scale) (Na- K ratio)	Mean of values	Standard deviation (SEM)	Reference	Remarks (Tolerant/ MR/R/ etc)
		AC 39394	2015					al. 2013; Chattopadhyay et al. 2018	moderately tolerant to reproductive stage salinity tolerance
3	Chettivirippu (AC39389)	AC 39389	2011, 2012, 2014, 2025	3	5	5	-	NICRA report (2010-2012), Chattopadhyay et al. 2013; Chattopadhyay et al. 2018	Tolerant to seedling stage and moderately tolerant to reproductive stage salinity tolerance
4	CherayiPokkali (AC 39416A)	INGR No.19004 (IC0413644; AC 39416A)	2021, 2023	2	3, 5	5	-	ICAR-NRRI Annual report 2023	Moderaltely Tolerant to salinity at reproductive stage
5	Bina Dhan 10		2016	1	5	5	-	Chattopadhyay et al. 2017	Tolerant to seedling stage and moderately tolerant to reproductive stage

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Chapter-4

Germplasm for high anaerobic germination potential in rice

Koushik Chakraborty and Ramani Kumar Sarkar

Introduction

Flash flood just after sowing imposes submergence stress by creating hypoxic condition (3% Oxygen) during germination as well as during vegetative stage (Narsai et al., 2015). Interestingly, mode of overcoming hypoxic stress by rice plants seems to be different during germination and vegetative stages. The genes and QTLs reported for vegetative stage submergence tolerance are of no use to tolerate germination stage submergence and vice-versa. Being adapted to aquatic ecology, rice (*Oryza sativa*) has developed the unique mechanism to germinate and extend its coleoptile under water even in complete absence of oxygen (Magneschi and Perata, 2009) – a phenomenon termed as anaerobic germination (AG). In general, rice coleoptile under water has been found to elongate about 1 mm h^{-1} to reach the atmosphere by rapid elongation of basal cells (up to 200 µm in 12 h) immediately after emerging from embryo (Narsai et al., 2015). However, anaerobic germination potential (AGP) varies greatly among different rice genotypes, which ultimately provide an edge to a few genotypes to perform better under oxygen deficient conditions over others.

Anaerobic respiration usually yields much less energy as compared to the aerobic respiration mode of respiration. Here, the energy requirement is largely fulfilled by glycolysis followed by alcoholic fermentation (Guglielminetti et al. 1995, 2001; Hwang et al. 1999). Transcriptome analysis data also revealed up-regulation of genes related to starch and glucose metabolism, glycolysis and fermentation during germination under anaerobic condition / submergence (Lasanthi-Kudahettige et al. 2007; Hussain et al. 2016; Narsai et al. 2017). Starch degrading enzymes like α-amylase, aldolase and sucrose synthase up regulated in GSOD tolerant cultivars greatly compared to susceptible cultivars (Ismail et al. 2009; Miro and Ismail 2013) with higher *RAmy* 3D gene expression (Ismail et al. 2009; Takahashi et al. 2014) as well as greater up-regulation of rice cytosolic hexokinase *OsHXK7* (Kim et al 2016). The work of mapping QTLs imparting high anaerobic germination potential (AGP) has been initiated (Angaji et al., 2010; Baltazar et al., 2014; Kretzschmar et al., 2015) and one of the identified QTL, *qAG-9-2* has been fine-mapped to *OsTPP7* gene which encodes trehalose-6-phosphate phosphatase involved in starch mobilization during germination (Kretzschmar et al., 2015).Recent studies showed effective operation of anaerobic respiration and nitrogen metabolism in tolerant rice genotypes led to more energy efficient metabolic system under oxygen limiting GSOD condition resulted in better ROS handling and cellular pH maintenance (Vijayan et al. 2018).

Screening for GSOD tolerance (anaerobic germination potential)

Breaking of seed dormancy: This is important for uniform germination and seedling growth. Seeds are kept in brown paper packet. Numbers of small hole are made on the packet with pointed pin. Packets with seeds are being placed in an oven at 48 $\pm$ 2 °C for five days. Packets are taken out from the oven and cool under ambient room temperature for further use.

Screening under net house conditions:

The anaerobic germination potential can be assessed by creating hypoxic/ anoxic stress during the germination process. Thirty seeds (per replication) of each tested genotype should be sown along with checks in polypropylenetrays (minimum height of the tray is 15 cm). The tray should be filled up with well-pulverized fine clay-loam farm soil up to 4 cm thickness. Dry seeds are sown about 1 cm below soil surface in 3 replications. Immediately after sowing, the tray is filled up with 10 cm depth of water, which would be kept in ambient environmental conditions under the temperature range of 25-32^{o}Cfor 21 days. Germination count should be taken at regular intervals for both control and anaerobic treatment conditions. Crop establishment / survival were counted after twenty days of sowing. Emergence of leaf tips above the water surface was considered as establishment or survival. Control trays (without standing water) were also maintained along with the treatment trays where the soil surfaces were adequately moistened by the regular sprinkling of water. The hypocotyl length (cm) was measured in the treatment after 21 days of imposing stress from the germination count data, we calculated the germination percent (GP) which is the percentage of seeds that complete the germination process (Chakraborty et al. 2021). The anaerobic germination index (AGI) was calculated to find the actual germinability under anaerobic conditions.

$$AGI = G_{p\_AG}/G_{p\_CONTROL}$$

c) *Screening under field conditions:*

The field should be prepared well. Dry seeding is preferable compared to wet seeding. Seeds are placed below the soil surface. Flooding is done with 15 cm depth of water immediately after seeding. Water depth is measured in regular intervals. Additional irrigation is provided if water level below from the soil surface 10 cm.

Caution:

1. Very old seeds should not be used. Seeds harvested in the previous season should preferably be used.
2. Seeds should be non-dormant. If required dormancy should be broken.

Table 4. List of selected genotypes with high anaerobic germination potential

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	AGI in multiple testing (after 21 days)	Mean of values	Standard deviation (SEM)	Reference	Remarks (Tolerant/ MR/R/ etc)
1.	Kodiyan	INGR05001 AC-1631 T1471	1999; 2000	2	83, 85	84	-	Sarkar & Ray (2003); Patra and Sarkar (2005)	Highly tolerant to anaerobic germination.
2.	Khora-I	INGR19006 AC-41620 IC-574806	2012-2015; 2017	5	92; 81; 87; 82; 85	85.5	2.53	Chakraborty et al. (2020); Vijayan et al. (2018); NICRA Ann. Rep. 2011-12.	Highly tolerant to anaerobic germination.
3.	Cherayi Pokkali	INGR19004 AC-39416A IC-413644	2011-2013	3	80; 65; 72	69.6	6.8	Sarkar et al. (2020); Sarkar & Bhattacharya (2011); AICRIP-PHY Ann Rep. 2013, 2016; NICRA Ann. Rep. 2012-13	Tolerant to anaerobic germination. Additionally, it is tolerant to SF, Salinity, osmotic stress and submergence
4.	Rahaspunjar	INGR21116 AC-43418 IC-575321	2011-12; 2018-2020	5	89; 68; 75; 84; 66	75	6.4	Chakraborty et al. (2021); Senapati et al. (2019); AICRIP-PHY Rep 2019; NICRA Ann Rep 2012-13	Highly tolerant to anaerobic germination. Additionally, it is tolerant to Salinity stress and fresh and saline water flooding
5.	Gurum	INGR22110 AC-43037 IC-0645858	2020; 2021	2	71; 62	66.5	3.7	NRRI Ann. Rep. 2020; AICRIP-PHY Rep 2021	Tolerant to submergence and AG stress; highly tolerant to drought stress with low stomatal

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	AGI in multiple testing (after 21 days)	Mean of values	Standard deviation (SEM)	Reference	Remarks (Tolerant/ MR/R/ etc)
									density
6.	Dudha Charisda	INGR22109 AC-43025 IC-0645857	2020; 2021	2	84; 72	78	6.0	NRRI Ann. Rep. 2020; AICRIP-PHY Rep 2021	Tolerant to submergence and AG stress; highly tolerant to drought stress with high WUE.
7.	Black gora	INGR23004 IC-0640862	2018; 2019; 2021	3	80; 75; 74	76.3	2.3	Roy et al. (2023); AICRIP-PHY Rep 2022.	Highly tolerant to AG and drought stress. Additionally, tolerant to submergenceand low-P stresses
8.	Dular	INGR22107	2018; 2019; 2021	3	76; 71; 85	77.3	5.0	Roy et al. (2023); AICRIP-PHY Rep 2022.	Highly tolerant to submergence, drought and low-P stress along with high AG potential
9.	IC-516149	IC-516149	2020; 2021; 2023	3	62; 71; 75	69.3	4.7	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann Rep 2022; AICRIP-PHY Rep 2023	Tolerant to anaerobic germination, drought and complete submergence up to 14 days
10.	IET-18716	IET-18716	2020; 2021; 2023	3	100; 86; 89	91.7	5.2	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann Rep 2022; AICRIP-PHY Rep 2023	Highly tolerant to anaerobic germination and vegetative stage drought stress
11.	Khandagiri		2020; 2021	2	62; 64	63	1.0	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann Rep 2022; AICRIP-PHY Rep 2023	Tolerant to anaerobic germination and vegetative stage drought stress
12.	Annapurna		2020; 2021	2	63; 68	65.5	2.5	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann	Tolerant to anaerobic germination and vegetative stage drought stress

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	AGI in multiple testing (after 21 days)	Mean of values	Standard deviation (SEM)	Reference	Remarks (Tolerant/ MR/R/ etc)
								Rep 2022 ; AICRIP-PHY Rep 2023	
13.	Sahabhagi Dhan		2020; 2021	2	56; 68	62	6.0	Chakraborty et al. (2023); NRRI Ann Rep 2021; NRRI Ann Rep 2022; AICRIP-PHY Rep 2023	Tolerant to anaerobic germination and vegetative stage drought stress
14.	AC-34245	AC-34245	2017; 2018	2	75; 61	68	7.0	Senapati et al. (2019)	Tolerant to anaerobic germination
15.	AC-40346	AC-40346	2009; 2017; 2018	3	76; 54; 66	65.3	5.5	Senapati et al. (2019); CRRI Ann Rep 2009-10	Tolerant to anaerobic germination and complete submergence

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Chapter-5

High carbon dioxide (CO_2)-responsive rice germplasm

Koushik Chakraborty and Amaresh Kumar Nayak

Introduction

Atmospheric carbon dioxide (CO_2) concentration has been continuously increasing in the environment. Based on recent reports of IPCC (Intergovernmental Panel on Climate Change), global CO_2 concentration increased substantially in the environment since the industrial revolution begins. It was dramatically increased within few decades from 280 ppm (previous) to beyond 400 ppm (current) concentration(Canadell et al., 2007; Tans and Keeling, 2016) and predictions on global carbon dioxide concentration showed that at the end of this century it may reach to 550 ppm or more (IPCC, 2014). Myriad evidences are present in the literature concerning elevated CO_2 and its interactions with the plant, among them majority comes with a conclusion that elevated CO_2 levels in the atmosphere might be hampering the normal balance of the ecosystem and may alter the productivity of plants (Long et al., 2006; Ainsworth, 2008; Kang et al., 2009; Mohamed et al., 2013; Satapathy et al., 2015). As a producer of the ecosystem, the response of plants under an increased concentration of CO_2 is an important issue for maintaining a balance or homeostasis in the ecosystem. Among different crop species, rice (*Oryzasativa* L.) is one of the most widely used staple food crops as it provides an immense amount of carbohydrate, nutrients and vitamins. Carbon dioxide (CO_2) is a greenhouse gas and involves in the global warming process, inimical for the health of humans or consumers. Conversely, for the producers (plants) it is indeed essential which acts as a substrate for the photosynthesis process (especially for the enzyme Rubisco) and increased the net photosynthetic rate of the plant (Drake et al., 1997; Ainsworth and Long, 2005; van der Kooi et al., 2016), and reduces the oxygenase activity of Rubisco enzyme, thus minimizes the photo-respirational energy loss (Makino and Mae, 1999; Taiz and Fizeiger, 2002).

Enormous pieces of evidence-based literature are available concerning "CO_2 fertilization effect" (Kazemi et al., 2018; Hasegawa et al., 2019), which showed the elevated concentration of CO_2 have a positive effect on rice production and improved growth, biomass, yield and carbohydrate status of the plant (Thompson et al., 2017). This has happened by increasing atmospheric CO_2 fixation and followed by effective compartmentalization through source to sink portions. Carbohydrates are the organic building blocks and therefore, considered as an immense source of energy, and its generation in leaf are associated with photosynthesis. Since rice genotypes differ based on their photosynthetic ability, thus, responses of different rice genotypes under elevated CO_2 conditions may not possibly the same always (Panda et al. 2023). Besides, as per the available reports on elevated CO_2 and its interaction with different rice genotypes, the relative response of all rice genotypes are not similar and different rice genotypes responds differentially based on the inter-specific variation and maturity period when grown under the elevated CO_2. Some genotypes are considered to be more-responsive whereas some genotypes are considered as less-responsive when grown under elevated CO_2.

Screening of rice genotypes for high CO_2-responses in open top chambers (OTC):

The selected rice genotypes, particularly popular and dominant cultivars from different rice growing ecologies of India were taken for evaluation. The plants were grown under three different conditions: field, OTCs with ambient CO_2 concentration (400 ± 10 ppm) and OTCs with elevated CO_2 concentration (550 ± 25 ppm). Field OTCs of 6×4×4 m (L×B×H) dimensions were used to raise the CO_2 concentration inside the chamber. The CO_2 feeding inside the eCO_2-chambers were done every day from 7.00 am to 4.00 pm (local time) to match the active photosynthesis period of the plants. Elevated CO_2 treatment was imposed during the entire crop growth period since transplanting. During screening, each treatment (field, ambient and elevated CO_2) should be replicated thrice. The elevated concentration of CO_2 was maintained in the OTCs by an automated computational system (Genesis Technologies), which pumps CO_2 from the source cylinders of 25L volume, mixes it with normal air and purges the appropriate quantity inside the chamber from perforated piping system lined inside the chamber at different heights. The automated console unit also records the CO_2, RH (%) and temperature data from inside and outside of the chamber at preselected time intervals.

Note: Due to the chamber effect, it was observed that there were about 1.6 °C rise in the temperature inside the OTCs as compared to the open-air adjacent fields, taking the average of temperature for the entire crop growth season.

Table 5. List of selected genotypes with high CO_2-responsiveness potential

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Yield improvement over field control (%)	Mean of values	Standard deviation (SEM)	Reference	Remarks
1.	Shatabdi		2019, 2020, 2021	3	21.25, 25.77, 23.25	23.42	1.30	Chakraborty et al. (2021) ; *NRRI Ann Rep* 2019; 2020; 2021	A very highly CO_2-responsive short duration variety for irrigated ecology
2.	Vandana		2019, 2020, 2021	3	20.30, 19.91, 22.50	20.90	0.80	Chakraborty et al. (2021) ; *NRRI Ann Rep* 2019; 2020; 2021	A very highly CO_2-responsive short duration variety for rain-fed upland ecology
3.	Abhishek		2019, 2020, 2021	3	16.88, 14.52, 16.80	16.06	0.77	Chakraborty et al. (2021) ; *NRRI Ann Rep* 2019; 2020; 2021	A highly CO_2-responsive mid-early duration variety for irrigated ecology
4.	IR64		2019, 2020, 2021	3	19.56, 13.34, 18.59	17.16	1.93	Chakraborty et al. (2021) ; *NRRI Ann Rep* 2019; 2020; 2021	A highly CO_2-responsive mid-early duration variety for irrigated ecology
5.	Shabhagidhan		2019, 2020, 2021	3	12.43, 10.39, 14.56	12.46	1.20	Chakraborty et al. (2021) ; *NRRI Ann Rep* 2019; 2020; 2021	A moderately CO_2-responsive short duration variety for rain-fed upland ecology
6.	MTU1010		2019, 2020, 2021	3	15.26, 10.95, 16.56	14.25	1.69	Chakraborty et al. (2021) ; *NRRI Ann Rep* 2019; 2020; 2021	A moderately CO_2-responsive mid-early duration

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Yield improvement over field control (%)	Mean of values	Standard deviation (SEM)	Reference	Remarks
									variety for irrigated ecology
7.	Maudamani		2019, 2020, 2021	3	9.38, 12.34, 13.56	11.76	1.24	Chakraborty et al. (2021) ; *NRRI Ann Rep* 2019; 2020; 2021	A moderately CO_2-responsive medium duration variety for irrigated ecology
8.	Varshadhan		2019, 2020, 2021	3	8.81, 9.93, 10.56	9.76	0.83	Chakraborty et al. (2021) ; *NRRI Ann Rep* 2019; 2020; 2021	A moderately CO_2-responsive long duration variety for semi-deep /waterlogged ecology

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Chapter-6

Rice germplasm with low phosphorus and nitrogen tolerance

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Brief description of trait

Phosphorus is crucial for rice growth, but its deficiency in soil is widespread, particularly in India. The source of phosphatic fertilizer is rock phosphate, which is renewable in nature and excessive phosphorus fertilizer use leads to environmental issues. Developing low phosphorus tolerant rice varieties is vital for sustainable agriculture as these varieties can thrive in phosphorus deficient soils, reducing the need for excessive fertilizer application. The breeding programs for low phosphorus tolerance focus on yield under low p condition and traits like enhanced root development and phosphorus uptake efficiency. The screening of around 600 germplasm including varieties, land races and wild species was done at the institute in field, hydroponics, sand culture to identify the low phosphorus tolerant genotypes, which can be used as donor for utilization in breeding programmes to improve phosphorus use efficiency in rice.

Methodology followed

Field experiments were conducted in control plots with low soil phosphorus content with 8-11 mg kg^{-1}. Available Phosphorus in soil was determined by the method suggested by Bray & Kurtz, 1945. The genotypes were assessed based on yield under stress and non-stress conditions, root and shoot characteristics, crop growth rate (CGR), Agronomic growth rate (AGR), Agronomic P use efficiency (AUE) and P uptake in straw and grains.

The sand culture technique was used to screen 14 rice varieties viz. IR36, Kalinga III, Vandana, Virendra, UpLPi7, Anjali, Rasi, Annada, CR Dhan 40, Sadabahar, Hazaridhan, Sahabhagidhan, Abhishek and Azucena for phosphorus deficiency tolerance. The plants were subjected to stress (nutrient solution containing 4 and 8 ppm of P) and non-stress (nutrient solution with 16 ppm of P) conditions. Data was observed on plant height, root length, number of roots/plant and dry weight/plant.

The rice genotypes comprising of landraces and improved rice varieties with different duration categories were evaluated in hydroponics media under different concentrations of P (0, 0.5 and 1) ppm of phosphorus. Kasalath and Dular were used as positive checks. The data was recorded on shoot length, root length, root and shoot dry weight and SPAD value at 28 days after sowing.

Table 6. The genotypes which performed better at low phosphorus content are listed below

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
1	ARC 11331	ARC 11331	2016 2017	2	CGR-0.3767 AGR-0.8286	CGR-0.3767 AGR-0.8286	-	ICAR-NRRI, Annual Report 2016-17	Selection for higher biomass
2	ARC 11356	ARC 11356	2016 2017	2	CGR-0.3162 AGR-1.1643	CGR-0.3162 AGR-1.1643	-	ICAR-NRRI, Annual Report 2016-17	
3	ARC 6249	ARC 6249	2016 2017	2	CGR-0.3157 AGR-1.0557	CGR-0.3157 AGR-1.0557	-	ICAR-NRRI, Annual Report 2016-17	
4	IC 459373	IC 459373	2018 2019	2	SDW-0.112 g, RDW-0.0208 g		-	ICAR-NRRI, Annual Report 2019	Hydroponics with 0.5 ppm phosphorus

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
5	Shankar		2018 2019	2	SDW - 0.132 g, RDW- 0.0306 g	-	-	ICAR-NRRI, Annual Report 2019	Checks: Kasalath (SDW-0.115 g, RDW-0.019 g) Dular (SDW-0.120 g, RDW 0.033 g) Presence of PSTOL 1 gene
6	IC459373	IC459373	2019	1	SL-28.93, NT-3.33, RL-15.12, SDW-1.459, RDW-0.278, TRPA-57.36, TSA-180.2, RV-2.78	-	-	Anandan *et al*, 2022	Dular (SL-25.93, NT-3.5, RL-11.55, SDW-1.22, RDW-0.27, TRPA-54.72, TSA-171.91, RV-4.25) Kasalath (SL-26.75, NT-3, RL-12.33, SDW-1.246, RDW-0.268, TRPA-33.48, TSA-105.18, RV-1.48)
7	Chakhao Aumbi		2019	1	SL-29.22, NT-3, RL-10.2, SDW-1.87, RDW-0.26, TRPA-44.24, TSA-138.98, RV-4.2	-	-	Anandan *et al*, 2022	
8	AC 100219	AC 100219	2019	1	SL-26.1, NT-3.33, RL-16.3, SDW-1.57, RDW-0.29, TRPA-54.44, TSA-133.85, RV-6.53	-	-	Anandan *et al*, 2022	
9	AC 100062	AC 100062	2019	1	SL-26.23, NT-3, RL-10.32, SDW-1.35, RDW-0.31, TRPA-35.84, TSA-112.61, RV-4.33	-	-	Anandan *et al*, 2022	
10	Sekri		2019	1	SL-30.48, NT-3.17, RL-11.62, SDW-1.12, RDW-0.3, TRPA-50.29, TSA-	-	-	Anandan *et al*, 2022	

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
					157.99, RV-5.5				
11	IC 467627	IC 467627	2021 2022	2	20.10 g (single plant yield under low P)	-	-	Authors own data	Check-Dular; 15.42 g (single plant yield under low P)
12	IC 426097	IC 426097	2021 2022	2	18. 45g (single plant yield under low P)	-	-	Authors own data	
13	IC 277228	IC 277228	2021 2022	2	18.01g (single plant yield under low P)	-	-	Authors own data	
14	AC 34978	AC 34978	2023	1	SL-32.55 cm, RL-17.7 cm, SDW-0.16 g, RDW-0.008 g	-	-	Authors own data	Hydroponics media with no phosphorus source added
15	AC 34981	AC 34981	2023	1	SL-33.40 cm, RL-21.75 cm, SDW-0.19 g, RDW-0.005 g	-	-	Authors own data	Hydroponics media with no phosphorus source added
16	Kasalath		2023	1	SL-36.80 cm, RL-22.95 cm, SDW-0.19 g, RDW-0.008 g	-	-	Authors own data	Hydroponics media with no phosphorus source added
17	Dular		2023	1	SL-36.60 cm, RL-23.00 cm, SDW-0.26 g, RDW-0.006 g	-	-	Authors own data	Hydroponics media with no phosphorus source added
18	TRB 420		2022 2023	2	32.18 (AUE)	-	-	Authors own data	Low P tolerance
19	CRRI 52		2022 2023	2	44.91 (AUE)	-	-	Authors own data	Low P tolerance
20	CRRI 55		2022 2023	2	6.52 (AUE)	-	-	Authors own data	Low P tolerance
21	CRRI 63		2022 2023	2	52.52 (AUE)	-	-	Authors own data	Low P tolerance
22	CR 4395-6-3-47	IET 31097	2021	1	11.71 (AUE)	-	-	AICRIP Progress Report, 2022, Vol. 1	Low P tolerance

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
23	CR 3562-2-1-1-3-1-1	IET 31098	2021	1	1.16 (AUE)	-	-	AICRIP Progress Report, 2022, Vol. 1	Low P tolerance
24	CR 4387-RGA-271	IET 31100	2021	1	4.74 (AUE)	-	-	AICRIP Progress Report, 2022, Vol. 1	Low P tolerance
25	CR 4392-RGA-130	IET 31104	2021	1	5.74 (AUE)	-	-	AICRIP Progress Report, 2022, Vol. 1	Low P tolerance
26	CR 4397-4-6-27	IET 31107	2021	1	43.70 (AUE)	-	-	AICRIP Progress Report, 2022, Vol. 1	Low P tolerance
27	Kalabokri	IRGC 43872	2022 2023	2	70.786 79.430	75.108	6.11	Sar *et al*, 2024	Low P tolerance
28	Jasure AUS	IRGC 43860	2022 2023	2	64.091 72.650	68.370	6.05	Sar *et al*, 2024	Low P tolerance
29	ARC 12021	IRGC 21837	2022 2023	2	62.404 70.920	66.662	6.02	Sar *et al*, 2024	Low P tolerance
30	Devarasi	IRGC 16173	2022 2023	2	60.953 68.450	64.702	5.30	Sar *et al*, 2024	Low P tolerance
31	ARC 7336	IRGC 20606	2022 2023	2	58.117 65.390	61.753	5.14	Sar *et al*, 2024	Low P tolerance
32	DM 49	IRGC 8775	2022 2023	2	56.833 64.610	60.722	5.50	Sar *et al*, 2024	Low P tolerance
33	AUS 329	IRGC 29116	2022 2023	2	56.928 64.370	60.649	5.26	Sar *et al*, 2024	Low P tolerance
34	ARC 12101	IRGC 21907	2022 2023	2	56.796 63.890	60.343	50.02	Sar *et al*, 2024	Low P tolerance
35	Porashi	IRGC 78397	2022 2023	2	55.914 63.840	59.877	5.60	Sar *et al*, 2024	Low P tolerance
36	Rani Bhog	IRGC 35109	2022 2023	2	55.248 62.840	59.044	5.37	Sar *et al*, 2024	Low P tolerance
37	Chakila	IRGC 27540	2022 2023	2	53.818 60.600	57.209	4.80	Sar *et al*, 2024	Low P tolerance
38	Kada Chopa	IRGC 34954	2022 2023	2	53.796 60.330	57.063	4.62	Sar *et al*, 2024	Low P tolerance
39	Bak Tulsi	IRGC 34831	2022 2023	2	52.607 60.280	56.444	5.43	Sar *et al*, 2024	Low P tolerance

CGR: Crop growth rate, AGR: Agronomic growth rate, SDW; Shoot dry weight (g), RDW: Root dry weight (g), SL: shoot length (cm), NT: number of tillers/plant, RL: Root length (cm), TRPA: total root projected area (cm^2), TSA: total root surface area (cm^2), RV: root volume (cm^3), AUE: Agronomic P use efficiency

Addressing phosphorus deficiency in rice is very important for sustainable agriculture, especially in regions like India where P deficiency is widespread. Various research initiatives, including phenotypic screening, identification of genes for phosphate utilization, evaluation of rice genotypes for low phosphorus tolerance and association studies, have been undertaken to develop low phosphorus-tolerant rice varieties. These efforts have led to the identification of promising rice genotypes with enhanced root systems and improved phosphorus uptake efficiency under low phosphorus conditions. Furthermore, the discovery of candidate genes and markers associated with low phosphorus tolerance offers valuable insights for marker assisted breeding programs to develop rice varieties resilient to phosphorus deficiency. Overall, these research findings contribute significantly to the sustainable production of rice, ensuring food security while minimizing environmental impacts associated with excessive phosphorus fertilizer use.

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Chapter-7

Germplasm with multiple and combined stress tolerance for rice improvement in coastal ecology

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Introduction

Flooding with salty water is posing greater threat due to climate change and other associated happenings to rice grown in coastal plains (Wassmann et al., 2004; Schumahcer 2006; IPCC 2007; Garcı´a et al., 2007). Flooding with salinity is a common problem (Flowers and Colmer 2008). It is also predicted that intrusion of sea water may displace millions of people from coastal plains which would be the direct threat of the food security of the poor and marginal people reside along the coastal belts (Wassmann et al., 2009). In coastal areas two types of flooding are seen: 1. submergence- where both roots and shoots are under water for a short period of about 2 weeks, and 2. partial submergence or stagnant flooding where certain portions of the shoots remain above the flood water surface and rests are under water. There is a high probability that flooding may occur with salty water in future. Usually, normal rainfall decreases salinity concentration whereas deficit in rainfall increases the problem. The main problem of salinity stress reduces plant growth for which it becomes weak. It was observed that salinity followed by flooding is more vulnerable. and the salt affected weak rice plants die out early compared to the healthy plants (Sarkar and Ray, 2016). Since salt tolerant plants maintain their health better under salt-stress compared to sensitive one, improving salt-tolerance is imperative for rice under coastal plains even to counteract the deleterious effects of flooding (Sarkar et al., 2019). Besides, our traditional landraces showed salinity tolerance for coastal area may not be high yielder but are treasurer of tolerance to salinity and other different stresses prevailed since long time during rice cultivation. Some of them are tolerant to multiple abiotic stresses.

Submergence and salinity

Submergence tolerance is mainly controlled by submergence tolerance gene, *Sub1A1* (Fukao and Bailey-Serres,2008), however, flood water quality like light, turbidity, concentrations of oxygen and carbon dioxide and even the concentration of ethylene in flood water influence the survival under submergence (Setter et al., 1997; Panda et al., 2006; Das et al., 2009). Damage of plants under salinity depends on the concentrations of Na^+, Cl^-, K^+ and Na^+: K^+ ratio. Transpiration ceases under submergence and therefore restricts the entry of ions whereas direct contact of shoots with flood water containing higher concentrations of salt broadens the entry of ions Floodwater under natural condition especially during day time is hardly anoxic rather sometimes super saturated with oxygen whereas during night floodwater is hypoxic in nature (Setter et al., 1995; Ramakrishnnya et al., 1999; Colmer et al., 2014). During darkness pO_2 in root declines sharply (0.24 kPa), yet it never reaches in anoxic state. Under light, however root $pO_2$is high (14 kPa). Under natural flooding floodwater is not at all anoxic, though oxygen concentrations vary greatly during 24 h time period starting from very low to very high. It might influence the entry of ions and therefore survival of plants under saline floods. Under submergence gas film is created between the surface of the leaf and surrounding floodwater (Winkel et al., 2014; Chakraborty et al., 2020). This restricts the entry of salts and helps in continuation of gas exchange between plant and surrounding floodwater (Tamang and Fukao, 2015). Gas films impart submergence tolerance both under saline and non-saline floodwater conditions. Sarkar and Ray (2016) observed no difference between saline (12 dS m^{-1}) and non-saline (0.17 dS m^{-1}) floods; FR13A, tolerant to submergence but susceptible to salinity showed similar survival under both the situations. Submergence is a short-term consequence with 1-2 weeks duration. Entries of injurious concentrations of Na^+ and collapses of gas films take time and therefore submergence tolerant cultivar FR13A survived the situations but cultivars susceptible to submergence did not.

Water logging and salinity

Lowland rice is tolerant to stagnant flooding (Kuanar et al., 2017) yet it suffers greatly under saline water stagnation (Prusty et al., 2017). Partial submergence (depth of water 45 cm) with salinity (12.0 + 0.2 dS m^{-1}) was imposed on forty-five days old seedlings and within 10 days symptoms of salt injury appeared though it is stated that rice is comparatively tolerant to salinity at vegetative and tillering stages (Munns and Tester, 2008;). Like salinity stress under combined effect of salinity and stagnant flooding tolerant plants try to inhibit the damage of pigment concentrations, maintain better chloroplast structural and functional ability (Zheng et al., 2009; Ray et al., 2017; Prusty et al., 2017), improve oxygen transport through formation of aerenchyma tissues and antioxidant systems (Flowers and Colmer, 2008; Zheng et al., 2009; Haddadi et al., 2016). Genotypes tolerant to combined stresses though are now well characterized (Prusty et al., 2018). Phenotyping technique has

been improved (Pradhan et al., 2019). Yet, development of high-yielding rice varieties tolerant to combined effect of salinity and water stagnation is still at stake. Among lowland rice cultivars which were tolerant to salinity at seedling stage showed tolerance to saline-stagnant flooding stress, though the degree of tolerance varied among them. A land race Rashpanjar was found tolerant to saline water under partial submerged condition. Well-developed constitutive aerenchyma in Rashpanjar provided an adaptive advantage during partial submergence due to saline water flooding in rice as the key process of induced aerenchyma formation is hampered in the presence of salinity stress coupled with partial submergence (Chakraborty et al., 2021).

Phenotyping for stagnant flooding tolerance with saline water: For the present experiment, three pregerminated seedlings per pot were transplanted 15 days after germination in earthen pots (D: 200 mm _ H: 200 mm) having Sun-dried soil mixed with farm-yard manure in a 3:1 ratio and fertilizers as per requirement. The plants were allowed to grow normally, without salinity or excess water stress, for 45 days after transplanting. After that, two sets of pots were placed in concrete cemented tanks (L _ B _ H:

2 m _ 1.5 m _ 1.2 m), where fresh water flooding (WL) and saline water flooding (WL + S) stresses were imposed on the plants 45 days after transplanting. The same experimental setup was repeated over two seasons (wet seasons of 2018 and 2019). In total, four cemented tanks were used in each season, where two tanks (each containing five pots of each genotype) were used for imposing fresh water flooding (depth of water: 45 ± 5 cm above soil surface) and the other two were used for saline water flooding (depth of water: 45 ± 5 cm above soil surface with a salinity level of 12.0 ± 0.2 dS m_1 equivalent to 105 mM of Na+) with a factorial, completely randomized design. Flooding stress (both fresh and saline) was imposed by maintaining the tank's water level at 45 ± 5 cm for 20 days after that stress was removed by draining out the water. Another set of plants were maintained at field capacity of the soil as control plants. Phenotyping technique has been followed (Pradhan et al., 2019) and with minor modification was adapted for physiological studies (Chakraborty et al. 2021). Key agro-morphological traits viz. plant height, the number of tillers and leaves, length of internodes and leaf sheaths, and total shoot and root dry biomass were measured immediately after stress release. The mean values of two replications were taken for each genotype _ treatment combination in each season. The leaf sheath and internode (N3–N4) were carefully separated before measurement. For dry biomass measurement, shoot and root tissues were separated and oven-dried at 65_C until a constant weight was achieved.

Table 7. Donors for combined stress tolerance

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	SES/ tolerance score	Mean of values	Reference	Remarks (Tolerant/ MR/R/ etc)
1.	CherayiPokkali (AC 39416A)	INGR No.19004 (IC0413644; AC 39416A)	2012	4	3	3	(Sarkar et al. 2013; Singh and Sarkar 2014; Sarkar and Ray 2016).	highly salt tolerant nature of AC 39416A for traits like photosynthesis, chlorophyll fluorescence and Na^+/K^+ ratio
			2014		59% (germination)	5		Anaerobic germination potential or tolerance to germination stage oxygen deficiency (GSOD)
			2014, 2015		<10% yield reduction under stagnant flooding	3	(Kuanar et al. 2017).	AC 39416A was also found tolerant to vegetative stage stagnant flooding (medium depth ≈ 50 cm).
			2014, 2015		3	3		AC 39416A is tolerant to combined stresses of stagnant flooding and salinity.

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	SES/ tolerance score	Mean of values	Reference	Remarks (Tolerant/ MR/R/ etc)
			2014-2018		5	5		Combined stresses of Salinity (12 dS m^{-1}) and moisture stress tolerance
2.	Rashpanjar		2009-2016	10	5	5	Chattopadhyay et al. (2014); Singh and Sarkar (2014); Sarkar et al. (2013); NICRA Research Highlights 2010-12; ICAR-NRRI Annual Report 2013-14; Sarkar and Ray (2016)	Tolerant to seedling stage salinity stress with 5.0 SES score; Tolerant with high tissue tolerance ability
					5	5	Panda et al. (2019)	Stagnant Flooding (40-50 cm) Tolerant with ~25% yield reduction as compared to control
			2012-13, 2013-14, 2015-16, 2016-17; 2018-19	5	5	5	NICRA Research Highlights 2012-13; Chakraborty et al. (2017); Pradhan et al. (2018); Chakraborty et al. (2021); ICAR-NRRI Annual Report 2019; Prusty et al. (2018)	Tolerant to combined stresses of salinity and SF at tillering and reproductive stages Identified a unique mechanism of tolerance to combined stress mediated by preformed constitutive aerenchyma and high basal level ethylene
			2011, 2015-16	2	5	5	Senapati et al. (2019); NICRA Research Highlights 2010-12	Anaerobic germination (10 cm standing water above soil surface) Possess high AG potential with ~71% germination and seedling establishment under germination stage submergence
			2018-2019	2	3, 5	3	AICRIP Plant Physiology Annual Report 2019; ICAR-NRRI Annual	Combined stresses of salinity (12 dS m^{-1}), osmotic stress (2% mannitol) and anaerobic

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	SES/ tolerance score	Mean of values	Reference	Remarks (Tolerant/ MR/R/ etc)
							Report 2020	germination; Tolerant to seedling stage salinity stress and possess high anaerobic germination potential
3.		AC43358	2016-2017	2	5	5	Authors own data	Salinity, Stagnant Flooding tolerance
4.		EC516602	2016-2017	2	5	5	Authors own data	Salinity, Stagnant Flooding tolerance
5.		AC39460	2016-2017	2	3	3	Authors own data	Salinity, Stagnant Flooding tolerance
6.		AC43365	2016-2017	2	3	3	Authors own data	Salinity, Submergence tolerance
7.		AC43351	2016-2017	2	3	3	Authors own data	Salinity, Submergence tolerance
8.		AC43359	2016-2017	2	5	5	Authors own data	Salinity, Stagnant flooding tolerance

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Chapter-8

Rice germplasm with higher photosynthetic efficiency and low light tolerance

MJ Baig, Padmini Swain, Milan Kumar Lal

Introduction

Light is the immense source of energy and also an important environmental factor for plant growth, development and metabolism that regulates photosynthesis process and photo-morphogenesis (Murty and Murty 1981a; Müller et al., 2014). However, plants frequently get exposed to different intensities of light like excess-light (EL) or low light (LL), causing stress to plants. Most leading rice varieties grown in India are found to be dependent on monsoon (Murty et al., 1976). There are two crop growing seasons exist in India, namely *kharif* (wet) and *rabi* (dry). *Kharif* season in the northern hemisphere includes months from May to November, sometimes it may extend until December. During this period the rice crop encounters the prevalence of low light intensity. During this period the rice crop encounters the prevalence of low light intensity. Solar radiation is recorded about 300 cal cm^{-2} d^{-1}, with wide fluctuations in day-to-day radiation (60-420 cal cm^{-2} d^{-1} or 2-5 bright sunshine hours d^{-1}). However, during the dry season, mean solar radiation is about 450 cal cm^{-2} $d^{-1}$and sunshine hours vary from 9 to 10 h d^{-1}, indicating 1.5-2 times more solar radiation and sunshine hours in the dry season than in the wet season. (Murty et al., 1973). These stressful conditions exert negative impacts on photosynthetic activity and eventually hamper the plant growth and yield (Nishiyama and Murata 2014). It has been reported that different intensities of light significantly hampered several physiological and metabolic processes including photosynthesis, antioxidant production and carbon-nitrogen fixation, which ultimately affect different important agronomic traits of plants (Apel and Hirt, 2004; Wang et al., 2016). The low incidence of solar radiation coupled with fluctuating light during the wet season is one of the major constraints for realizing the low productivity in Eastern and North-Eastern India. Light being a crucial factor for the plant development, stress experienced by the plants under low irradiance results in an increased leaf length and width, increased leaf area, increased time period for growth, decreased differentiation of panicle and reduced grain yield (Murchie et al., 2005). Lower rates of photosynthesis (due to low irradiance per unit leaf area) are accompanied by the reduction in the thickness of mesophyll and number of cells mm^{-2} in leaves. But surprisingly the total chlorophyll content, especially chlorophyll-b was higher under low light. Low light stress negatively influences the stomatal conductance. The decreased rubisco activity accompanied by subsequent increase in the intracellular carbon dioxide concentrations is also observed under low light intensity.

Mechanism of Low light stress

The exhaustive research carried out to understand the mechanisms of low light tolerance in rice exhibited two kinds of mechanism when they encounter low light (LL) stress such as (i) shade avoidance and (ii) shade tolerance. Primarily the phytochrome photoreceptors sense the reduction in the R:FR ratio, which may occur either due to the neighbouring vegetation, actual shade, future shade or reduced PAR, and induce a suite of traits to grow towards the light. Collectively this is known as shade avoidance response (SAS). Shade tolerance is exhibited by species from forest under stories that cannot outgrow the surrounding trees and adopt tolerance responses (Gommers et al., 2012).

- Under low light, chlorophyll b increases with reduction in chlorophyll a/b ratio.
- Maintenance of higher photosynthetic activity and absorption of optimum nitrogen content.
- Slower senescence with lower respiration and higher carbohydrate translocation from shoot to the developing grains.
- High specific leaf weight at flowering under normal light condition is significantly associated with biomass or grain yield at harvest under low light, suggesting its usefulness as a preliminary selection criterion for low light adapted variety. Further, a critical value of leaf area ratio 80 cm2 g-1 found to be ideal ceiling under light stress situations to assure yield of >3 t ha-1 or more under low light environment.
- Since leaf area ratio (LAR) and yield were negatively associated with low light, this phenomenon could be . exploited for identifying varieties tolerant to light stress.

Characters useful in screening for low light adaptability are

- Survival of 10-d-old seedlings under complete darkness for 7 d (Sahu et al., 1984).
- Lower reduction in dry weight and specific leaf weight of 2-wk-old seedlings under 30% normal light (30 klx) for 15 d, high photosynthetic rate of both leaf and panicle and high chlorophyll b content under 30% normal light, and relatively high efficiency in photosynthesis under blue light at vegetative stage (Nayak et al., 1979).
- Greater accumulation of dry matter at flowering with high efficiency in translocation and high proline and cytokinin content in the panicle with low sterility under reduced light at flowering (Murty and Murty., 1982).

Methodology/Protocol

Shading is to be created by putting Agro Shade net HDPF Fabrics mounted on the wooden frame as shown in the below figures and shading used to implement from Primordial Initiation to grain filling stage of the crop as flowering stage is the most critical stage of the crop growth which determines the yield of rice varieties under low light environment.

Crop growth modeling for low light stress situations

The macros model L1D.CSM was taken as the base model. Various physiological process-oriented functions as appropriate to wet season of eastern India, were incorporated to simulate dynamics of crop growth more realistically. The model identified essential features of desirable plant type to assure grain yield of 3.0 t ha^{-1} (against <1.2 t ha^{-1} average).

- Plant height 1-1.15 m
- Tiller number per hill 5-6 (15×10 cm spacing)
- Grain number per panicle 125-135
- Maximum photosynthetic rate 35-40 kg CO_2 ha^{-1} h^{-1}
- Initial solar energy utilization efficiency 0.4-0.45 [kg CO_2 ha^{-1} h^{-1}]/[J m^{-2} s^{-1}]
- Maintenance respiration 0.03-0.05 g CO_2 g^{-1} dry matter per day at 30°C
- Specific leaf weight not more than 350 kg ha^{-1}
- Light extinction coefficient 0.7

Table 8. List of donors with higher photosynthetic efficiency and low light tolerance

Sl. No.	Name of Germplasm/ Variety	IC/AC Number/ NBPGR Registration no	Yes of testing	Frequency of testing (no of times tested)	Trait	Mean value	Reference	Remark (Tolerant/ MR/R/etc)
1	Rajalaxmi	IC594001	2007-2008	1	Photosynthetic efficiency (P_n)	15.55 (Veg); 16.32 (Flw)	CRRI Annual report 2008	Higher photosynthetic efficiency and low light tolerance in rice
					Stomatal conductance (g_s)	110.24 (veg); 86.06 (Flw)		
					Grain yield (t/ha)	7.2		
					Harvest Index (HI)	53.77		
			2008-2009	1	Grain yield (t/ha)	9.1	CRRI Annual report 2009	

Sl. No.	Name of Germplasm/ Variety	IC/AC Number/ NBPGR Registration no	Yes of testing	Frequency of testing (no of times tested)	Trait	Mean value	Reference	Remark (Tolerant/ MR/R/etc)
2	Ajay		2007-2008	1	Grain yield (t/ha)	6.6	CRRI Annual report 2008	Higher photosynthetic efficiency and low light tolerance in rice
					Harvest Index (HI)	54.87		
			2008-2009	1	Grain yield t/ha	8.3	CRRI Annual report 2009	
3	PHB 71		2008-2009	1	Grain yield t/ha	8.7	CRRI Annual report 2009	Higher photosynthetic efficiency and low light tolerance in ric
4	Vandana		2012-2013 2022-2023	2	Yield loss (%) in the shade-grown rice genotypes over the normal light-grown crop	10.57	CRRI Annual report 2013	Low light tolerance in rice
					Relative yield reduction %	40-50%	CRRI Annual report 2023	
5	Govinda		2012-2013 2013-2014	2	Yield loss (%) in the shade-grown rice genotypes over the normal light-grown crop	49.52	CRRI Annual report 2013	Identified as low light Tolerant
					Sterility % under low light	12.04	CRRI Annual report 2014	
6	Satyam		2012-2013	1	Yield loss (%) in the shade-grown rice genotypes over the normal light-grown crop	10.54 14.85 9.87	CRRI Annual report 2013	Low light tolerance
7	Saraswati		2012-2013	1	Yield loss (%) in the shade-grown rice genotypes over the normal light-grown crop	14.85	CRRI Annual report 2013	Low light tolerance
8	Sarala		2012-2013	1	Yield loss (%) in the shade-grown rice genotypes over the normal light-grown crop	9.87	CRRI Annual report 2013	Low light tolerance
9	CSR-4		2013-2014	1	Sterility %under low light	26.55	CRRI Annual report 2014	Low light tolerance
					Decrease in chlorophyll b % in the shade-grown rice genotypes over the normal light	84.32		
					Yield loss (%) in the shade-grown rice genotypes over the normal light	84.32		

Sl. No.	Name of Germplasm/ Variety	IC/AC Number/ NBPGR Registration no	Yes of testing	Frequency of testing (no of times tested)	Trait	Mean value	Reference	Remark (Tolerant/ MR/R/etc)
10	Suphala		2013-2014	1	Sterility %under low light	24.89	CRRI Annual report 2014	Low light tolerance
					Decrease in chlorophyll b % in the shade-grown rice genotypes over the normal light	83.10		
					Yield loss (%) in the shade-grown rice genotypes over the normal light	8.8		
11	*O. nivara*		2014-2015	1	The maximum P_N (µmol CO_2 m^{-2} s^{-1})	26.0 15.0	CRRI Annual report 2015	Low light tolerance
12	A0410 (mutant)		2014-2015	1	The maximum P_N (µmol CO_2 m^{-2} s^{-1})	12.91	CRRI Annual report 2014	Low light tolerance
13	Akitokomachi		2014-2015	1	The maximum P_N (µmol CO_2 m^{-2} s^{-1})	17.86	CRRI Annual report 2014	Low light tolerance
14	Sadamotasel		2015-2016	1	Grain yield t/ha	7.19	NRRI Annual report 2016	Low light tolerance
15	Pantdhan-102		2016-2017 2018	2	Photosynthetic rate (µmol/m2/sec)	17.33	NRRI Annual report 2016	Low light tolerance
					Stomatal conductance (mol H_2O/m^2/sec)	23	Incentivizing research in agriculture annual report 2018	
					Photosyntesis (µmol CO_2 m^{-2} s^{-1})	21.37	Incentivizing research in agriculture annual report 2018	
16	LLS 2519 (T)		2017-2018	1	Grain yield t/ha	4.49	NRRI Annual report 2016	Identified as low light Tolerant
					Higher grain yield	(4.0 t/ ha)		
17	T. Basmati		2018-2019	1	Relative gene expression studies of Sedoheptulose 1-7 bisphosphate	13 (25%LL) 2.3 (50%LL)	NRRI Annual report 2019	Identified as low light Tolerant
18	IR 72		2020-2021	1	Highest grain yield t /ha^{-1}	3.51	NRRI Annual report 2021	Identified as low light Tolerant
					Minimal relative yield reduction (RYR)	14.30%		

Sl. No.	Name of Germplasm/ Variety	IC/AC Number/ NBPGR Registration no	Yes of testing	Frequency of testing (no of times tested)	Trait	Mean value	Reference	Remark (Tolerant/ MR/R/etc)
19	Naveen		2022-2023	1	Relative yield reduction %	30-40%	NRRI Annual report 2023	Identified as low light Tolerant
20	Pathara		2022-2023	1	Relative yield reduction %	40-50%	NRRI Annual report 2023	Identified as low light Tolerant
21	Black gora		2022-2023	1	Relative yield reduction %	40-50%	NRRI Annual report 2023	Identified as low light Tolerant
22	Sathi		2016	1	Chlorophyll a content under 25% light	2-3 fold increase	Incentivizing research in agriculture annual report 2016	Identified as low light Tolerant
					Panicle number under 25% light	11-12		
23	VLdhan 209		2017 2018 2020	3	Chl (a/b) mg g^{-1} fw	15.48	Incentivizing research in agriculture annual report 2017	Identified as low light Tolerant
					Photosyntesis (µmol CO_2 m^{-2} s^{-1})	19.53	Incentivizing research in agriculture annual report 2018	
					Stomatal conductance (mol $H_2O/m^2/sec$)	17.79	Incentivizing research in agriculture annual report 2018	
					Expression identifies transcript Gene and epigenome miRNAs involved in photosynthesis	Osa-miR5161 Osa-miR395josa-miR3-NRRI Osa-miR2-NRRI	Incentivizing research in agriculture annual report 2020	
24	Santhi		2017	1	Chl (a/b) mg g^{-1} fw	6.20	Incentivizing research in agriculture annual report 2017	Identified as low light Tolerant
25	Purnendu		2017 2018 2019 2020 2021	5	Chl (a/b) mg g^{-1} fw	8.88	Incentivizing research in agriculture annual report 2017	Identified as low light Tolerant
					Stomatal conductance ($molH_2OM^{-2}S^{-1}$)	19.57	Incentivizing research in agriculture annual report 2018	

Sl. No.	Name of Germplasm/ Variety	IC/AC Number/ NBPGR Registration no	Yes of testing	Frequency of testing (no of times tested)	Trait	Mean value	Reference	Remark (Tolerant/ MR/R/etc)
					Anatomical study of pollen fertility	8.5	Incentivizing research in agriculture annual report 2019	
					Expression identifies transcript Gene and epigenome miRNAs involved in photosynthesis	Osa-miR5161 Osa-miR395josa-miR3-NRRI Osa-miR2-NRRI	Incentivizing research in agriculture annual report 2020	
					Expression and epigenome profiling to identify transcript/ genes epigenome associated with low light	Osa-miR166c-3p osa-miR2102-3p, osa-miR530-3p (chl a-b)	NRRI Annual report 2021	
26	IR-8		2017 2018 2021	3	Chl (a/b) mg g^{-1} fw	14.34	Incentivizing research in agriculture annual report 2017	Identified as low light Tolerant
					Total soluble sugar (Tss) mg/g FW	9.65	Incentivizing research in agriculture annual report 2018	
					Expression and epigenome profiling to identify transcript/ genes epigenome associated with low light	Osa-miR166c-3p osa-miR2102-3p, osa-miR530-3p (chl a-b)	NRRI Annual report 2021	
27	Swarnaprabha (TC)		2017 2018 2019 2020 2021	5	Stomatal conductance (mol H_2O $m^{-2}s^{-1}$)	7.22	Incentivizing research in agriculture annual report 2017	Identified as low light Tolerant
					Photosyntesis (µmol CO_2 m^{-2} s^{-1})	20.49	Incentivizing research in agriculture annual report 2018	
					Stomatal conductance (mol H_2O $m^{-2}s^{-1}$)	18.97	Incentivizing research in agriculture annual report 2018	
					Carbohydrate	13.5	Incentivizing	

Sl. No.	Name of Germplasm/ Variety	IC/AC Number/ NBPGR Registration no	Yes of testing	Frequency of testing (no of times tested)	Trait	Mean value	Reference	Remark (Tolerant/ MR/R/etc)
					metabolism enzymes		research in agriculture annual report 2020	
					Expression identifies transcript Gene and epigenome miRNAs involved in photosynthesis	Osa-miR5161 Osa-miR395josa-miR3-NRRI	Incentivizing research in agriculture annual report 2020	
					Lipid peroxidation (nmol g^{-1} fw)	10.87	Incentivizing research in agriculture annual report 2020	
					Anatomical, physiological, and biochemical bases of low light	0.559	Incentivizing research in agriculture annual report 2021	
28	Sashi		2017 2018 2020	2	Stomatal conductance ($molH_2OM^{-2}S^{-1}$)	24.79	Incentivizing research in agriculture annual report 2017	Identified as low light Tolerant
					Stomatal conductance ($molH_2OM^{-2}S^{-1}$)	13.73	Incentivizing research in agriculture annual report 2018	
					Stomatal conductance ($molH_2OM^{-2}S^{-1}$)	12.79	Incentivizing research in agriculture annual report 2020	
29	Lal dhan		2018	1	Photosynthesis (µmol CO_2 m^{-2} s^{-1})	22.93	Incentivizing research in agriculture annual report 2018	Identified as low light Tolerant
					Stomatal conductance ($molH_2OM^{-2}S^{-1}$)	20.00	Incentivizing research in agriculture annual report	
	Maliksali		2017	1	Stomatal conductance ($molH_2OM^{-2}S^{-1}$)	32.04	Incentivizing research in agriculture annual report 2017	Identified as low light Tolerant
30	Rudra		2017	1	Stomatal conductance ($molH_2OM^{-2}S^{-1}$)	38.92 29.32	Incentivizing research in agriculture annual report 2017	Identified as low light Tolerant

Sl. No.	Name of Germplasm/ Variety	IC/AC Number/ NBPGR Registration no	Yes of testing	Frequency of testing (no of times tested)	Trait	Mean value	Reference	Remark (Tolerant/ MR/R/etc)
31	Megha rice-1		2017	1	Stomatal conductance ($molH_2OM^{-2}S^{-1}$)	29.32	Incentivizing research in agriculture annual report 2017	Identified as low light Tolerant
32	Barhaballi Dhan		2018	1	Photosyntesis (µmol CO_2 m^{-2} s^{-1})	15.45 14.00	Incentivizing research in agriculture annual report 2018	Identified as low light Tolerant
33	Nirajo Dhan		2018 2019 2020	3	Photosyntesis (µmol CO_2 m^{-2} s^{-1})	14.00	Incentivizing research in agriculture annual report 2018	Identified as low light Tolerant
					Stomatal conductance ($molH_2OM^{-2}S^{-1}$)	12.2	Incentivizing research in agriculture annual report 2019	
					Stomatal conductance ($molH_2O$ $M^{-2}S^{-1}$)	7.83	Incentivizing research in agriculture annual report 2020	
34	Brahabali Dhan		2018 2020	2	Stomatal conductance ($molH20M^{-2}S^{-1}$)	14.55	Incentivizing research in agriculture annual report 2018	Identified as low light Tolerant
					Stomatal conductance ($molH_2O$ $M^{-2}S^{-1}$)	5.69	Incentivizing research in agriculture annual report 2020	
35	Sarajo 52		2018 2020	2	Stomatal conductance ($molH_2O$ $M^{-2}S^{-1}$)	17.19	Incentivizing research in agriculture annual report 2018	Identified as low light Tolerant
					Stomatal conductance ($molH_2O$ $M^{-2}S^{-1}$)	12.83	Incentivizing research in agriculture annual report 2020	
36	Santi		2018	1	Stomatal conductance ($molH_2O$ $M^{-2}S^{-1}$)	15.09	Incentivizing research in agriculture annual report 2018	Identified as low light Tolerant
37	Chamaramani		2018	1	Stomatal conductance ($molH_2O$ $M^{-2}S^{-1}$)	15.87	Incentivizing research in agriculture annual report 2018	Identified as low light Tolerant

Sl. No.	Name of Germplasm/ Variety	IC/AC Number/ NBPGR Registration no	Yes of testing	Frequency of testing (no of times tested)	Trait	Mean value	Reference	Remark (Tolerant/ MR/R/etc)
38	Chamaraman		2020		Stomatal conductance (mol H_2O $M^{-2}S^{-1}$)	6.96	Incentivizing research in agriculture annual report 2020	Identified as low light Tolerant
39	Shubhadra		2020	1	Lipid peroxidation (nmol g^{-1} fw)	11.94	Incentivizing research in agriculture annual report 2020	Identified as low light Tolerant
					Superoxide Dismutase (U mg^{-1} prot g^{-1} fw)	0.647		
40	Danteswari		2020	1	Lipid peroxidation (nmol g^{-1} fw)	10.97	Incentivizing research in agriculture annual report 2020	Identified as low light Tolerant

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Chapter-9

Rice germplasm for Preharvest sprouting resistance, seed viability and seed vigour

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Introduction

The global demand for rice is projected to rise by 33% over the next thirty years (Manners and Etten 2018). To increase the production and mitigate the demand high-quality seeds is important component of agricultural production, can boost productivity by approximately 30% (Hasanuzzaman 2015). Resistance to preharvest sprouting, higher seed viability and high seed vigour are the potential trait of quality seed that directly influences the crop productivity by ensuring uniformity in seed germination, seedling growth, establishment of seedling in the field and withstanding unfavourable environmental condition. Improvement of these traits of rice remains a primary breeding objective of the agriculture and seed industry as it is not only essential to enhance the yield but also can improve crop resilience against climate change effects (Sahoo et al.,2020). Utilizing the genetic variability existing in the rice germplasm, identifying the superior donors and its utilization in rice breeding programmes is an essential requirement in development of superior high yielding cultivars with improved seed quality traits. Preharvest sprouting (PHS) occurs when seeds germinate on the panicle before harvest, often due to rain or high humidity. PHS can significantly reduce grain quality and yield. Germplasm with resistance to PHS can help mitigate these losses. Breeders often select for traits like dormancy (where seeds are less likely to germinate immediately after maturity). Seed viability refers to the ability of seeds to germinate and produce healthy seedlings. High seed viability is essential for longer stirage duration of seed. Seed vigor encompasses various traits that determine the seed's potential for rapid, uniform emergence and development under a wide range of field conditions. High-vigor seeds tend to produce stronger seedlings that can better withstand stressors like drought, pests, and diseases.

Methodology

Seed vigour indices (seed vigour index I and II) were estimated by sowing 50 seeds in three replications following top of paper method by incubating at 30 °C. The final germination percentage and seedling length were recorded on 10th day. The seedlings (five) used for recording of the seedling length from each replication were subsequently oven dried at 70 °C for 48 h after removing the cotyledon and seedling dry weight was expressed in gram per seedling. Seed vigour indices were calculated using the formula suggested by Abdul-Baki and Anderson (1973). Seed vigour index I= Germination (%) X seedling length(cm) and Seed vigour index II= Germination (%) X seedling dry weight(g)(Sahoo et al.,2020). Vivipary, germination of seeds on the maternal plant, is observed in nature and provides ecological advantages in certain wild species, such as mangroves. However, precocious seed germination in agricultural species, such as preharvest sprouting (PHS) in cereals, is a serious issue for food security. PHS reduces grain quality and causes economic losses to farmers. For screening genotypes in field condition after flowering, panicles of each variety were tagged according to the flowering date. For the field evaluation of viviparity at 20, 25, 30, 35, 40 days after flowering, 10 panicles were placed into the irrigated water in the field by gently bending stems toward the ground with the help of a rope and kept under water for 12 days (Lodging treatment). Research plot was irrigated as needed to keep the panicles wet throughout the treatment period. For the examination of viviparous germination in the laboratory conditions, 5 panicles from each genotype were harvested at 20, 25, 30, 35, 40 days after flowering and were sandwiched between two wet blotting papers in aluminum trays of 25 x 25 cm and were incubated for 12 days with 12/12 photoperiod of day/night at 280C. Germinated seeds were counted every day for 12 days in all the above two tests. Viviparity (number of grains germinated per panicle) was recorded at 20, 25, 30, 35, 40 days after flowering under the field and laboratory conditions (Hanjagi et al.,2022)

Pre-harvest sprouting (PHS): It is one of the primary problems associated with seed dormancy in rice (Oryza sativa L.). It causes yield loss and reduces grain quality under unpredictable humid conditions at the ripening stage, thus affecting the economic value of the rice crop. Miao et al. (2013) reported that PHS leads to a yield loss of approximately 10%, with the average annual loss caused directly by PHS exceeding $1 billion worldwide.

Table 9: Selected genotypes with resistance to pre- harvest sprouting

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Trait	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Refer-ence	Remarks (Tolerant/ MR/R/ etc)
1.	IC256580		Preharvest sprouting resistance	Kharif 2021 Kharif 2022	2	0% germination 40 daaaaaaaay s after flowering	0% germination 40 days after flowering	Raju et al., 2024	Resistant
2.	Rajamani	AC35090							
3.	IC300267	Budidhan							
4.	IC258606	Mahulata							
5.	Bhojna	IC256559							
6.	Kusuma	IC256577							
7.	BaradiaChampa	IC256771							
8.	BaidyaRaj	IC256562							
9.	PB-68	IC-256580	Pre- harvest sprouting	2021 2022	2	0% germination	0%	Raju et al., 2024	Resistant
10.	HT-81	AC-35090,		2021 2022	2	0% germination	0%	Raju et al., 2024	Resistant
11.	Budidhan	Budidhan		2021 2022	2	0% germination	0%	Raju et al., 2024	Resistant
12.	PB-47	IC-256559		2021 2022	2	0% germination	0%	Raju et al., 2024	Resistant
13.	Mahulata	Mahulata		2021 2022	2	0% germination	0%	Raju et al., 2024	Resistant
14.	PB-65	IC-256577		2021 2022	2	0% germination	0%	Raju et al., 2024	Resistant
15.	PB-259	IC-256771,		2021 2022	2	0% germination	0%	Raju et al., 2024	Resistant
16.	PB-50(1)	IC-256562		2021 2022	2	0% germination	0%	Raju et al., 2024	Resistant

Seed viability and Seed vigour: Seed vigour is one of the most important seed quality parameter that includes seed longevity, germination speed, seedling growth, early stress tolerance and determines the crop productivity. It is the sum of seed properties that determine the ability of viable seeds to germinate fast and uniform, and to produce healthy seedlings with rapid and uniform emergence under both optimal and suboptimal environmental conditions (AOSA 1983; ISTA 2021). High seed vigour is important for direct seeding as it enhances early crop establishment and produces vigorous seedling that can compete with weeds. Seed vigour tests provide a more sensitive index of seed performance per se than the germination test. Seed vigour index is calculated by multiplying germination (%) and seedling length (Abdul-Baki and Anderson, 1973)

Table 10. Selected genotypes with higher seed viability

Sl. No.	Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Trait	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Reference	Remarks (Tolerant/ MR/R/ etc)
1.	1.Neela 2.Shaktiman		Seed viability	2016-17	1		Viability (98% after 10 months of storage)	ICAR-NRRI Annual report 2016-17	High viability

Table 11. Selected genotypes with higher Seed vigour Index

Trait	Name of Germplasm /variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Reference	Remarks (Tolerant/ MR/R/ etc)
Seed vigour Index	Pandya	AC44594	Kharif 2019	1	1987	Seed vigour index I of - 1987	Barik et al., 2022	High seed vigour index I
	CR Dhan 303		2020, 2021	2	741.86 776.04 726.32 735.14	744.84	Authors own data	
	Supriya		2020, 2021	2	760.32 764.66 740.36 733.25	749.65	Authors own data	
	CR Dhan70		2020, 2021	2	600.12 645.32 752.32 763.65	690.35	Authors own data	
	Sonamani		2020, 2021	2	680.26 777.32 741.55 688.65	721.95	Authors own data	
	Heera		2020, 2021	2	700.65 698.32 684.32 764.32	711.9	Authors own data	
	CR Dhan501		2020, 2021	2	699.22 689.32 706.36 744.35	709.81	Authors own data	
	Udaya		2020, 2021	2	670.95 742.36 698.64 739.36	712.83	Authors own data	
	Manipuri Black		2020, 2021	2	688.68 795.64 687.79 762.78	733.72	Authors own data	
	Improved Lalat		2020, 2021	2	652.96 689.32 741.86 728.36	703.13	Authors own data	

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Chapter-10

Rice germplasm with superior grain quality traits

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Grain Protein Content

Rice supplies abundant carbohydrate as its kernel constitutes mainly of starch (>80%) but protein (7–8%) is the source of concern. However, the protein quality measured by protein digestibility index and amino acid composition in rice grain is the best among cereals, which makes it preferable for the food and feed industries.

Methodology followed

Total protein content is estimated using Kjeldahl method (Yoshida *et al*, 1976) by taking ten grains of milled/brown rice. The grain protein content is calculated by multiplying percent nitrogen content by factor 5.95.

Table 12. Selected genotypes with higher grain protein content in brown rice

Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing (%)	Mean of values (%)	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
Minatik charang	ARC-10075/ IC0597237/INGR21092	2009	09	10.43	12.47	1.52	Chattopadhyay, K., et al (2011).	High GPC in brown rice
		2010-11		11.75			NRRI Annual Report 2010-11	
		2011-12		15.27			NRRI Annual Report 2011-12	
		2012-13		11.20			NRRI Annual Report 2012-13	
		2013-14		12.52			NRRI Annual Report 2013-14	
		2014-15		13.0			NRRI Annual Report 2014-15	
		Kharif 2013		11			Chattopadhyay, K., et al., (2019).	
		Rabi 2014		12.70				
		Kharif 2014		11.89				
ARC- 10063		2008-09	3	16.41	14.94	2.5	NRRI Annual Report 2008-09	
		2011-12		16.41			NRRI Annual Report 2011-12	
		Kharif 2013		12.02			Chattopadhyay, K., et al., (2019). Chattopadhyay, K., et al., (2018).	
Mamihunger	INGR 23121	2013	2	13.0	13.3	0.42	NRRI Annual Report 2013-14	
		2014		13.60			Chattopadhyay, K., et al., (2019).	

Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing (%)	Mean of values (%)	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
Bindli		2015	2	13.20	12.6	0.84	Chattopadhyay, K., et al., (2019).	
		2017		12			NRRI Annual Report 2017-18	
Kalinga-III		2015	2	12.80	11.9	1.2	Chattopadhyay, K., et al., (2019).	
		2017		11			NRRI Annual Report 2017-18	
CR2829-PLN-32		2012-13	4	12.15	11.16	1.20	NRRI Annual Report 2012-13	
		2013-14		11.14			Annual Report 2013-14	
		Rabi 2015		11.90			Chattopadhyay, K., et al., (2019).	
		Kharif 2015		9.47				
CR 2829-PLN-97		2012-13	2	11.0	11.38	0.54	NRRI Annual Report 2012-13	
		2013-14		11.77			NRRI Annual Report 2013-14	
CR 2829-PLN-99		2012-13	4	11.69	11.08	0.92	NRRI Annual Report 2012-13	
		2013-14		12.06			NRRI Annual Report 2013-14	
		Rabi 2015		10.15			Chattopadhyay, K., et al., (2019).	
		Kharif 2015		10.45				
CR2829-PLN-108		2012-13	2	11.51	11.47	0.05	NRRI Annual Report 2012-13	
		2013-14		11.43			NRRI Annual Report 2013-14	
CR 2829-PLN-114		2012-13	2	10.98	11.76	1.11	NRRI Annual Report 2012-13	
		2013-14		12.55			NRRI Annual Report 2013-14	
CR 2829-PLN-116		2012-13	4	11.86	11.43	0.8	NRRI Annual Report 2012-13	
		2013-14		12.27			NRRI Annual Report 2013-14	
		Rabi 2015		11.17			Chattopadhyay, K., et al., (2019).	
		Kharif 2015		10.43				
CR 2829-PLN-37		2012-13	4	11.56	10.84	0.85	NRRI Annual Report 2012-13	
		2013-14		11.52			NRRI Annual Report 2013-14	
		Rabi 2015		10.51			Chattopadhyay, K., et al., (2019).	

Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing (%)	Mean of values (%)	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
		Kharif 2015		9.79				
CR2829-PLN-98		2012-13	4	11.58	10.99	1.13	NRRI Annual Report 2012-13	
		2013-14		12.29			NRRI Annual Report 2013-14	
		Rabi 2015		9.86			Chattopadhyay, K., et al., (2019).	
		Kharif 2015		10.25				
Naveen		Kharif 2012	6	8.10	8.24	0.69	NRRI Annual Report 2012-13	Low GPC in brown rice
		Kharif 2013		8.3			Chattopadhyay, K., et al., (2018).	
		Rabi 2014		9.57			NRRI Annual Report 2013-14	
		Kharif 2014		7.64			Chattopadhyay, K., et al., (2019).	
		Kharif 2015		7.74				
		Rabi 2015		8.13				

Table 13. Selected genotypes with higher grain protein content in milled rice

Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing (%)	Mean of values (%)	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
Minatikcharang	ARC-10075/ IC0597237/INGR21092	Kharif 2015	02	10.80	10.84	0.05	Chattopadhyay, K., et al., (2019).	High protein in milled rice
		Rabi 2015		10.88				
CR Dhan 310	IET24780: CR2829-PLN-37	2014	03	10.3	10.3	0.1	NRRI Annual Report 2014-15	
		2016		10.4			NRRI Annual Report 2014-15	
		2019		10.2			NRRI Technology Bulletin, 2019	
CR Dhan 311 (Mukul)	IET 24772: CR2829-PLN-100	2015	03	10.0	10.1	0.1	NRRI Annual report 2014-15	
		2017		10.1			NRRI Annual report 2014-15	

Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing (%)	Mean of values (%)	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
		2019		10.1			NRRI Technology Bulletin, 2019	
CR Dhan 411 (Swarnanjali)	IET 27852	2021	01	10.01	10.01	--	NRRI Annual Report 2021 Biofortified Varieties: Sustainable Way to Alleviate Malnutrition. 4th Edition. ICAR Publication	
Kalinga-III		2002-03	02	7.81 (milled rice)	8.45 (milled rice)	0.9	NRRI Annual Report 2002-03	
		2003-04		9.09 (milled rice)			NRRI Annual Report 2003-04	

Zn (Zinc) content (ppm) of rice grain

Zinc is also an essential element for human nutrition. It serves as a cofactor of the enzyme carbonic anhydrase and other enzymes. Severe Zn deficiency often accompanies vitamin A deficiency, hypothyroidism, diabetes and lower breast milk. Recommended dietary allowance value of Zn for females and males aged 31–50 are 8 and 11 mg/day, respectively. Zinc is also required for normal cell metabolism and functioning of different proteins and enzymes (Zoroddu et al., 2019; Prasad, 2014). Excess Zn might cause epigastric pain, metal fume fever, focal neuronal deficiency, elevated risk of prostate and altered lymphocytes function (Plum et al., 2010).

Methodology followed: Zinc content of the sample is determined by Atomic Absorption Spectrophotometer (Analytik Jena, Zeenit 700p, Germany) after digestion of the sample with HNO_3, H_2O_2, and water in Microwave digestion system (Milestone Ethoseasy) (Bagchi et al.,2023). The AAS system is calibrated with the respective standard solutions of 0.25,0.50, 0.75 and 1.00 ppm and assayed through the software in flame ionization mode. The R square value of standard samples is 0.99.

Table 14. Promising varieties/germplasms for Zn content (ppm)

Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years	Frequency of testing (no of times tested)	Values (score) in multiple testing			Mean of values	SD	References	Remarks1((*10% milling)
HMT PKU		2020 and 2021, 2022	3	69.2 41.52*	67.5 40.5*	62.3 37.38 *	66.33 39.79*	3.6	Authors own data, IRC 20,21,22, NRRI Ann. Rep. 21-22	Brown rice *Milled rice
CR2829-PLN-23		2,020	1	66.89 40.13*	0	0	66.89 40.13*	0.0	Authors own data, IRC 20,21,22	Brown rice *Milled rice

Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years	Frequency of testing (no of times tested)	Values (score) in multiple testing			Mean of values	SD	References	Remarks1((*10% milling)
BANSKATHI		2020 and 2021,	2	58.14 34.88*	52.3 31.38*	0	55.22 34.18*	2.3	Authors own data, IRC 20,21,22 NRRI Ann. Rep. 21-22	Brown rice *Milled rice
CR2829-PLN-114		2020 and 2021,	2	54.76 32.85*	55.3 33.18*	0	55.03 33.01*	1.3	Authors own data, IRC 20,21,22	Brown rice *Milled rice
CR2830-PLS-17		2020 and 2021,	2	54.125 32.47*	50.12 30.07*	0	52.12 31.27*	1.5	Authors own data, IRC 20,21,22	Brown rice *Milled rice
HEERA		2020 and 2021, 2022	3	50.76 30.45*	47.3 28.38*	42.3 25.38 *	46.79 29.56*	4.3	Authors own data, IRC 20,21,22 Ann. Rep. 21-22	Brown rice *Milled rice
CR4103-B-2		2020 and 2021, 2022	3	49.455 29.67*	42.3 25.38*	45.3 27.38 *	45.69 27.25*	3.6	Authors own data, IRC 20,21,22	Brown rice *Milled rice
NUAKALAJE ERA		2020 and 2021, 2022	3	49.385 29.63*	45.3 27.18*	41.3 24.18 *	45.33 28.36*	4.0	Authors own data, IRC 20,21,22 NRRI Ann. Rep. 21-22	Brown rice *Milled rice
CR2829-PLN-98		2020 and 2021, 2022	3	49.15 29.49*	46.3 27.78*	45.3 24.78 *	46.92 28.64*	2.0	Authors own data, IRC 20,21,22	Brown rice *Milled rice
HAJARI DHAN		2020 and 2021, 2022	3	48.13 28.87*	47.5 28.50*	42.5 27.19 *	46.04 27.25*	3.1	Authors own data, IRC 20,21,22 NRRI Ann. Rep. 21-22	Brown rice *Milled rice
Bindli		2020 and 2021, 2022	3	0	0	42.5 28.19 *	42.5 28.19*	NA	Authors own data, IRC 2024	Brown rice *Milled rice

Fe (Iron) content (ppm) of rice grain

Iron is mostly found in heme proteins in our blood. Generally, the amount of available Fe in staple food is low due to the presence of phytic acid, which form chelate with minerals. Iron content in grains ranged between 12 to 81 mg/kg (Tyagi, N., et.al.2020) and RDA values (Recommended Dietary Allowance) for females and males are set to 18 and 8 mg/day, respectively. Deficiency in Fe causes anemia, problem in breathing etc. Iron deficiency especially causes anemia while exposure to excess Fe may be toxic (Miller, 2013).

Methodology followed: Iron content of the sample is determined by Atomic Absorption Spectrophotometer (Analytik Jena, Zeenit 700p, Germany) after digestion of the sample with HNO_3, H_2O_2, and water in Microwave digestion system (Milestone Ethoseasy) (Bagchi et al.,2023). The AAS system is calibrated with the respective

standard solutions of 1.0,2.0,3.0 and 4.0 ppm and assayed through the software in flame ionization mode. The R square value of standard samples is 0.99.

Table 15. Promising varieties/germplasms for Fe content (ppm)

Name of Germplasm/ variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years	Frequency	Values (score) in multiple testing			Mean	SD	Refere-nces	Remarks (*10% milling)
PB312		2020 and 2021, 2022	3	83.42 25.01*	80.2 20.1*	78.3 21.47*	80.64 22.14*	2.59	Authors own data, IRC 20,21,22	Brown rice *Milled rice
PB140		2020 and 2021, 2022	3	79.24 23.77*	72.5 18.12*	70.2 19.25*	73.98 20.46*	4.70	Authors own data, IRC 20,21,22	Brown rice *Milled rice
CR DHAN 310		2020 and 2021, 2022	3	76.045 22.81*	65.3 15.32*	62.3 17.45*	67.88 18.52*	7.23	Authors own data, IRC 20,21,22	Brown rice *Milled rice
PUSA1176		2020 and 2021, 2022	3	63.795 19.25*	61.3 15.12*	58.3 16.23*	61.13 16.84*	2.75	Authors own data, IRC 20,21,22	Brown rice *Milled rice
MTU1010		2020 and 2021, 2022	3	63.035 17.58*	61.2 14.52*	57.8 16.24*	60.68 16.14*	2.66	Authors own data, IRC 20,21,22	Brown rice *Milled rice
PB-3-23		2020 and 2021, 2022	3	61.895 16.33*	56.3 14.12*	52.6 13.25*	56.93 14.55*	4.68	Authors own data, IRC 20,21,22	Brown rice *Milled rice
PB16		2020 and 2021, 2022	3	47.055 14.11*	41.3 10.25*	40.3 11.25*	42.89 11.88*	3.65	Authors own data, IRC 20,21,22	Brown rice *Milled rice
Bindli		2024				33.9 12.10*	33.9 12.10*	NA	Authors own data, IRC 2024	Brown rice *Milled rice

Head Rice Recovery (HRR) of rice

Although Head rice recovery % is a heritable trait that is controlled by genetic factors and varietal characteristics, it is significantly affected by the crop growth environment, agronomic practices, harvesting, drying and the process of milling (Asish et al., 2006). HRR is defined as the weight of head grain or whole

kernels in the rice lot. It is very important trait with respect to miller and consumer point of view. Higher HRR value of rice indicates more income of farmers as well as millers. Sanghamitra et al. (2017) reported that white rice HRR is more than pigmented rice. The post-harvest handling affects the breaking of grains during milling. But for release of any variety in India, at least 55% HRR is necessary (Ayyenar B et al., 2021).

Methodology followed: HRR value of rice grain can be obtained after hulling and milling of rice (Pal S et al., 2019). Head rice recovery (%) = (Weight of full kernel/ Weight of rough rice) X 100

Table 16. Promising rice varieties for Higher Head Rice Recovery (HRR%)

Sl. No	Name of Variety	IC /Ac No./ NBPGR regn.	Year of Testing	Frequency of testing	Values (%)			Mean	SD	References	Remarks
1.	Swarna sub-1		2020,2021, 2022	3	66.5	65.3	62.5	64.77	2.05	Authors own data, IRC 2020,21,22	High HRR
2.	Chandan		2020,2021, 2022	3	66.0	65.2	66.3	65.83	0.57	Authors own data, IRC 2020,21,22	
3.	Sonamani		2020,2021, 2022	3	68.0	64.2	65.2	65.80	1.97	Authors own data, IRC 2020,21,22	
4.	Tapaswini		2020,2021, 2022	3	66.5	64.2	64.2	64.97	1.33	Authors own data, IRC 2020,21,22	
5.	Durga		2020,2021, 2022	3	65.5	65.3	65.3	65.37	0.12	Authors own data, IRC 2020,21,22	
6.	Lunabarial		2020,2021, 2022	3	67.0	66.8	64.5	66.10	1.39	Authors own data, IRC 2020,21,22	
7.	Tapaswini (MAS)		2020,2021, 2022	3	67.0	65.3	63.5	65.27	1.75	Authors own data, IRC 2020,21,22	
8.	Savitri		2020,2021, 2022	3	65.5	67.3	64.2	65.67	1.56	Authors own data, IRC 2020,21,22	
9.	Jayanti Dhan		2020,2021, 2022	3	65.00	64.5	64.5	64.67	0.29	Authors own data, IRC 2020,21,22	
10.	Gayatri		2020,2021, 2022	3	66.0	63.5	68.5	66.00	2.50	Authors own data, IRC 2020,21,22	
11.	Udaya		2020,2021, 2022	3	65.5	65.3	64.2	65.00	0.70	Authors own data, IRC 2020,21,22	
12.	Saket-4		2020,2021, 2022	3	65.5	65.9	65.3	65.57	0.31	Authors own data, IRC 2020,21,22	
13.	CR Dhan 315		2020,2021, 2022	3	65.0	65.4	64.3	64.90	0.56	Authors own data, IRC 2020,21,22	
14.	TKM-13		2020,2021, 2022	3	71.7	68.9	63.2	67.93	4.33	Authors own data, IRC 2020,21,22	
15.	MTU- 1156 (Tarangini)		2020,2021, 2022	3	68.0	67.3	68.5	67.93	0.60	Authors own data, IRC 2020,21,22	
16.	MTU- 1121 (Sri Dhruthi)		2020,2021, 2022	3	67.0	64.5	64.2	65.23	1.54	Authors own data, IRC 2020,21,22	
17.	RNR-15048		2020,2021, 2022	3	67.0	68.5	66.3	67.27	1.12	Authors own data, IRC	

Sl. No	Name of Variety	IC /Ac No./ NBPGR regn.	Year of Testing	Freque-ncy of testing	Values (%)			Mean	SD	References	Remarks
	(Telengana Sona)									2020,21,22	
18.	BPT-5204		2020,2021, 2022	3	66.5	67.2	67.5	67.07	0.51	Authors own data, IRC 2020,21,22	

Phytic acid content

Phytic acid (PA) is considered as an anti-nutritional factor present in rice grain where it bind to cationic minerals including iron (Fe) and zinc (Zn), thus reducing their bioavailability in both ruminants and nonruminants. In view of the impact of PA on minerals bioavailability, screening of rice germplasm/ genotypes for low PA content in grains will be helpful in improvement of mineral bioavailability and help to tackle micronutrient malnutrition in the populations dependent on rice as a staple food.

***Methodology followed*:** Phytic acid is estimated by an assay procedure specific for the measurement of phosphorus released as available phosphorus from PA, myo-inositol (phosphate)n, and monophosphate esters by phytase and alkaline phosphatase.

Table 17. Selected genotypes for low Phytic acid.

Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing (g/100g)	Mean of values (g/100g)	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
Bindli		2015	3	0.82, 0.83, 0.82	0.82	0.005	ICAR-NRRI Annual report 2015-2016	Low Phytic acid content
Mornodoiga		2015	3	0.34, 0.29, 0.40	0.34	0.054	ICAR-NRRI Annual report 2015-2016	
Mugai		2015	3	0.35, 0.38, 0.35	0.36	0.017	ICAR-NRRI Annual report 2015-2016	
PB-480		2015	3	0.45, 0.39, 0.39	0.41	0.033	ICAR-NRRI Annual report 2015-2016	
Setaka-36		2015	3	0.53, 0.55, 0.52	0.53	0.012	ICAR-NRRI Annual report 2015-2016	
Khaibadal		2015	3	0.61, 0.6, 0.6	0.60	0.007	ICAR-NRRI Annual report 2015-2016	
Nalbora		2015	3	0.76, 0.77, 0.75	0.76	0.008	ICAR-NRRI Annual report 2015-2016	
Balam		2015	3	0.82, 0.83, 0.82	0.82	0.005	ICAR-NRRI Annual report 2015-2016	
Khira		2020	3	0.29, 0.28, 0.31	0.30	0.015	ICAR-NRRI Annual report 2020	
Vanaprava		2020	3	0.71, 0.68, 0.80	0.73	0.062	ICAR-NRRI Annual report 2020	

Name of Germplasm / variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing (g/100g)	Mean of values (g/100g)	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
Hue		2020	3	0.79, 0.80, 0.8	0.80	0.003	ICAR-NRRI Annual report 2020	
Kalinga-II		2020	3	0.79, 0.83, 0.85	0.83	0.028	ICAR-NRRI Annual report 2020	

Low Glycemic Index

Glycemic index (GI) is treated as a crucial indicator of starch digestion, which provides a comprehensive understanding of how foods high in carbohydrates affect blood glucose levels. Rice typically falls into the category of foods with GI ranging from 55–69 to >70. Foods low in GI (<55) slow down the pace at which starch is hydrolyzed, thus helping in decreasing levels of plasma glucose, insulin response and plasma insulin demand. In view of the impact of GI on blood glucose level, screening of rice germplasm for low GI will provide better health benefits to people in general and the diabetics in particular.

Methodology followed: An improved *in vitro* method, where digestive enzymes (alpha amylase, pepsin and amyloglucosidase) is used to digest rice starch into glucose. The dialysis membrane tube is used to mimic the human small intestinal system. The Hydrolysis index is calculated by dividing the area under the curve of the sample by that of the D-glucose (used as a reference carbohydrate). The predicted GI value is calculated using the formula given by Goni et al.,1997.

Table 18. Selected genotypes with low Glycemic index value

Name of Germplasm/ variety	IC/AC number/ NBPGR Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/MR/ R/etc)
Improved Lalat		2020	2	53.41 53.55	53.48	0.19	ICAR-NRRI IRC 2021	Low GI
Lalat		2017	3	58.53 54.55 53.57	55.53	0.15	ICAR-NRRI Annual Report 2017-18	Low GI
Shaktiman		2017	3	57.05 56.80 58.65	57.50	1.00	ICAR-NRRI Annual Report 2017-18	Moderately low GI
Savitri		2018	3	59.47 57.98 58.87	58.77	0.75	ICAR-NRRI Annual Report 2018-19	Moderately low GI
Nuadhusura		2018	3	59.61 59.71 59.81	59.71	0.10	ICAR-NRRI Annual Report 2018-19	Moderately low GI

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Chapter-11

Rice germplasm donors for improving straw quality

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Introduction

Rice straw, the byproduct left after harvesting rice grains, is a significant agricultural residue with various uses, including livestock feed, soil amendment, and as a raw material for bioenergy production. The quality of rice straw is determined by several factors including its protein content, fiber composition, lignin content, silica content, and overall digestibility. Rice straw typically contains low protein levels, usually around 3-6%. This low protein content is a limiting factor for its use as livestock feed without supplementation. Rice straw is high in fibrous content, which includes cellulose, hemicellulose, and lignin. The fiber composition is crucial for determining its utility in various applications. Cellulose and Hemicellulose are polysaccharides that act as primary structural components of plant cell walls. They are essential for microbial digestion in the rumen of ruminants. However, the high fiber content in rice straw can be both beneficial and problematic; while it provides necessary roughage, excessive fiber can limit the digestibility and energy availability for livestock. Lignin in straw is a complex polymer that binds with cellulose and hemicellulose, providing rigidity to plant cell walls. Rice straw typically has a high lignin content, which reduces its digestibility because lignin is resistant to microbial breakdown. This high lignin content is one of the main challenges in using rice straw as an effective feed component. Similarly, rice straw has a high silica content, ranging from 10-15%. Silica accumulates in the cell walls of rice plants, providing structural support and defense against pests. However, high silica content can negatively impact the digestibility of rice straw. The digestibility of rice straw is generally low due to its high fiber, lignin, and silica contents. The digestibility can be measured in terms of invitro organic matter digestibility (IVOMD).

Rice straw, while abundant and rich in fiber, presents challenges for use in animal feed due to its low protein content, high lignin, and silica content, and poor digestibility. Effective utilization of rice straw can contribute to sustainable farming practices by reducing waste and providing alternative feed resources for livestock. The rice straw quality has been analyzed to improve the use of rice straw for various applications. In the year 2018, Bhattacharyya et al. (2020) evaluated eighteen popular rice cultivars grown in Eastern for identification of rice varieties for industrial applications. Further, Subudhi et al. (2020) evaluated 132 rice varieties over two consecutive years to identify the rice varieties suitable for higher In-Vitro Dry Matter Digestibility (IVOMD) and showed a trade-off between rice straw and yield. In continuation of the work of IVOMD, Sah et al. (2024, Unpublished) summarized the evaluation of 449 rice varieties for their suitability as straw fodder by considering traits such as protein, fibre, lignin, silica, digestibility, and straw yield. The varieties were evaluated for at least two seasons or years for confirmation of the result. All the above experiments were conducted at ICAR-National Rice Research Institute in Cuttack, Odisha. The information provided valuable insight into rice straw quality and its possible utilization as fodder and industrial applications. The donor for the above straw quality traits are given below.

Methodology

Bhattacharyya et al. (2020) conducted biochemical, chemical, and morphological characterization of rice cultivars, primarily using biochemical profiling, with SEM and FTIR data as supporting parameters. The straw samples were tested in 2018 at ICAR-NRRI, Cuttack. Further, the straw quality analysis by Subudhi et al. (2020) and Sah et al. (2024) was conducted in collaboration with ILRI, Hyderabad. Each varieties straw was tested a minimum of two season/ year for confirmation. Here, Near Infrared Spectroscopy (NIRS) with a FOSS Forage Analyzer 6500 was employed to analyze straw samples, calibrated against traditional wet chemistry and in vitro laboratory tests, to evaluate parameters such as nitrogen, fibre content, lignin, silica, and in vitro organic matter digestibility (IVOMD). The statistical analysis was carried out utilizing SAS software.

Straw samples were analyzed using Near Infrared Spectroscopy (NIRS), which was calibrated for this experiment using conventional wet chemistry and in vitro laboratory analyses. The NIRS instrument utilized was a FOSS Forage Analyzer 6500 with the WinISI II software package. For calibration and validation, a diverse range of rice straws, including those from NRRI, were analyzed using traditional methods: nitrogen (N) by the Kjeldahl method, neutral detergent fiber (NDF) and acid detergent fiber (ADF), acid detergent lignin (ADL), and silica according to Goering and Van Soest (1970), and in vitro organic matter digestibility (IVOMD) by Menke and Steingass (1988). The goodness-of-fit for NIRS calibrations and the agreement

between NIRS predicted values and conventional analysis were expressed as R^2 and the standard error of prediction (SEP)

Table 19. Donors for straw quality

Trait	Name of Germplasm / variety	Year of testing (multiple years)	Frequency of testing (no of times tested)	Mean of values	Reference
High straw protein (%)	Ghanteswari	2018-2021	2	9.05	Subudhi et al. 2020; Authors own data
	GR4	2018-2021	2	8.57	Subudhi et al. 2020; Authors own data
	Nagarjuna	2018-2021	2	9.62	Subudhi et al. 2020; Authors own data
	Pavizam	2018-2021	2	9.51	Subudhi et al. 2020; Authors own data
	PR113	2018-2021	2	8.64	Subudhi et al. 2020; Authors own data
	Pusabasmati-6	2018-2021	2	8.59	Subudhi et al. 2020; Authors own data
	Ratnagiri-5	2018-2021	2	9.29	Subudhi et al. 2020; Authors own data
	Richharia	2018-2021	2	8.82	Subudhi et al. 2020; Authors own data
	RTN-3	2018-2021	2	8.50	Subudhi et al. 2020; Authors own data
	SYE-2001	2018-2021	2	8.67	Subudhi et al. 2020; Authors own data
High straw fibre (%)	B.R-2655	2018-2021	2	55.77	Subudhi et al. 2020; Authors own data
	BVD-110	2018-2021	2	55.20	Subudhi et al. 2020; Authors own data
	IR-28	2018-2021	2	56.27	Subudhi et al. 2020; Authors own data
	Karishma	2018-2021	2	56.03	Subudhi et al. 2020; Authors own data
	Makom	2018-2021	2	55.84	Subudhi et al. 2020; Authors own data
	Mangala	2018-2021	2	56.23	Subudhi et al. 2020; Authors own data
	Pusa Sugand-3	2018-2021	2	55.23	Subudhi et al. 2020; Authors own data
	Richharia	2018-2021	2	54.96	Subudhi et al. 2020; Authors own data
	VL Dhan-61	2018-2021	2	55.20	Subudhi et al. 2020; Authors own data
	VL Dhan-85	2018-2021	2	60.55	Subudhi et al. 2020; Authors own data
Low straw lignin (%)	CO-34	2018-2021	2	2.43	Subudhi et al. 2020; Authors own data
	CO-07	2018-2021	2	2.46	Subudhi et al. 2020; Authors own data
	Tanmayee	2018-2021	2	2.49	Subudhi et al. 2020; Authors own data
Low straw silica (%)	CO-30	2018-2021	2	10.98	Subudhi et al. 2020; Authors own data
	Samalei	2018-2021	2	10.95	Subudhi et al. 2020; Authors own data
	Jalaprava	2018-2021	2	10.95	Subudhi et al. 2020; Authors own data
	CO-07	2018-2021	2	10.62	Subudhi et al. 2020; Authors own data
High straw digestibility (%)	Asha MO5	2018-2021	2	48.15	Subudhi et al. 2020; Authors own data
	BVD-108	2018-2021	2	47.12	Subudhi et al. 2020; Authors own data
	Daya	2018-2021	2	49.16	Subudhi et al. 2020; Authors own data
	Ghanteswari	2018-2021	2	47.18	Subudhi et al. 2020; Authors own data
	GR101	2018-2021	2	47.54	Subudhi et al. 2020; Authors own data

Trait	Name of Germplasm / variety	Year of testing (multiple years)	Frequency of testing (no of times tested)	Mean of values	Reference
	IR-28	2018-2021	2	47.23	Subudhi et al. 2020; Authors own data
	Jalamani	2018-2021	2	47.32	Subudhi et al. 2020; Authors own data
	Jalaprava	2018-2021	2	47.87	Subudhi et al. 2020; Authors own data
	Pusa Sugand-2	2018-2021	2	47.49	Subudhi et al. 2020; Authors own data
	Pusa Sugand-3	2018-2021	2	47.08	Subudhi et al. 2020; Authors own data

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Chapter-12

Donors for Biotic stress Resistance: An Insect-pest perspective

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Insect pest complex of rice

Insect pests attack almost all plant parts of rice at one or another growth stage. There are about 800 insect species that can damage rice either in fields or storage, however only a dozen or so can be acknowledged as potential threats. Rice pests also can be classified into several groups according to the way they feed, e.g. grain insects such as the stink bugs (*Oebalus pugnax*) and gundhi bug (*Leptocorisa acuta*) which suck milk from the developing grain, defoliator insects such as cutworm (*Spodoptera maurita*) and leaf folder (*Cnaphalocrocis medinalis*) feed on the leaves and yellow stem borer (*Scirpophagaincertulas*) and gall midge (*Orseolia oryzae*) feeds within the stem. Likewise, phloem feeding insects are predominant in rice as they use phloem sap as their main food. Of these, brown planthopper (BPH), *Nilaparvata lugens* is the one inflicting huge yield loss.

If we examine the pest status in rice during last 20 years (2001-2020) a gradual increase in the spread of insects to more rice growing areas was observed year after year. Brown planthopper which was restricted to certain south and eastern states of India during 1970's and was almost negligible during 1980's, again assumed the major pest status by invading to almost all rice growing regions of the country. The insects like leaf folder, yellow stem borer are occurring in severe form and more often cause yield losses. The gall midge infestation was in a decreasing trend earlier, but its occurrence in severe form is being reported South India. The case worm spread was noticed in many states of southern and eastern India like Odisha, Jharkhand, AP, Maharashtra, Kerala, Tamilnadu and Gujarat. Swarming caterpillar was also causing severe yield loss in Odisha and Assam. In addition, now swarming caterpillar also reported from Kerala and Karnataka. Insects like Gundhi Bug, WBPH, Hisppa, Thrips were still showing their severity in small pockets. Recently, new insect-pests like black bug, white grubs were also injurious to rice crop in small pockets. So overall, most of the insects over the years increased their severity of occurrence (Jena et al., 2018).

Modern-day high yielding varieties are lacking in resistance reaction against biotic stresses. Therefore, it is necessary to discover and describenovel insect resistance genes for secure rice production because identification of the resistance sources not only solve the problem but also provides durable management strategy, hence it is essential to locate the gene along with tightly linked molecular markers for the respected resistant gene. Further, it is important to note that future host plant resistance programme should focus to identify the insect resistant genes that effective against local insect populations. Moreover, present rice market demands for high yielding varieties with quality rice pose a challenge in front of the scientists to transmit biotic stress resistance genes to farmers' preferred elite cultivars for more economical benefits. For this reason, researchers have turned towards traditional landraces or rice varieties in search ofvarious resistance traits due to their superiority in several traits compared to cultivated rice varieties.

Brown planthopper, *Nilaparvatalugens* resistance

Brown planthopper (*Nilaparvatalugens*) is one of the most devastating pest of rice which can cause severe yield loss ranges from 20-80% (Jena et al., 2018). Sometimes BPH can cause 100% damage of crops and thus farmers have to bear a economical loss. Brown planthopper has the potential to migrate from one field to another and their vigorous feeding behavior gives very less time for its management. So along-with chemical control, there are another eco-friendly management to control BPH i.e., Host Plant Resistance (HPR), where resistant varieties play a crucial role in the management of this notorious pest. The resistant varieties must carry one or more resistant genes which produce such proteins/substances against brown planthopper and thus resistant varieties lengthen or prolonged the duration of damage. So resistant varieties are vital source for breeding programs as well as for minimizing the risk of yield loss due to brown planthopper's attack.

Methodology followed

The rice germplasm were screened for BPH resistance with standard seed box technique (IRRI, 2013). The seed box test is a choice test by which rice germplasms can be ranked according to damage caused by planthopper nymphs. In brief, seeds of each cultivar (usually 20 cultivars per test) are sown in a single row in a seed-box of about 60 × 40 × 10 cm. Suitable susceptible and resistant checks are sown in similar rows in the same box. Ten days after sowing, seedlings are thinned to about 20-25 plants per row and infested with about eight-second

instar nymphs per seedling. When susceptible check TN1 seedlings in a box had become completely died due to planthopper feeding, the tests were terminated, and the damage to all seedlings in a box was scored.

Standard Seedbox screening score for brown planthopper resistance

Score	Meaning
0	No damage
1	Very slight damage
3	First and second leaves of most plants partially yellowing
5	Pronounced yellowing and stunting or about 10-25% of plants wilting or dying
7	More than half of the remaining plants' population severely stunted or dead
9	All plants dead

BPH screening

The screening of rice genotypes against brown planthopper was undertaken from 2000 to 2023 at ICAR-NRRI Cuttack. In total 950 genotypes were screened under net house conditions. Out of the total genotypes screened, Dhobanumberi and Salkathi showed consistent resistance (Score 1) for 15 years, CR Dhan 317 (CR 2711-76), CR 3006-8-2 showed high resistance (Score 1) for 12 years and RP-2068-18-3-5 showed high resistance (Score 1) for seven years. Whereas material from Odisha farmers variety namely Jaidubi, Jaigudi/kh-12, Kakudimanji-p, Laghu santi, Landi, Langudi, Akula, Balangir-Kahaliapalin-Assamchudi, Assamchudi, Ngrh-bhapur-Baigan Marji, Balibha Jan-j, Champa, NgrhbhapurChampesiali, GanjeiJata, Dkl/Harishankar, Kakudimanji-g, Balangir-mirdhapaliKalakrushna, Balangir-Kalajira, Kalama, Kalikati-s, Kanak champa, Katkala, Kevtia, Kuja, Lucheie, Parijat, Yada showed high resistant (score) for consecutive three years against rice brown planthopper. Besides, IC322922, IC75881, IC426149, IC256515, IC273558, IC426148, IC426126, IC256545, IC346890, IC346237, IC256547, IC752742, IC574971, IC75883, IC283249, IC426092, IC256849, IC346892, IC752742, and IC256545 showed consistently moderately resistant for three years. Whereas, popular varieties (Naveen, Swarna, Pooja) showed susceptible reactions (Score 9) for consecutive five Years.

Table 20. List of resistant donors against brown planthopper

Sl. No	Name of Germplasm/Variety	Year of testing (multiple years)	Frequency of testing (Number)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
1	Dhobanumberi	2009-2022	14	1	HR	Jena et al. 2022
2	Salkathi	2009-2022	14	1	HR	Jena et al. 2022
3	CR Dhan 317	2012-2022	11	1	HR	Jena et al. 2022
4	CR 3006-8-2	2012-2022	11	1	HR	Jena et al. 2022
5	RP-2068-18-3-5	2017-2022	6	1	R	Jena et al. 2022
6	Jaidubi	2018-2020	3	1	HR	Anant et al. 2022
7	Jaigudi/kh-12	2018-2020	3	1	HR	Anant et al. 2022
8	Kakudimanji-p	2018-2020	3	1	HR	Anant et al. 2022
9	Laghu santi	2018-2020	3	1	HR	Anant et al. 2022
10	Landi	2018-2020	3	1	HR	Anant et al. 2022
11	Langudi	2018-2020	3	1	HR	Anant et al. 2022
12	Akula	2018-2020	3	1	HR	Anant et al. 2022
13	Balangir-Kahaliapalin-Assamchudi	2018-2020	3	1	HR	Anant et al. 2022
14	Ngrh-bhapur-Baigan Marji	2018-2020	3	1	HR	Anant et al. 2022
15	Balibha Jan-j	2018-2020	3	1	HR	Anant et al. 2022

Sl. No	Name of Germplasm/Variety	Year of testing (multiple years)	Frequency of testing (Number)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
16	Champa	2018-2020	3	1	HR	Anant et al. 2022
17	Ngrhbhapur Champesiali	2018-2020	3	1	HR	Anant et al. 2022
18	GanjeiJata	2018-2020	3	1	HR	Anant et al. 2022
19	Dkl/Harishankar	2018-2020	3	1	HR	Anant et al. 2022
20	Kakudimanji-g	2018-2020	3	1	HR	Anant et al. 2022
21	Balangir-mirdhapaliKalakrushna	2018-2020	3	1	HR	Anant et al. 2022
22	Balangir-Kalajira	2018-2020	3	1	HR	Anant et al. 2022
23	Kalama	2018-2020	3	1	HR	Anant et al. 2022
24	Kalikati-s	2018-2020	3	1	HR	Anant et al. 2022
25	Kanak champa	2018-2020	3	1	HR	Anant et al. 2022
26	Katkala	2018-2020	3	1	HR	Anant et al. 2022
27	Kevtia	2018-2020	3	1	HR	Anant et al. 2022
28	Kuja	2018-2020	3	1	HR	Anant et al. 2022
29	Lucheie	2018-2020	3	1	HR	Anant et al. 2022
30	Parijat	2018-2020	3	1	HR	Anant et al. 2022
31	Yada	2018-2020	3	1	HR	Anant et al. 2022
32	IC322922	2020-2021-2022	3	1	HR	Babu et al. 2023
33	IC75881	2020-2021-2022	3	1	HR	Babu et al. 2023
34	IC426149	2020-2021-2022	3	1	HR	Babu et al. 2023
35	IC256515	2020-2021-2022	3	1	HR	Babu et al. 2023
36	IC273558	2020-2021-2022	3	1	HR	Babu et al. 2023
37	IC426148	2020-2021-2022	3	1	HR	Babu et al. 2023
38	IC426126	2020-2021-2022	3	1	HR	Babu et al. 2023
39	IC256545	2020-2021-2022	3	1	HR	Babu et al. 2023
40	IC346890	2020-2021-2022	3	1	HR	Babu et al. 2023
41	IC346237	2020-2021	2	1	R	Babu et al. 2023
42	IC256547	2020-2021	2	1	R	Babu et al. 2023
43	IC752742	2020-2021	2	1	R	Babu et al. 2023
44	IC574971	2020-2021	2	1	R	Babu et al. 2023
45	IC75883	2020-2021	2	1	R	Babu et al. 2023
46	IC283249	2020-2021	2	1	R	Babu et al. 2023
47	IC426092	2020-2021	2	1	R	Babu et al. 2023

Sl. No	Name of Germplasm/Variety	Year of testing (multiple years)	Frequency of testing (Number)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
48	IC256849	2020-2021	2	1	R	Babu et al. 2023
49	IC346892	2020-2021	2	1	R	Babu et al. 2023
50	IC752742	2020-2021	2	1	R	Babu et al. 2023
51	IC256545	2020-2021	2	1	R	Babu et al. 2023
52	Naveen	2019 to 2022	4	9	HS	Jena et al. 2022
53	Swarna	2019 to 2022	4	9	HS	Jena et al. 2022
54	Pooja	2019 to 2022	4	9	HS	Jena et al. 2022

Leaf Folder (*Cnaphalocrocis medinalis*)

Leaf folder, *Cnaphalocrocismedinalis*, is one of the major pests of rice which can damage rice severely. Mainly its larval stage is the most dangerous. After hatching from eggs laid on rice leaves, the larvae start feeding on the leaf tissue. They fold the leaves longitudinally, using silk threads spun by them, and reside inside these folded leaves for protection while feeding. Leaf Folder larvae feed on the green leaf tissues between the midrib and the leaf margin. They consume the leaf material within the fold, causing characteristic damage that appears as rolled or folded leaves. This feeding behaviour reduces the photosynthetic area of the leaf and affects plant growth. Beside chemical pesticide application, there are several resistant varieties which can withstand the attack of leaf folder and can minimize the economical loss of farmers.

Methodology followed

Seedlings of 25-30 day old were transplanted in the main field using single seedling per hill in rows at spacing of 20x15cm. The responses of genotypes along with the standard checks against rice leaf folder were assessed in the field by following a rapid screening method (Padmavathi et al., 2017). Each genotype was grown in a row of 20 hills and the checks were repeated after 10 rows of test lines. In addition, two rows of the susceptible check (TN1) were planted as a border. At 30-40 DAT, the genotypes were then covered with nylon net and leaf folder adults were released twice (at 40 DAT and 60 DAT, each time with 100 adults) inside the net. The adults were allowed to remain in the net for a week before it was removed. Thereafter, observations (the total number of leaves and the number of leaves damaged by leaf folder) were recorded on 10 randomly selected plants of each genotype in both the replications at 20 days after each release. The percentage of damaged leaves were counted and converted to adjusted damaged leaves rating (ADLR) using the following formula, which was then converted to 0–9 score according to the standard evaluation score (SES) for rice.

Damaged leaves (%) = (Number of damaged leaves in a hill per plant / Total number of leaves observed in a hill per plant) x 100

Adjusted damaged leaves rating (% ADLR) = (% damaged area in test entry/ % damaged area in susceptible check) x 100

Standard screening score for leaf folder resistance

Scale	ADLR	Reaction
0	No damage	R
1	1 to 20%	
3	21 to 40%	
5	41 to 60%	MR
7	61 to 80%	S
9	81 to 100%	

Leaf folder screening

The screening of rice genotypes against leaf folder was undertaken from 2000 to 2023 at ICAR-NRRI Cuttack. In total 137 genotypes were screened under net house conditions. Out of the total genotypes screened, IC282818, CR 2711-76, Mahasuri, Jangalijatashowed consistent resistance (Score 1) for 2 years. Variety Manipuri Black, and Ankulshowed moderately resistance (Score 3) for two years.

Table 21. List of resistant donors against rice leaf folder

Name of Germplasm/Variety	Year of testing	Frequency of testing (no of times tested)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
IC282818	2012-2013	2	1	R	NRRI Annual Report 2012-2013
CR 2711-76	2012-2013	2	1	R	NRRI Annual Report 2012-2013
CR Dhan 802	2017-2018	2	1	R	NRRI Annual Report 2017-2018
CR Dhan 410	2017-2018	2	1	R	NRRI Annual Report 2017-2018
Nadia phula	2011-2012	2	3	MR	NRRI Annual Report 2011-2012
CR Dhan 206	2014-2015	2	3	MR	NRRI Annual Report 2014-2015
CR Dhan 101	2014-2015	2	3	MR	NRRI Annual Report 2014-2015
CR Dhan 408	2014-2015	2	3	MR	NRRI Annual Report 2014-2015
CR Dhan 203	2014-2015	2	3	MR	NRRI Annual Report 2014-2015
CR Dhan 506	2015-2016	2	3	MR	NRRI Annual Report 2015-2016
CR Dhan 307	2014-2015	2	3	MR	NRRI Annual Report 2014-2015
CR Dhan 506	2015-2016	2	3	MR	NRRI Annual Report 2015-2016
CR Dhan 409	2015-2016	2	3	MR	NRRI Annual Report 2015-2016
CR Dhan 510	2016-2017	2	3	MR	NRRI Annual Report 2015-2016
CR Dhan 511	2017-2018	2	3	MR	NRRI Annual Report 2017-2018
CRR 356-29	2017-2018	2	3	MR	NRRI Annual Report 2017-2018
Manipuri (black)	2021-2022	2	3	R	Nayak et al., 2024
Mahasuri	2021-2022	2	1	R	Nayak et al., 2024
Jangalijata	2021-2022	2	1	R	Nayak et al., 2024
Pahadiabanki	2021-2022	2	3	R	Nayak et al., 2024
Black rice	2021-	2	3	R	Nayak et al., 2024

Name of Germplasm/Variety	Year of testing	Frequency of testing (no of times tested)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
	2022				
Kalajeera(I)	2021-2022	2	3	R	Nayak et al., 2024
Baiganamanji	2021-2022	2	3	R	Nayak et al., 2024
OR237	2021-2022	2	5	MR	Nayak et al., 2024
Basumatibanki	2021-2022	2	3	R	Nayak et al., 2024
OR258	2021-2022	2	3	R	Nayak et al., 2024
Agnisar	2021-2022	2	5	MR	Nayak et al., 2024
Ankul	2021-2022	2	3	R	Nayak et al., 2024
Benabahar	2021-2022	2	3	R	Nayak et al., 2024
Baikani-D	2021-2022	2	3	R	Nayak et al., 2024
Bhutia	2021-2022	2	3	R	Nayak et al., 2024
Biradiabankoi	2021-2022	2	1	R	Nayak et al., 2024
Chamarmani	2021-2022	2	1	R	Nayak et al., 2024
Balibhuta	2021-2022	2	1	R	Nayak et al., 2024
Basudha	2021-2022	2	1	R	Nayak et al., 2024
Bayabhanda	2021-2022	2	3	R	Nayak et al., 2024
Bhalunki	2021-2022	2	1	R	Nayak et al., 2024
Bhatta	2021-2022	2	1	R	Nayak et al., 2024
Champaneuli	2021-2022	2	3	R	Nayak et al., 2024
Champasola	2021-2022	2	3	R	Nayak et al., 2024
Champeisiali	2021-2022	2	5	MR	Nayak et al., 2024
Chinamal	2021-2022	2	5	MR	Nayak et al., 2024
Chinamali-k	2021-2022	2	5	MR	Nayak et al., 2024
Chiptiphal	2021-2022	2	5	MR	Nayak et al., 2024

Name of Germplasm/Variety	Year of testing	Frequency of testing (no of times tested)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
Dhanarekha	2021-2022	2	5	MR	Nayak et al., 2024
Gelheiguti	2021-2022	2	5	MR	Nayak et al., 2024
Gelhei	2021-2022	2	3	R	Nayak et al., 2024
Gorumani	2021-2022	2	5	MR	Nayak et al., 2024
OdapadaHarishankar	2021-2022	2	5	MR	Nayak et al., 2024
Harishankar	2021-2022	2	5	MR	Nayak et al., 2024
Ispit	2021-2022	2	5	MR	Nayak et al., 2024
Jata	2021-2022	2	5	MR	Nayak et al., 2024
Kadalikenda	2021-2022	2	3	R	Nayak et al., 2024
Kalakatiki	2021-2022	2	5	MR	Nayak et al., 2024
Kalakrushna	2021-2022	2	5	MR	Nayak et al., 2024
Kalakusuma	2021-2022	2	3	R	Nayak et al., 2024
Kalamugajai	2021-2022	2	5	MR	Nayak et al., 2024
Kalamulia	2021-2022	2	3	R	Nayak et al., 2024
Kaliasaru	2021-2022	2	3	R	Nayak et al., 2024
Kanakachampa	2021-2022	2	3	R	Nayak et al., 2024
Kanhav	2021-2022	2	1	R	Nayak et al., 2024
Kansapurimajhijhuli	2021-2022	2	1	R	Nayak et al., 2024
Karpuramoti	2021-2022	2	3	R	Nayak et al., 2024
Kathidhan	2021-2022	2	5	MR	Nayak et al., 2024
Labangalata	2021-2022	2	5	MR	Nayak et al., 2024
Langudi	2021-2022	2	3	R	Nayak et al., 2024
Bolangirbhalukanaluche	2021-2022	2	5	MR	Nayak et al., 2024

Name of Germplasm/Variety	Year of testing	Frequency of testing (no of times tested)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
Boudhluchei	2021-2022	2	5	MR	Nayak et al., 2024
Luna	2021-2022	2	5	MR	Nayak et al., 2024
Sundargarhlungudi	2021-2022	2	5	MR	Nayak et al., 2024
Koraputmachhakanta	2021-2022	2	5	MR	Nayak et al., 2024
Maguramanji	2021-2022	2	5	MR	Nayak et al., 2024
Maharaji	2021-2022	2	5	MR	Nayak et al., 2024
Mahipal-B	2021-2022	2	5	MR	Nayak et al., 2024
Klanjigarhmahipal	2021-2022	2	5	MR	Nayak et al., 2024
Majhalijhuli	2021-2022	2	5	MR	Nayak et al., 2024
Makadhan	2021-2022	2	3	R	Nayak et al., 2024
Makarkand	2021-2022	2	3	R	Nayak et al., 2024
Malata	2021-2022	2	1	R	Nayak et al., 2024
Mayurkantha-k	2021-2022	2	3	R	Nayak et al., 2024
Menaka	2021-2022	2	3	R	Nayak et al., 2024
Mogra	2021-2022	2	3	R	Nayak et al., 2024
Motahalkal	2021-2022	2	5	MR	Nayak et al., 2024
Naliguntha	2021-2022	2	5	MR	Nayak et al., 2024
Nagara	2021-2022	2	3	R	Nayak et al., 2024
Nadalghanta	2021-2022	2	5	MR	Nayak et al., 2024
Padmakesari	2021-2022	2	3	R	Nayak et al., 2024
Pahadbhanga	2021-2022	2	5	MR	Nayak et al., 2024
Pandukalyan	2021-2022	2	3	R	Nayak et al., 2024
Panikoili	2021-2022	2	5	MR	Nayak et al., 2024

Name of Germplasm/Variety	Year of testing	Frequency of testing (no of times tested)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
Saraswati	2021-2022	2	3	R	Nayak et al., 2024
Radhajugal	2021-2022	2	3	R	Nayak et al., 2024

Gall Midge (*Orseolia oryzae*)

Gall midges are of seasonal occurrence and pre-vail mostly in*kharif*season, but in the off-season, they spend their life in grasses. During *kharif* (monsoon) season, adults of gall midge start mating and the females start egg-laying 2 days after the completion of the mating process. As soon as the eggs hatch, the tiny maggots start crawling with the help of the thin film of water on the leaf tissue and reach the primordial region, and they puncture the tissue near the crown region and get an entry into it. The plant is in succulent condition at that time, providing a suitable dwelling place where they feed on the plant tillers' phloem tissue, complete all their developmental stages, and emerge as adults. Because of the infestation of the gall midge, plants become sterile without having any panicles (Sardesaiet al.,2002). While feeding, the maggots secrete salivary secretion containing a chemical called cecidogen which is involved in forming the silver shoots by manipulating the plant growth mechanism.

Seven biotypes of Asian gall midge have been identified in India (Himabindu et al.,2010; Vijay Lakshmi et al.,2006). In order to contain the infestation by different biotypes of gall midge, one should understand the importance of resistance of rice plants and accordingly select the crop variety having a resistance trait. To resolve this problem, identifying biotype-specific resistant donors will help to develop durable gall midge resistant varieties through the molecular breeding program (Vijaykumar et al.,2022). In plant systems, two kinds of resistance are existing—constitutive resistance and induced resistance (Traw & Dawson,2002). Resistance mechanisms in these crop plants are again categorized into three types: antixenosis, antibiosis, and tolerance mechanism (Painter,1951). Antixenosis mechanism is mainly associated with the morphological traits of the plants like plant height, leaf thickness, colour of the leaves, moisture content of the plants, number of tillers, tightness of the leaf sheath, density of trichomes, wax content of the leaves, and so forth (Roy et al.,1971; Venkataswamy,1966). In contrast, antibiosis mechanism is mainly attributed to the biochemical features of the plants like phenol, total sugar, reducing sugar, protein, and amino acids content. Various mechanisms of secondary plant metabolism mainly regulate antibiosismechanism of plants.

Methodology followed

Phenotyping of rice genotypes against gall midge was undertaken in glasshouse conditions. The genotypes were sown in lines in the plastic trays (50x30x5cm^3) by keeping 3cm spacing between the lines and in each tray one line was sown with TN1 seeds as susceptible check and one line was sown with Abhaya seeds as resistant check. In each line 25 seedlings were maintained and rest were discarded. The trays containing the genotypes were raised in the glass house with proper care. When these seedlings are 15 days old then these were infested with the adult gall midge in the ratio of 30 female: 15 male by keeping the trays inside the cage. The trays were maintained inside the cage for 2 days to achieve a successful mating of the adults and egg laying of the females. During this period proper humidity was maintained inside the cages by frequent spraying of water so that the humidity inside the cage was maintained at more than 90-95% and temperature was kept in between the range of 28-30 ^{o}C. When the mating and egg laying by the female gall midge were completed these trays were taken outside and kept under sunlight for proper growth of the plants and were watered regularly for proper growth of the gall midge maggots (Sahu et al., 2022).

Table 22. Standard screening score for Gall Midge resistance

Serial Number	Damage (Plants with silver shoot) per cent		SES Score	Reaction
	Glass house condition	Field condition		
1	No damage	No damage	0	Highly Resistant
2	<5%	<1%	1	Resistant
3	6-10%	1-5%	3	Moderately Resistant

Serial Number	Damage (Plants with silver shoot) per cent		SES Score	Reaction
	Glass house condition	Field condition		
4	11-20%	6-10%	5	Moderately Susceptible
5	21-50%	11-25%	7	Susceptible
6	>50%	>25%	9	Highly Susceptible

(IRRI, 2013; Seni & Naik, 2019)

Gall midge screening

The screening of rice genotypes against gall midge was undertaken from 2000 to 2023 at ICAR-NRRI Cuttack. In total 667 genotypes were screened under net house conditions. Out of the total genotypes screened, Aganni, Abhaya, AC5984, INC3021 showed consistent resistance (Score 0) for 7years.Variety Sameli, and CR Dhan 300 showed high resistance (Score 1) for four years and AC44525, AC44897 showed high resistance (Score 0) for two years.

Tble 23. List of resistant donors against rice gall midge

Name of Germplasm/Variety	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
Abhaya	2012, 2016-2023	7	0	HR	Sahu et al., 2023; CRRI Annual report, 2012-13 (Page No. 14) ICAR-IIRR Annual Progress Report 2021 Vol-2 Entomology (page No. 2.7)
AC 5984	2012, 2016-2023	7	0	HR	Adak et al., 2019; Patra et al., 2018 NRRI Annual report, 2016-17 (Page No. 106) NRRI Annual report, 2017-18 (Page No. 105) CRRI Annual report, 2012-13 (Page No. 14) CRRI Annual report, 2012-13 (Page No. 14) ICAR-IIRR Annual Progress Report 2021 Vol-2 Entomology (page No. 2.27)
CR Dhan 300	2015, 2016, 2021 2022	4	1	R	NRRI Annual report 2019 (Page No. 44); Authors own data
Aganni	2016-2023	7	0	HR	Adak et al., 2019, NRRI Annual report, 2016-17 (Page No. 106) NRRI Annual report, 2017-18 (Page No. 105) NRRI Annual report, 2014-15 (Page No. 109) ICAR-IIRR Annual Progress Report 2021 Vol-

Name of Germplasm/Variety	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
					2 Entomology (page No. 2.27)
INRC 3021	2016-2023	7	0	HR	Adak et al., 2019, NRRI Annual report, 2015-16 (Page No. 112) NRRI Annual report, 2017-18 (Page No. 105) NRRI Annual report, 2014-15 (Page No. 109)
Phalguna	2021-2022	2	1	R	Patra et al., 2018; Sahu et al., 2023
AC 39738	2019-2020	2	1	R	NRRI Annual report 2019 (Page No. 44) NRRI Annual report 2020 (Page No. 50) AICRIP annual report
Kavya (GM1)	2020-2022	2	1	R	Sahu et al., 2023
ARC 6605	2021-2022	2	3	MR	Patra et al., 2018
AC-44525	2020-2023	04	0	HR	Sahu et al., 2023
AC-44897	2020-2023	04	0	HR	Sahu et al., 2023
Kavya (GM1)	2020-2022	2	1	R	Sahu et al., 2023
Abhaya	2012, 2016-2023	7	0	HR	Sahu et al., 2023; CRRI Annual report, 2012-13 (Page No. 14) ICAR-IIRR Annual Progress Report 2021 Vol-2 Entomology (page No. 2.7)
AC 5984	2012, 2016-2023	7	0	HR	Adak et al., 2019; Patra et al., 2018 NRRI Annual report, 2016-17 (Page No. 106) NRRI Annual report, 2017-18 (Page No. 105) CRRI Annual report, 2012-13 (Page No. 14) CRRI Annual report, 2012-13 (Page No. 14) ICAR-IIRR Annual Progress Report 2021 Vol-2 Entomology (page No. 2.27)

Angoumois Grain Moth (*Sitotrogacerealella*)

Angoumois grain moths primarily infest paddy that are stored. Adult female moths lay eggs directly on the surface of paddy. Upon hatching, the larvae bore into the paddy, seeking out the nutrient-rich endosperm within.

As the larvae continue to feed and grow, they undergo several molts inside the paddy. Once fully developed, they exit the grain, often leaving behind exit holes, and may pupate inside paddy. The feeding activity of Angoumois grain moth larvae results in hollowed-out paddy, making them lighter and more susceptible to breakage. Infested paddy may also become contaminated with frass (larval excrement) and silk webbing, further compromising their quality.

Methodology followed

A group of diverse rice varieties and landraces were selected to evaluate their resistance/ tolerance against test insectunder laboratory conditions. Freshly harvested grains of each variety (around 100 g) were collected, cleaned and disinfected by keeping them at 5°C for two weeks prior to the start of the experiment to kill any existing infestations of other invaders. The grains of each entry were maintained in two replications. The grains were then kept for two weeks at the experimental conditions for acclimatization. The moisture content of the paddy grains was adjusted to 14%.

Each variety was evaluated for resistance/ susceptibility response against *S. cerealella* under laboratory conditions. About 100g paddy from each of the rice genotypes were placed in a 250 cm^3 plastic jar covered with muslin cloth allowing ventilation and preventing the escape of the adult insects. The no-choice test method was followed and insects were introduced to each jar of grains. About 20 pairs of freshly emerged moths were placed in the plastic jar containing paddy. The open end of jar was covered with muslin cloth and kept for 7 days to allow mating and oviposition, later on, dead moths were removed. The remaining content of each jar (paddy grains and freshly laid eggs) was kept for further multiplication and completion of the next generation to know the response of varieties under screening.

Calculation of susceptibility index

Resistance or susceptibility response of selected rice varieties was evaluated against Angoumois grain moth by considering moth emergence data and Dobies susceptibility index.

Adult moth emergence (N): Total number of adults that emerged after exposure for median developmental period.

Weight loss (WL): When the test insect emergence ceased, the number and weight of damaged and undamaged grains for each replication of 100 grains were recorded, and the percentage weight loss was computed using the formula below.

$$\textbf{WL (\%)} = \frac{(Wu \times Nd) - (Wd \times Nu)}{Wu \times (Nd + Nu)} \times 100$$

Wu= undamaged grains weight, Nu= undamaged grains number

Wd= damaged grain weight, and Nd= damaged grains number

Index of susceptibility (SI): Calculated using the method of Dobie& Kilminster (1978).

SI= (Log_e F)/D × 100

Total number of F_1 adults is denoted by F.

The median development period is D.

The susceptibility index was used to classify the rice types, which ranged from 0 to 11.

Where 0 - 3 indicates resistance, 3.1 – 7.0 indicates moderate resistance, 8.0 – 10.0 indicates susceptibility, and >10 indicates highly susceptibility.

Angoumois Grain Moth screening

The screening of rice genotypes against Angoumois grain moth- *Sitotrogacerealella* was undertaken from 2000 to 2023 at ICAR-NRRI Cuttack. In total 103 genotypes were screened under laboratory conditions. Out of the total genotypes screened, 1 variety (BINA Dhan 8) showed consistently resistant for 2 years (ICAR-NRRI Annual Report 2019 & 2021), 3 varieties (Kala Jeera, Durga & CR Dhan 310) showed moderately resistant for 3 years (ICAR-NRRI Annual Report 2019, 2020 & 2021). Besides, 1 variety (Annada) showed consistently tolerant reaction for 4 years (ICAR-NRRI Annual Report 2001, 2002, 2003 & 2004), 3 varieties (Annada, Ketekijoha and Kalakeri) showed consistently tolerant for 2 years (ICAR-NRRI Annual Report 2003 & 2004), the remaining 97 varieties (Heera , Kalinga III, Vandana, Sattari , Sneha, Dhaula, Jaya, Indira, Tara, Panidhan, Pusa Basmati-1, Basmati-370, Shatabdi , Naveen, CR Dhan- 10, Padmini, NuaChinikamini, Geetanjali, TN-1, Suka- 5, Lunishree, Satyabhama, Cross- 12, Luna Sampad, Swarna Sub- 1, Gayatri, Kala Jeera, Durga, CR Dhan- 310, Pooja, Manipuri Black, CR-Dhan-311, CR-Dhan-909, CR-Dhan-800, CR-Dhan-508, CR-Dhan-506,

CR-Dhan-209, CR-Dhan-409, CR-Dhan-310, CR-Dhan-301, CR-Dhan-307, CR-Dhan-203, CR-Dhan-101, CR-Dhan-407, CR-Dhan-305, CR-Dhan-304, CR-Dhan-303, CR-Dhan-300, CR-Dhan-202, CR-Dhan-201, CR-Sugandh Dhan 907, CR-Dhan-100, Improved Lalat , CR-Dhan-500, Sahabhagi Dhan, Phalguni, Luna Suvarna, CR-Dhan-601, CR-Dhan-401, Swarna Sub-1, CR-Boro Dhan-2, Varshadhan , Sarala, Anjali, Khitish, CR Dhan 507, CR Dhan 908, IMP Tapaswini, CR Dhan 408, CR Dhan 200, Hensaswari, Durga, Savitri, CR Dhan 204, Luna Sankhi, CR Dhan 404, CR Dhan 1014, Jayanti Dhan, Dharitri, Moti, CR Dhan 802, Pradhan Dhan, Utkalprabha, NuaKalajeera, CR Dhan 205, Ratna, CR Dhan 306, NuaDhusara, CR Dhan 501, CR Dhan 206, Tapaswini, CR Sugandh Dhan 3, CR Dhan 602, Supriya, Saket 4, BINA Dhan 10, CR Dhan 510) showed susceptible reaction for 2 years (Source: ICAR-NRRI Annual Report 2001, 2019, 2021, 2023).

Table 24. List of resistant donors against Angoumois Grain Moth

Name of Germplasm/Variety	Year of testing (multiple years)	Frequency of testing (no of times tested)	Dobies susceptibility indices (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
Bina Dhan 8	2019, 2021 2022	3	3 – 5.0	R/MR	Priyadarshini et al., 2024; NRRI Annual Report, 2019; NRRI Annual Report, 2021
Kala jeera	2019, 2020 2022	3	3.60	MR	Priyadarshini et al., 2024; NRRI Annual Report, 2019; NRRI Annual Report, 2020; NRRI Annual Report, 2021
Durga	2019, 2020 2022	3	3 – 4	MR	Priyadarshini et al., 2024; NRRI Annual Report, 2019; NRRI Annual Report, 2020
CR Dhan- 310	2019, 2020 2022	3	3 – 4	MR	Priyadarshini et al., 2024; NRRI Annual Reports 2019, 2020, 2022
Annada	2001, 2002 2004	4	3 – 5	T	NRRI Annual Reports 2001, 2002, 2003, 2004
Ketekijoha	2003, 2004 2017	3	3 – 5	T	NRRI Annual Reports 2003, 2004, 2017
Kalakeri	2003, 2004	2	3 – 5	T	NRRI Annual Reports 2003, 2004
Black Gora	2003, 2004	2	3 – 5	T	NRRI Annual Reports 2003, 2004

Yellow Stem borer (*Scirpophaga incertulas*)

Yellow stem borer (YSB), *Scirpophagaincertulas* (Walker) (Crambidae: Lepidoptera) considered as a predominant pest that occurs all over the rice producing regions in Asia. This pest attacks rice crop at all the stages causing yield loss varying from 10% to 90% depend on crop stage. During vegetative stage, it causes ‘dead hearts’ and at reproductive stage it inflicts ‘white ear’. The farmers in their yearlong battle against this deleterious pest rely solely on synthetic insecticide as a tool of choice because of their broad-spectrum activity and rapid killing attributes. Even after the repeated insecticidal application, managing YSB was challenging due to its cryptic behavior and feeding habit. Therefore, researchers around the world in search of viable alternate strategies to check this pest paving the way for reduced use of insecticide without compromising the pest control ability. One such an effective strategy is growing of insect-pest resistant varietieswhich leaves no insecticide residues in environment, food and also shows constant effectiveness.

Methodology followed

Twenty-five days old seedlings were transplanted at two rows per each entry at the rate of two seedlings per hill. The susceptible variety, TN1 was also transplanted after every 10 rows of the genotypes. The plants were kept free of pesticide spraying and followed standard agronomic practices. The plants were supplemented with field-

collected YSB moth-laid egg masses per each entry to make enough population and damage load. The data on the number of tillers and dead hearts were taken at 35 and 55 days after transplanting during the vegetative stage and the number of productive tillers and white ear-head at 75 and 90 days after transplanting during the reproductive stage. The percent dead heart and white ear-head were calculated following the standard formula. On calculating the dead heart and white ear-head percent the scoring following IRRI Standard Evaluation System (SES) for rice (IRRI, 2002) was done.

Table 25. Screening score for yellow stem borer resistance

Percent dead hearts (% DH)			Percent white ears (% WE)		
Damage (%)	Scale	Status	Damage (%)	Scale	Status
0	0	Highly Resistant (HR)	0	0	Highly Resistant (HR)
1-10	1	Resistant (R)	1-10	1	Resistant (R)
11-20	3	Moderately Resistant (MR)	11-20	3	Moderately Resistant (MR)
21-30	5	Moderately Susceptible (MS)	21-30	5	Moderately Susceptible (MS)
31-60	7	Susceptible (S)	31-60	7	Susceptible (S)
61 and above	9	Highly Susceptible (HS)	61 and above	9	Highly Susceptible (HS)

(Reference: IRRI, 2002)

YSB screening

The screening of rice genotypes against rice yellow stem borer (YSB), *Scirpophagaincertulas* (Walker)was undertaken from 2000 to 2023 at ICAR-NRRI Cuttack and its regional stations. Out of the total genotypes screened Kusuma, Kshira and Geleigutti were resistance for three years; Achinha, Champeisali, Raghukunawar, Raghuchinamali, Bahalmali, Kalamuli, Kanelaka, Brahmanabhojni, Dahijhil, Kankada, Mahalaxmi, Punsi, Nalihazara, Senka, Gelleigutti, Baidyaraj, Bhramanbhojni, Chadheinakhi, Daonara, Padmatali, Maladhan, Malkanhei, Kantamugdhi, Kusampura, Munubhadraj, Angulia, Tulasikanthi, Mirigasiali, Saruchinamali, Mayurkantha, Mani, Kalamkathi, Bhaduasali, Dhusarakali, Kartika, Kuliha, Kenragali, Jaigudi, Laghubhutia, Kayilibat, Jhogodi, Kasara kantha, Samata, Khoda, Akashmali, Sitachori, Jangalijota, Mugudhi, Nalibansagaja, Kalakhuda and Nambari are resistant for two years; Salkathi, and PTB-33 were moderately resistance for three years; Brahmanabhojni, Agnisal, Rotu, Kandha, Jayaphul, Sunakhadika, Chitoukar, Kurgaon, Raghukunwar, Kalikata, Kurgaon, Rotu, Ratna, CR-801, Tara, Chandan, and CR1014 were moderately resistant for two years (Source: NRRI Annual Reports, 2000 – 2023).

Table 26. List of resistant donors against Yellow Stem borer

Name of Germplasm/ Variety	Year of testing	Frequency of testing (Number)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
Kshira	2001, 2002 2004	3	1	R	ICAR-NRRI Annual Report, 2001-02, 2002-03, 2004-05
Kusuma	2000, 2001 2002	3	1	R	ICAR-NRRI Annual Report 2000-01, 2001-02, 2002-03
Achinha	2001-2002	2	1	R	ICAR-NRRI Annual Report, 2001-02
Champeisalli	2001-2002	2	1	R	ICAR-NRRI Annual Report, 2001-02, 2002-03
Mahalaxmi	2001-2002	2	1	R	ICAR-NRRI Annual Report, 2002-03
Raghuchinamali	2001-2002	2	1	R	ICAR-NRRI Annual Report, 2001-02
Bahalmali	2001-2002	2	1	R	ICAR-NRRI Annual Report, 2002-03

Name of Germplasm/ Variety	Year of testing	Frequency of testing (Number)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
Kalamuli	2001-2002	2	1	R	ICAR-NRRI Annual Report, 2001-02, 2002-03
Kanelaka	2001-2002	2	1	R	ICAR-NRRI Annual Report, 2002-03
Brahmanabhojni	2001-2002	2	1	R	ICAR-NRRI Annual Report, 2002-03
Dahijhil	2001-2002	2	1	R	ICAR-NRRI Annual Report, 2002-03
Kankada	2001-2002	2	1	R	ICAR-NRRI Annual Report, 2002-03
Nalihazara	2000, 2003	2	1	R	ICAR-NRRI Annual Report, 2002-03
Senka	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2000-01, 2004-05
Gelleigutti (34968)	2000, 2004 2005	3	1	R	ICAR-NRRI Annual Report, 2004-2005
Bhramanbhojni (34973)	2004 -2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Chadheinakhi (34975)	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Daonara (34983)	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Padmatali (35005)	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Maladhan (35042)	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Malkanhei (35075)	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Kantamugdhi (35081)	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Kusampura (35085)	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Munubhadraj (35096)	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Angulia (35100)	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Tulasikanthi (35226)	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Mirigasiali	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Saruchinamali	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Mayurkantha	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Mani	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005

Name of Germplasm/ Variety	Year of testing	Frequency of testing (Number)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
Kalamkathi	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Bhaduasali	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Dhusarakali	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Kartika	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Kuliha	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Kenragali	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Jaigudi	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Laghubhutia	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Kayilibat	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Jhogodi	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Kasara kantha	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Samata	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Khoda	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Akashmali	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Sitachori	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Jangalijota	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Mugudhi	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Nalibansagaja	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Kalakhuda	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Nambari	2004-2005	2	1	R	ICAR-NRRI Annual Report, 2004-2005
Saket 4	2001, 2021	2	3	MR	ICAR-NRRI Annual Report, 2004-2005
Ratna	2001, 2002 2021	3	3	MR	ICAR-NRRI Annual Report, 2001-2002, 2021
TKM 6	2005, 2021 2022	3	1	R	ICAR-NRRI Annual Report, 2001-2002, 2021

Name of Germplasm/ Variety	Year of testing	Frequency of testing (Number)	Values (score) in multiple testing	Remarks (Tolerant/ MR/R/ etc)	Reference
Dhalaheera	2001	1	3	MR	ICAR-NRRI Annual Report, 2005-06,2021,2022
Satabdi	2020	1	3	MR	ICAR-NRRI Annual Report, 2022
Jitendra	2021	1	3	MR	ICAR-NRRI Annual Report, 2022
Kalinga- 3	2001	1	3	MR	ICAR-NRRI Annual Report, 2001-02
Salkathi	2020, 2021 2022	3	3	MR	ICAR-NRRI Annual Report, 2021; ICAR-NRRI Annual Report 2022
PTB-33	2020, 2021 2022	3	3	MR	ICAR-NRRI Annual Report, 2021; ICAR-NRRI Annual Report 2022
Ratna	2001-2002	2	3	MR	ICAR-NRRI Annual Report, 2021; ICAR-NRRI Annual Report 2022
CR-801	2021-2022	2	3	MR	NRRI Annual Report, 2022
Tara	2021-2022	2	3	MR	NRRI Annual Report,2001-2002
Chandan	2021-2022	2	3	MR	NRRI Annual Report, 2001-02

(References: NRRI Annual Report 2000-2023)

Root-knot Nematode (*Meloidogyne graminicola*)

Root knot nematodes are destructive plant-parasitic nematodes that can infest a wide range of crops, including rice. RRKN (*Meloidogyne graminicola*) primarily attack the roots of rice plants. They enter the root system and establish feeding sites, causing characteristic swellings or galls to form on the roots. This feeding activity disrupts the normal functioning of the root system, impairs water and nutrient uptake, and weakens the plants. Due to inadequately filled kernels in upland rice, crop loss has been estimated to be between 17 and 30 percent in India incurred by *M. graminicola* (Jain *et al*., 2012). Overall, *M. graminicola* has a well-established negative impact on rice yield, resulting in yield losses of up to 20 to 90 per cent (Phani *et al*., 2021). Host Plant Resistance is important for management options against nematodes as chemicals are being phased out due to deleterious environmental effect and more than one resistant genes in a single variety can divert the energy sink towards productivity of rice. So resistant varieties are vital source for breeding programs as well as for minimizing the risk of yield loss due to RRKN attack.

Methodology followed

The rice germplasm was screened for *M. graminicola* resistance with pot screening method (All IndiaCoordinated Rice Improvement Project). The rice germplasm lines (*Oryza sativa*) were grownin earthen pots of 20 cm diameter with autoclaved soil. Three to four seeds were sown per pot and thinningwas done after germination to maintain only one healthyplant per pot. Fifteen days after sowing, each pot with single plantwas inoculated with approximately 100 second stageinfective juveniles. The Economic threshold level was maintained at $1J_2$/gm of soil. Three replicates were maintained for each germplasm lines and the extent of gall formation was estimated at 45th day after nematode inoculation, based on the scale given by All India Coordinated Rice Improvement Project.

Table 27. Screening score for RRKN resistance

Rating	Galling percentage	Scale
1.	No galling	Highly resistant (HR)
2.	1-10% galling	Resistant (R)
3.	11-30% galling	Tolerant (T)
4.	31-50% galling	Susceptible (S)
5.	50 % or more	Highly susceptible (HS)
Scale provided by All IndiaCoordinated Rice Improvement Project		

GI = [score of test cultivar/ score of check] x 5.

Root-knot Nematode screening

In the preliminary screening, 1731 germplasms of *O. sativa* have been screened against *M. graminicola*. These include released varieties, landraces, breeding lines and several germplasm collections. Among all, 49 germplasms recorded toleranceto *M. graminicola*, while, 725 and957 germplasms (Berlinar et al, 2022 & NRRI Database (https://icar-nrri.in/m-graminicola-nematodes-database/) were reported to fall under susceptible and highly susceptible categories.

Table 28. List of resistant donors against Root-knot nematode

Genotype	AC/IC No.	Year	Frequency	Screening Score	Reaction	Gall Percentage	Reference
ADT 14	40184	2013	2	3	T	11-30%	NRRI Database
ADT 37 (BG 367-4)	40853	2014	2	3	T	11-30%	NRRI Database
ARC 5158	40341	2012	2	3	T	11-30%	NRRI Database
AU-7/21-2	40766	2013	2	3	T	11-30%	NRRI Database
Basumati 370		2009	2	3	T	11-30%	NRRI Database
Bharathy	40218	2014	2	3	T	11-30%	NRRI Database
BJ 1	40130	2012	2	3	T	11-30%	NRRI Database
Carreon	40187	2013	2	3	T	11-30%	NRRI Database
EC 203650	40768	2014	2	3	T	11-30%	NRRI Database
GR 11	40820	2012	2	3	T	11-30%	NRRI Database
IET 4786	40079	2013	2	3	T	11-30%	NRRI Database
IR 38	40462	2014	2	3	T	11-30%	NRRI Database
Jhona 20	40345	2012	2	3	T	11-30%	NRRI Database
Kalinga 1	40977	2013	2	3	T	11-30%	NRRI Database
Khanish		2009	2	3	T	11-30%	NRRI Database
Lal dangar	298563	2012	2	3	T	11-30%	NRRI Database
Laxman Sali	44579	2013	2	3	T	11-30%	NRRI Database
Manhar	40827	2014	2	3	T	11-30%	NRRI Database
Moianosingga	40735	2012	2	3	T	11-30%	NRRI Database
MTU 15	40247	2013	2	3	T	11-30%	NRRI Database
Mugi		2013	2	3	T	11-30%	NRRI Database
Palghar 1	40836	2014	2	3	T	11-30%	NRRI Database
Patni	40349	2012	2	3	T	11-30%	NRRI Database
PTB 21	40630	2013	2	3	T	11-30%	NRRI Database
Pusa 169	40239	2014	2	3	T	11-30%	NRRI Database
Sathi	40226	2012	2	3	T	11-30%	NRRI Database

Genotype	AC/IC No.	Year	Frequency	Screening Score	Reaction	Gall Percentage	Reference
Sathia		2013	2	3	T	11-30%	NRRI Database
Sebati		2013	2	3	T	11-30%	NRRI Database
ASGVT 3	40246	2014	2	3	T	11-30%	NRRI Database
Solani		2013	2	3	T	11-30%	NRRI Database
SYE 1	40826	2012	2	3	T	11-30%	NRRI Database
TKM 6	40129	2015	2	3	T	11-30%	NRRI Database
TTB 4/7	40245	2014	2	3	T	11-30%	NRRI Database
V 20-B	40835	2015	2	3	T	11-30%	NRRI Database
Zeera	40163	2015	2	3	T	11-30%	NRRI Database
Fukuhikari	41023	2011	2	3	T	11-30%	NRRI Database
Nigeria 5	41078	2011	2	3	T	11-30%	NRRI Database
IR-72	41108	2011	2	3	T	11-30%	NRRI Database
Fukunishiki	41164	2011	2	3	T	11-30%	NRRI Database
	41297	2011	2	3	T	11-30%	NRRI Database
PY-2	41453	2011	2	3	T	11-30%	NRRI Database
ECS-1581	42403	2011	2	3	T	11-30%	NRRI Database
NONA SAL	42462	2011	2	3	T	11-30%	NRRI Database
LPR-56-49	42497	2011	2	3	T	11-30%	NRRI Database
Cempocelac	42540	2011	2	3	T	11-30%	NRRI Database
Basmata	42611	2011	2	3	T	11-30%	NRRI Database
Basmati 12-21	42634	2011	2	3	T	11-30%	NRRI Database
Kali lohiji	43019	2011	2	3	T	11-30%	NRRI Database
Padar bank	43035	2011	2	3	T	11-30%	NRRI Database

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Chapter-13

Germplasm donors for improving disease resistance in rice

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Sheath Blight Disease (*Rhizoctonia solani*)

Sheath blight is one of the most economically significant and destructive diseases of rice causing yield losses of upto 50% under favorable environmental conditions. The initial symptoms usually develop on the leaf sheath or just above the water line as circular, oval or ellipsoid, water-soaked spots which are greenish-grey in colure. As the disease progresses, the spots enlarge and coalesce to form larger lesion and cover entire stem and sheath. Similar symptoms can be observed on leaves also. Formation of sclerotial bodies can be seen at advanced stage of infection.

Methodology followed

In ICAR-NRRI, Cuttack the screening for sheath blight resistance has been done by following artificial inoculation with highly virulent strain. The Fully grown pathogen mycelia along with sclerotia are placed inside the leaf sheath at maximum tillering stage followed by tying the tillers with thread. Disease assessment was made by following 0-9 SES scale based on relative lesion height on the whole plant (IRRI, 2013). The plants were regularly observed for appearance of the symptoms from 12h after inoculation and data on disease severity was recorded at 7, 14 and 21 days after inoculation. The data on disease incidence was converted to 0-9 scale where, 0= free from infection (Immune); 1=lesion limited to lower 20% of the plant height (Resistant); 3= 20-30% (Moderately Resistant); 5=31-45% (Moderately Susceptible); 7= 46-65% (Susceptible); 9= more than 65% (Highly Susceptible).

False Smut Disease (*Ustiloginoidea virens*)

False smut disease is a serious emerging problem in all the rice growing regions. The disease can cause more than 50% yield loss (Baite et al. 2020). The disease can produce chaffy grain (24.6–87.5%) with simultaneous reduction in filled grains (3.4–71.8%) which eventually decreased 1000-grain weight by 1.2–10.8%. Seedlings vigor was negatively affected when emerged from infected panicle (Bag et al. 2016). The symptoms of the disease visible only after panicle excertion. It can infect the plant during flowering stage. Plants infected with false smut pathogen have individual rice grain transformed into a mass of spore balls. These spore balls are initially yellow orange, and then turn into greenish black when these mature. In most cases, only few grains in a panicle are usually infected and the rest are normal.

Methodology

In ICAR-NRRI, Cuttack the screening for False smut resistance has been done by following artificial inoculation with highly virulent strain. Scoring for false smut was done at maturity stage by using following scale Zhang et al (1992). Rating scale of false smut of rice based on number of infected grains (Smut balls). Where, 0: Immune/No disease (Highly Resistant); 1: 1smut ball (Resistant); 3: 2 smut balls (Moderately Resistant); 5: 3-6 smut balls (Moderately Susceptible); 7: 7-10 smut balls (Susceptible); 9: > 10 smut balls (Highly Susceptible).

Bakanae (*Fusarium fujikuroi*)

Bakanae disease, also called foot rot or foolish seedling, has emerged as a major problem for rice production in several regions of the world. In India, this disease is a major problem in basmati-growing areas of north-western India (Bashyal et al., 2014). The research has shown that the pathogen can cause losses ranging from a sporadic incidence to as much as a 70% yield loss in the field (Sun and Snyder, 1981; Webster and Gunnell, 1992; Fiyaz et al., 2014; Raghu et al., 2018). On infected plants, symptoms such as abnormal seedling elongation, lanky and pale green plants, larger inter-nodal length, roots produced from each node, growth of fungal mass on each node and production of chaffy or sterile panicles develop based on the amount of inoculum and environmental conditions

Methodology

In ICAR-NRRI, Cuttack the screening for bakanae resistance has been done by following artificial inoculation with highly virulent strain. Inoculation of pre-soaked seeds with spore suspension (1.0 × 106 conidia/ml) of highly virulent strain for 24 h. The disease incidence was recorded starting 12 days after sowing, when 100% germination was observed in control treatments. The data on germination percentage, number of dead seedlings, elongation percentage and normal plants were taken. The disease incidence (including elongated and dead seedlings) was recorded and scored using the 0–9 scale proposed by Fiyaz et al. (2014). 0: Disease incidence of 0-10% (Highly Resistant); 1: Disease incidence between 11-20% (Resistant); 3: Disease incidence between 21-40% (Moderately Resistant); 5: Disease incidence between 41-60% (Moderately Suceptible); 7: Disease incidence between 61-80% (Suceptible); More than 80% Disease incidence (Highly Suceptible).

Sheath rot disease (*Sarocladium oryzae*)

Rice sheath rot disease is one of the most devastating diseases of rice due to its ability to reduce the yield significantly in all rice cultivating areas. Sheath rot disease can cause yield losses ranging from 10% to 85%, depending on the weather conditions during the crop growth phase (Bigirimana et al., 2015; Panda and Mishra 2019; Sawant et al., 2023). The symptoms showed oblong or somewhat irregular spots, 0.5-1.5 cm long, with brown margins and grey centers that became enlarge and cause rotting of the uppermost sheath enclosing the young panicle. The white to pinkish powdery growth observed inside the infected sheath leading to chaffy and discolored grains.

Methodology

In ICAR-NRRI, Cuttack the screening for sheath rot resistance has been done by following artificial inoculation with highly virulent strain. The chaffy grains fully covered with pathogen was placed in between boot leaf sheath and panicle in each tiller and covered with moist cotton (Saravanakumar *et al*., 2008). Observations were recorded at mature flag leaf sheath by using 0-9 rating scale given by Standard Estimation System (SES), IRRI (2013). The sheath rot disease was assayed using percent disease index (PDI). Whereas disease grade was given with the following descriptions: 0 = no incidence; 1 = less than 1%; 3 = 1 to 5%; 5 = 6 to 25%; 7 = 26 to 50%; 9 = 51 to 100%. Varietal reactions are recorded as described by Sharma et al., (2013); 0 % PDI – Immune; 1 to 10% PDI - Resistant; 1 to 25% PDI - Moderately resistant; 26 to 50% PDI - Moderately susceptible; 51 to 75% PDI – Susceptible; 75 to 100% PDI - Highly susceptible.

Blast disease (*Magnaporthe oryzae*)

Blast is one of the most destructive diseases of rice and causes substantial yield losses to rice growers (Ou 1985). It is estimated that rice blast disease alone causes a reduction in rice yield ranged from 10-30% annually (Skamnioti and Gurr 2009). The disease is mainly noticeable when the pathogen attacks the leaf collar, nodes, leaf blades, neck, and panicles. Leaf blast is the most common type of blast observed and characterized by elliptical or spindle shaped lesions. The lesions or spots first appear as minute brown specks, and eventually grows to become spindle shaped. The centre is greyish with a brown margin. The lesions may expand and ultimately coalesce, thus killing the entire leaf.

Methodology

In ICAR-NRRI, Cuttack the screening for leaf blast resistance has been done by following artificial inoculation with highly virulent strain under Uniform Blast Nursery (UBN). In order to facilitate uniform disease spread, susceptible check plants (CO39 and HR-12) were interspersed among the rows, after every five entries and along the borders and after every ten test entries one row of resistant check variety Tetep was also sown. To ensure the disease spread at high rate, about 30-40 ml of the spore suspension of the virulent isolate (RLB 06) of the blast pathogen (approximately 10^{5} spores/ml mixed with Tween-20 @ 0.2 %) was sprayed on 15-day old seedlings using a glass atomizer. The scoring for blast disease reaction was performed at regular intervals of every five days until either the 40^{th} day of sowing or when the susceptible checks had 85% of the disease symptoms, whichever occurred earlier. The severity of disease reaction was scored visually on a 0 to 9 scale, following the Standard Evaluation System (SES) established in International Rice Research Institute (IRRI), Philippines, 2013 (IRRI,2013). Test entries with scores ranging from 0 to 3 were considered highly resistant, 4 to 5 as moderately resistant, and 6 to 9 as susceptible (Yadav et al., 2017).

Bacterial Blight (*Xanthomonas oryzae pv oryzae*)

Disease appear as water-soaked to yellowish stripes on leaf blades or starting at leaf tips with a wavy margin. Leaves with undulated yellowish white or golden yellow marginal necrosis, drying of leaves back from tip and curling, leaving mid rib intact are the major symptoms. If noticed carefully then appearance of bacterial ooze

that looks like a milky or opaque dewdrop on young lesions early in the morning. Severely infected leaves tend to dry quickly. The disease may cause a loss in grain yield may be up to 60%.

Methodology

The virulent culture of *Xanthomonas oryzae* pv *oryzae* bacteria were inoculated at active tillering stage of rice by cutting the rice leaves' tips using sterile scissors dipped in *Xoo* suspension (population 10^7 CFU/mL) for ±10 seconds. Disease symptoms are recorded daily until 14 days after inoculation (Kauffman et.al. 1973). Scoring can be done by SES score (IRRI SES, 2002). Where. 0: immune, 1: Resistant, 3: Moderately resistant, 5: moderately susceptible, and 7-9 is susceptible.

Table 29. Selected genotypes with disease resistance

Trait	Name of Germplasm / variety	IC/AC number/ NBPGR /PPVFRA Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
Sheath Blight	CR 1014	NRRI Released variety	2014-2023	10 Years	3		NA	Bal, et al 2020	MR
	Oryza rufipogon	AC100444	2017-2022	7 Years	3		NA	Lenka et al. 2017	MR
	Hanseswari	NRRI Released variety	2017-2022	7 Years	3		NA	NRRI Annual Report, 2018	MR
	Chandan	NRRI Released variety	2017-2022	7 Years	3		NA	NRRI Annual Report, 2018	MR
	Naveen	NRRI Released variety	2017-2022	7 Years	3		NA	NRRI Annual Report, 2018	MR
	Sahbhagidhan	NRRI Released variety	2017-2022	7 Years	3		NA	NRRI Annual Report, 2018	MR
	Chandrama	NRRI Released variety	2017-2022	7 Years	3		NA	NRRI Annual Report, 2018	MR
	CR Dhan 602	NRRI Released variety	2017-2022	7 Years	3		NA	NRRI Annual Report, 2020	MR
	Tetep		2017-2022	7 Years	3		NA	NRRI Annual Report, 2018	MR
	Jasmine 85		2017-2022	7 Years	3		NA	NRRI Annual Report, 2018	MR
	Durga	NRRI Released variety	2017-2022	7 Years	3		NA	NRRI Annual Report, 2018	MR
	Biradia Bankoi	REG/2011/515	2017-	7 Years	3		NA	NRRI Annual	MR

Trait	Name of Germplasm / variety	IC/AC number/ NBPGR /PPVFRA Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
			2022					Report 2018-19	
	Champei Siali-D	REG/2011/890	2017-2022	7 Years	3		NA	NRRI Annual Report, 2018-19	MR
	Dubraj-S	REG/2011/905	2017-2022	7 Years	3	3	NA	NRRI Annual Report, 2018-19	MR
	Ganjamgedi	REG/2011/1107	2017-2022	7 Years	3	3	NA	Lenka et al. 2017	MR
	Kalaketiki	REG/2011/1026	2017-2022	7 Years	3	3	NA	Lenka et al. 2017	MR
	Rajamani-K	REG/2011/850	2017-2022	7 Years	3	3	NA	Lenka et al. 2017	MR
	Kendrapara-Haladigundi	REG/2011/1090	2017-2022	7 Years	3	3	NA	NRRI Annual Report, 2018-19	MR
	Kandhamal-Jhalaka	REG/2011/1050	2017-2022	7 Years	3	3	NA	Lenka et al. 2017	MR
	Kanak Champa	REG/2011/932	2017-2022	7 Years	3	3	NA	Lenka et al. 2017	MR
	K-Balisara-Lakti Marchi	REG/2011/743	2017-2022	7 Years	3	3	NA	Lenka et al. 2017	MR
	Lakshmi vilash	REG/2011/635	2017-2022	7 Years	3	3	NA	Lenka et al. 2017	MR
	Balangir-Baidipali-Mahipal	REG/2011/1180	2017-2022	7 Years	3	3	NA	Lenka et al. 2017	MR
	Balangir-Jhilli	REG/2011/1173	2017-2022	7 Years	3	3	NA	NRRI Annual Report, 2019	MR
	Gangabhalu	REG/2011/394	2017-2022	7 Years	3	3	NA	Authors own data	MR
	Tulasimali	REG/2011/632	2017-2022	7 Years	3	3	NA	Authors own data	MR
	Koraput-Dasamantapur-Assam Chudi	REG/2011/962	2017-2022	7 Years	3	3	NA	Authors own data	MR
	Koraput-Kundra-Haldi Chudi	REG/2011/959	2017-2022	7 Years	3	3	NA	Authors own data	MR
	Latamahu	REG/2011/410	2017-2022	7 Years	3	3	NA	Authors own data	MR
	Boudh-Jholi Puagi		2017-2022	7 Years	3	3	NA	Authors own data	MR

Trait	Name of Germplasm / variety	IC/AC number/ NBPGR /PPVFRA Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
	Ngrh-Baigana Manji	REG/2011/1106	2017-2022	7 Years	3	3	NA	Authors own data	MR
	Chintamali-K	REG/2011/873	2017-2022	7 Years	3	3	NA	Authors own data	MR
	CRHR-DH-6	Double Haploid Line	2017-2022	7 Years	3	3	NA	Authors own data	MR
	CRHR-DH-8	Double Haploid Line	2017-2022	7 Years	3	3	NA	Authors own data	MR
	CRHR-DH-14	Double Haploid Line	2017-2022	7 Years	3	3	NA	Authors own data	MR
	CRHR-DH-21	Double Haploid Line	2017-2022	7 Years	3	3	NA	Authors own data	MR
False smut	Ketakijoa	NRRI Released variety	2015-2018	5 Years	3	3	0.12	Bag et al., 2021	MR
	Nua Chnikamini	NRRI Released variety	2015-2018	5 Years	3	3	0.65		MR
	Ranjit	NRRI Released variety	2015-2018	7 Years	0	3	0.02		HR
	Moudamani	NRRI Released variety	2015-2021	11 years	9	3	0.80		HS
	Tapaswini	NRRI Released variety	2015-2021	11 years	7	3	0.40		S
	Nua Dhusara	NRRI Released variety	2016-2018	3 years	1	3	-	NRRI Annual Report 2016-17	
	CR Dhan 303	NRRI Released variety	2016-17	2 years	2	3	-	NRRI Annual Report 2016-17	MR
	CR Dhan 907	NRRI Released variety	2016-18	2 years	2	3	-	NRRI Annual Report 2016-17	MR
	Nua kalajira	NRRI Released variety	2016-2018	3 years	1	3	-	NRRI Annual Report 2016-17	MR
	ARC 5786	Landrace	2017-2022	6 years	1	3	-	NRRI Annual Report 2022	R
	ARC 5982	Landrace	2017-2022	6 years	1	3	-	NRRI Annual Report 2022	R
	ARC 6006	Landrace	2017-2022	6 years	1	3	-	NRRI Annual Report 2022	R

Trait	Name of Germplasm / variety	IC/AC number/ NBPGR /PPVFRA Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
	ARC 6596	Landrace	2017-2022	6 years	1	3	-	NRRI Annual Report 2022	R
	ARC6606	Landrace	2017-2023	7 years	1	1	-	NRRI Annual Report 2022	R
	ARC 6609	Landrace	2017-2023	7 years			-	NRRI Annual Report 2022	R
	ARC 5940	Landrace	2017-2022	6 years	1	1	-	NRRI Annual Report 2018-19	R
	ARC 6023	Landrace	2017-2021	6 years	1	1	-	NRRI Annual Report 2018-19	R
	ARC 6040	Landrace	2017-2021	6 years	1	1	-	NRRI Annual Report 2018-19	R
	ARC 6060	Landrace	2017-2019	6 years	1	1	-	NRRI Annual Report 2018-19	R
	ARC 6102	Landrace	2017-2022	6 years	4	4	-	NRRI Annual Report 2018-19	MS
	ARC 6117	Landrace	2017-2022	6 years	1	1	-	NRRI Annual Report 2018-19	R
	ARC 6147	Landrace	2017-2022	6 years	1	1	-	NRRI Annual Report 2018-19	R
	ARC 6183	Landrace	2017-2022	6 years	1	1	-	NRRI Annual Report 2018-19	R
Bakanae	Improved Tapaswini	NRRI Released variety	2017-2022	7 Years	0	0	-	Raghu S et al. 2023	HR
	Luna Sanki	NRRI Released variety	2017-2022	7 Years	0	0	-		R
	Nua Kalajeera	NRRI Released variety	2017-2022	7 Years	1	1	-		R
	Chandan	NRRI Released variety	2017-2022	7 Years	3	3	-		MR

Trait	Name of Germplasm / variety	IC/AC number/ NBPGR /PPVFRA Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
Sheath Rot	*Oryza sativa* (Manipur landraces)	AC 9002	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9004	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9038	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9044	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9052	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9058	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9064	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9067	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9070	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9074	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9076	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9086	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9102	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9118	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9119	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
		AC 9136	2021-2022	2 years	3	3	-	NRRI Annual report 2023	R
Leaf Blast	Chandrama	NRRI released variety	2016-2021	6 years	3	3	-	Yadav et al. 2017	R

Trait	Name of Germplasm / variety	IC/AC number/ NBPGR /PPVFRA Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
	Samalei	NRRI released variety	2016-2021	5 years	3	3	-	Yadav et al. 2017	R
	Savitri	NRRI released variety	2016-2021	5 years	3	3	-	Yadav et al. 2017	R
	Panidhan	NRRI released variety	2016-2021	5 years	3	3	-	Yadav et al. 2017	R
	Sumit	NRRI released variety	2016-2021	4 years	3	3	-	Yadav et al. 2017	R
	Sarasa	NRRI released variety	2016-2021	4 years	3	3	-	Yadav et al. 2017	R
Neck blast & leaf blast	Satya Krishna	NRRI released variety	2016-2021	2 years	3	3	-	Yadav et al. 2017	R
Bacterial Blight	RP-BIO-226	AICRIP	2014- 23	10 years	3	3	-	Authors own data	R
	IC-280557	AICRIP	2016 -22	7 Years	3	3	-	Authors own data	R
	IC-366456	AICRIP	2016 -22	7 Years	3	3	-	Authors own data	R
	IC-283257	AICRIP	2016 -22	7 Years	3	3	-	Authors own data	R
	Reeta	NRRI released variety	2017 -23	6 Years	3	3	-	Authors own data	R
	Kalashree	NRRI released variety	2017 -23	6 Years	3	3	-	Authors own data	R
	Chakaakhi	NRRI released variety	2017 -23	6 Years	3	3	-	Authors own data	R
	Radhi	NRRI released variety	2017 -23	6 Years	3	3	-	Authors own data	R
	Binidhan-II	NRRI released variety	2017 -23	6 Years	3	3	-	Authors own data	R
	Kasalath-15	NRRI released variety	2017 -23	6 Years	3	3	-	Authors own data	R
	MPI-37	AICRIP	2019-23	5Years	3	3	-	Authors own data	R
	SB-23	AICRIP	2019-23	5Years	3	3	-	Authors own data	R
	AC-36259	AICRIP	2014-19	6 Years	3	3	-	Authors own data	R
	AC-36332	AICRIP	2014-19	6 Years	3	3	-	Authors own data	R
	Poornabhog	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Pyari	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	NuaKalajeera	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R

Trait	Name of Germplasm / variety	IC/AC number/ NBPGR /PPVFRA Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
	Saket-4	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	IR-8	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	CRDhan601	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	CR Dhan 505	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Gayatri	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	IR64-MAS	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Khitish	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Kalyani-2	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Kalyani-3	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Luna Barial	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Moti	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Naveen	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Nua	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Chinikamini	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Neela	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	NuaDhusura	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Varshadhan	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	CR Dhan 701	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Tapaswini MAS	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	CR-2983-4	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Jalamani	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	CR Dhan 300	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Satyakrishna	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R

Trait	Name of Germplasm / variety	IC/AC number/ NBPGR /PPVFRA Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
	Panikekoa/ 36308	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Jaya	NRRI released variety	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Murgi Badam	Land race ARC36386	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	ARC5791	Land race	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	ARC5774	Land race	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Rudra Ahu/	Land race ARC5801	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Kasalath(ahu)/	Land race ARC6000	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	BahalMathura/	Land race ARC34976	2016-18	3 Years	3	3	-	Banerjee et al. 2018	R
	Kala Mula/	Land race ARC35700	2016-18	3 Years	5	5	-	Banerjee et al. 2018	MR
	Palasaphula/	Land race ARC37503	2016-18	3 Years	5	5	-	Banerjee et al. 2018	MR
	BordubiSali/	Land race ARC36277	2016-18	3 Years	5	5	-	Banerjee et al. 2018	MR
	BadalSali/	Land race ARC5787	2016-18	3 Years	5	5	-	Banerjee et al. 2018	MR
	Kakhuria/	Land race ARC36435	2016-18	3 Years	5	5	-	Banerjee et al. 2018	MR
	ARC5772	Land race ARC5772	2016-18	3 Years	5	5	-	Banerjee et al. 2018	MR
	Ryllo White/	Land race ARC5823	2016-18	3 Years	5	5	-	Banerjee et al. 2018	MR
	KhasibaBedguri/	Land race ARC5912	2016-18	3 Years	5	5	-	Banerjee et al. 2018	MR
	Balum-II/	Land race ARC5976	2016-18	3 Years	5	5	-	Banerjee et al. 2018	MR
	TingriSali/	Land race ARC5994	2016-18	3 Years	5	5	-	Banerjee et al. 2018	MR
	Bahadur	Land race	2016-18	3 Years	5	5	-	Banerjee et al. 2018	MR
	CR Dhan 500	NRRI released variety	2016-18	3 Years	5	5	-	Banerjee et al. 2018	MR
	Sumeet	NRRI released variety	2016-18	3 Years	3	3	-	Authors own data, Validated	R

Trait	Name of Germplasm / variety	IC/AC number/ NBPGR /PPVFRA Registration no	Year of testing (multiple years)	Frequency of testing (no of times tested)	Values (score) in multiple testing	Mean of values	Standard deviation (SD)	Reference	Remarks (Tolerant/ MR/R/ etc)
	Savitri	NRRI released variety	2016-18	3 Years	3	3	-	Authors own data, Validated	R
	CR Dhan 326	NRRI released variety	2021-2023	3 years	3	3	-	Authors own data, Validated	R
	CR Dhan 412	NRRI released variety	2021-2023	3 years	5	5	-	Authors own data, Validated	MR
	CR Dhan 800	NRRI released variety	2021-2023	3 years	3	3	-	Authors own data, Validated	R
	IC86097	Taken from EAP 312	2022-23	2 Seasons	1	1	-	Deposited in Gene Bank of NRRI on 28th Feb 2024	HR
	IC123871	Taken from EAP 312	2022-23	2 Seasons	1	1	-	Deposited in Gene Bank of NRRI on 28thFeb 2024	HR
	IRGC1662	Taken from EAP 312	2022-23	2 Seasons	1	1	-	Deposited in Gene Bank of NRRI on 28th Feb 2024	HR

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