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Estimation of genetic variability, heritability and genetic advance using early backcross population of rice (*Oryza sativa* L.) at seedling stage stress condition

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Abstract
Rice (*Oryza sativa* L.) stands as one of the most crucial staple crops worldwide providing sustenance for over half of the global population. This study evaluated a total of 155 BC1F3population were screened under sand culture at seedling stage and reproductive stage with tolerant check Dular as positive control and improved lalat as susceptible at Crop Improvement Division, ICAR-National Rice Research Institute-Cuttack, focusing on yield and grain yield related traits under nutrient stress conditions. Significant genetic variability was observed for traits such as SPAD, shoot length and root length. Traits like SPAD and shoot length exhibited high heritability and genetic advance, indicating the effectiveness of direct selection methods. Leaf number showed high heritability with low genetic advance, suggesting the influence of both additive and non-additive gene effects.

Keywords: Rice, *Oryza sativa*, variability, heritability, genetic advance

1. Introduction

Importance of rice as a staple food globally

Rice, scientifically known as *Oryza sativa* L., holds an esteemed position as one of the most indispensable staple crops on a global scale. With its ability to provide nutrition for over half of the world's population, rice serves as a fundamental source of nourishment for billions of individuals (Fanzo *et al*., 2013) [1]. Its high carbohydrate content, coupled with essential vitamins and minerals, makes it a vital component in combating nutrient deficiencies and promoting food security (Khush, 2005) [2]. Thus, the cultivation, trade, and consumption of rice play a pivotal role not only in sustaining livelihoods but also in fostering cultural identity and addressing pressing global challenges such as hunger and malnutrition.

Factors influencing rice yield potential

The potential yield of rice is influenced by various factors, including nutrient availability in the soil. Nutrient stress, particularly deficiencies in essential elements such as nitrogen (N), phosphorus (P), and potassium (K), can significantly limit rice productivity (Dobermann and Fairhurst, 2000) [3]. In regions where soil fertility is compromised or where fertilizer application is limited due to economic constraints, nutrient stress poses a formidable challenge to rice cultivation, jeopardizing food security and livelihoods. Addressing nutrient stress in rice cultivation is paramount for sustaining and enhancing productivity. Improving the nutrient use efficiency of rice plants, optimizing fertilizer management practices, and developing nutrient-efficient rice varieties are essential strategies for mitigating the impact of nutrient stress on yield (Peng *et al*., 2008) [4]. Furthermore, advancing our understanding of the genetic mechanisms underlying nutrient uptake, utilization, and stress tolerance in rice is crucial for the development of resilient crop varieties capable of thriving in low-nutrient environments (Swamy and Sarla, 2012) [5]. By enhancing rice yield and fortifying its resilience against nutrient stress, we can not only ensure food security fora growing global population but also promote sustainable agricultureand mitigate environmental degradation associated with excessive fertilizer use. Furthermore, improving the nutritional quality of rice through biofortification strategies can address malnutrition and contribute to the well-being of millions of people who depend on rice as a dietary staple (Bouis and Saltzman, 2017) [6].

Challenges posed by nutrient deficiencies in rice cultivation
Nutrient deficiencies represent a significant challenge in rice cultivation, impacting both yield and crop quality. Among the most prevalent deficiencies are those of nitrogen (N), phosphorus (P)and potassium (K), which are essential for rice growth and development (Fageria *et al*., 2012) [7]. Nitrogen deficiency, in particular, can lead to reduced tillering, delayed maturity, and decreased grain yield (Dobermann and Cassman, 2002) [8]. Phosphorus deficiency affects root development and nutrient uptake efficiency, resulting in stunted growth and decreased yield potential (Fageria *et al*., 2012) [7]. Similarly, potassium deficiency impairs various physiological processes, including photosynthesis and water regulation, thereby limiting rice productivity (Dobermann and Cassman, 2002) [8]. Addressing nutrient deficiencies requires a holistic approach, encompassing soil testing, balanced fertilization and nutrient management practices tailored to specific agro ecological conditions (Fageria *et al*., 2012) [7].

Advantages and challenges of DSR compared to traditional transplantation methods
Direct Seeded Rice (DSR) has gained attention as a viable alternative to traditional transplantation methods due to its numerous benefits, including significant water conservation, reduced labor requirements, earlier crop maturity, and lower greenhouse gas emissions. Nutrient deficiencies pose significant challenges to rice cultivation, impacting plant growth, development, and ultimately, yield potential. In DSR systems, where seedlings are directly sown into the soil without the pre-soaking typically provided in transplanting, nutrient availability plays a critical role in seedling establishment and early growth stages (Bouman *et al*., 2007) [9]. Nutrient deficiencies, particularly in essential elements such as nitrogen (N), phosphorus (P), and potassium (K), can impair root development, nutrient uptake, and overall plant vigor, leading to stunted growth and reduced yields (Kumar *et al*., 2017) [10].

Advantages of sand hydroponics, including water efficiency and space utilization
Sand hydroponics optimizes water use through precise irrigation management, minimizing wastage compared to traditional soil-based methods (Senthil kumar *et al*., 2019) [11]. The controlled environment of sand hydroponics systems allows for efficient recycling and reuse of water within the system, reducing overall water consumption and promoting sustainable water management practices (Gupta *et al*., 2016) [12]. This water-saving feature is particularly crucial in regions facing water scarcity or where agriculture competes with other sectors for water resources. By eliminating soil-borne pathogens and pests, sand hydroponics also reduces the need for chemical pesticides, promoting environmentally friendly pest management practices (Hussain *et al*., 2019) [13].

2. Materials and Methods
Experimental Materials
The study was initiated with the population BC1F1 of improved Lalat x Dular which was obtained from the Crop Improvement Division, ICAR-National Rice Research Institute-Cuttack.

Methodology
A total of 155 BC_1F_3 population of BC1F3plants of improved Lalat and Dular were subjected to phenotyping in sand culture hydroponics with 50% NP nutrients (stress) at seedling stage in greenhouse following the standard protocol of IRRI with some modifications (AI Azzawi *et al*., 2020) [14], (Yoshida *et al*., 1976) [15]. The screening was carried out using a randomized complete block design coupled with three replications. Seeds were sown in acid washed sand containing half strength (N&P) nutrient solution as well as full strength nutrient solution.

Table 1: Preparation of Rice culture solution (modified Yoshida solution)

Stock	Reagent	g/L	g/10L
1	NH4NO3	91.4	914
2	K2SO4	97.8	978
3(a)	KH2PO4	29.0	290
(b)	K2HPO4	8.0	80
4	CaCl2.6H2O	175	1750
5	MgSO4.7H2O	324	3240
6	**Minor nutrients**		
a	MnCl2.4H2O	1.5	15
b	(NH4)6.Mo7O24.4H2O	0.074	0.74
c	H3BO3	0.93	9.30
d	ZnSO4.7H2O	0.035	0.35
e	CuSO4.5H2O	0.03	0.30

Recording of Observations
Data on Chlorophyll content (SPAD), shoot length (cm), root length (cm), Leaf number, root number, shoot dry weight (g) and root dry weight (g) were taken for five plants after thirty days of sowing.

3. Results and Discussion
Analysis of variance of seedling traits under hydroponics stress condition
The ANOVA summary reveals significant insights into the sources of variation among hydroponics conditions. SPAD- Soil Plant Analysis Development, SL-Shoot length, RL-Root Length, LN-Leaf number, RN-Root number, SDW -Shoot dry weight, RDW-Root dry weight) across genotypes. Replicates showed variation ($p > 0.05$) except for RL-Root Length and LN- Leaf Number, indicating consistent experimental replication. Treatments significantly impact ($p < 0.01$) all conditions except LN- Leaf number and RDW- Root dry weight, indicating varied responses to hydrological regimes. Genotypes contribute significantly ($p < 0.01$) to all conditions, with notable variation in SPAD- Soil Plant Analysis Development and SL- Shoot length. Interaction effects ($p < 0.01$) between treatments and genotypes are evident across all conditions except SDW- Shoot dry weight and RDW- Root dry weight, highlighting genotype-specific responses under varying hydrological conditions. Overall, the data demonstrate moderate to low variability (coefficients of variation, CV%), underscoring the robustness of experimental measurements (Johnson *et al*., 2024) [16], Smith *et al*., 2022) [17].

Table 2: Analysis of variance of seedling traits under hydroponics stress condition

ANOVA Summary								
	DF	**SPAD**	**SL**	**RL**	**LN**	**RN**	**SDW**	**RDW**
Replicates	2	0.993	0.502	0.663	0.320	0.179	0	0
Treatments	1	1804.542**	87.072**	15.770**	0.272	0.009	0.145**	0.009**
Genotypes	156	46.524**	145.584**	8.059**	1.060**	64.301**	0.026**	0.001**
Treatments x Genotypes	156	43.477**	68.197**	7.351**	0.894**	50.094**	0.012**	0.001**
Error B	626	1.622	2.854	0.147	0.097	0.47	0	0
Total	941	17.919	37.433	2.67	0.39	19.277	0.006	0
General Mean	1	20.797	27.016	5.836	5.382	10.194	0.156	0.022
C.V.%	1	6.123	6.253	6.56	5.798	6.721	6.19	9.115

DF-Degrees of freedom, SPAD-Soil Plant Analysis Development, SL-Shoot length, RL-Root Length, LN-Leaf number, RN-Root number, SDW-Shoot dry weight, RDW-Root dry weight

*, **Significance level at 5% and 1% respectively, ns- non significant

Genetic parameters of seedling traits under hydroponics stress condition

Broad-sense heritability (h^2) values indicate the genetic contribution to phenotypic variation, with higher values suggesting stronger genetic influence. Additionally, genetic advance as percentage of mean (GAM) values are shown, representing the average genetic effect on each parameter. Traits like SPAD and shoot length exhibited high heritability and genetic advance, indicating the effectiveness of direct selection methods. Leaf number showed high heritability with low genetic advance, suggesting the influence of both additive and non-additive gene effects.

Table 3: Genetic parameters of seedling traits under hydroponics condition

	SPAD	**SL**	**RL**	**LN**	**RN**	**SDW**	**RDW**
GCV	18.89	20.85	26.16	8.40	36.54	43.51	60.30
PCV	19.80	21.72	26.96	10.07	37.00	44.00	60.88
h^2 (Broad Sense)	91.00	92.10	94.10	69.60	97.50	97.80	98.10
GAM	37.10	41.21	52.27	14.44	74.34	88.62	123.05

SPAD- Soil Plant Analysis Development, SL-Shoot length, RL-Root Length, LN-Leaf number, RN-Root number, SDW-Shoot dry weight, RDW-Root dry weight, HS-Hydroponics stress

GCV-Genotypic coefficient of variation, PCV-Phenotypic coefficient of variation, h2-Heritability, GAM-Genetic Advance as percentage of mean

4. Discussion

The ANOVA summary reveals significant insights into the sources of variation among seedling traits in hydroponics conditions (SPAD-Hydro, SL, RL, LN, RN, SDW and RDW) across genotypes. Replicates show minimal variation ($p > 0.05$) except for RL-Hydro and LN-Hydro, indicating consistent experimental replication.

Genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) highlight variability among genotypes and individuals, respectively. Broad-sense heritability (h^2 values indicate the genetic contribution to phenotypic variation. Genetic advance as percentage of mean (GAM) values represent the average genetic effect on each parameter, providing insights into plant adaptation and resilience in hydroponic environments (Johnson *et al*., 2024; Smith *et al*., 2022; Lee, H. 2019.) [16, 17, 18].

5. Conclusion

In conclusion, the comprehensive analysis of hydrological parameters, agronomic traits, and their genetic underpinnings underscores their intricate interplay in shaping crop productivity and resilience. The study's findings highlight significant variability in both hydrological parameters and agronomic traits across diverse rice genotypes and experimental conditions. This variability underscores the necessity for tailored crop management strategies and precision breeding programs aimed at optimizing yield potential and enhancing resilience to environmental stresses.

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