"Genetic variability analysis for yield and its attributing characters in rice (*Oryza Sativa* L.) under phosphorus availability sufficient and deficient field conditions"

ABSTRACT

Rice (*Oryza sativa* L.) is a staple food of half of the world's population and its production faces challenges in phosphorus-deficient soils. Soil phosphorus availability hinders plant absorption due to low solubility, prompting increased fertilizer use. Hence, there is a need to breed rice cultivars adapted to low phosphorus levels. Therefore, the objectives of the present study are to identify phosphorus deficiency tolerant rice genotypes under both phosphorus-sufficient and deficient conditions. The experiment took place at instructional Farm UBKV, during the Kharif seasonof 2021. Two kinds of fields (high and low phosphorus content) were selected based on their soil phosphorus availability. 100 diverse rice germplasm were collected and planted in an augmented design along with four local checks namely, Swarna sub-1, MTU 1153, MTU 7029 and Uttar Sona. The data were recorded for 14 characters and the data were subjected to various kinds of diversity analysis. The variability analysis revealed that phosphorus uptake showed a high GCV under phosphorus-deficient condition and high PCV under both conditions. Grain yield showed high GCV and PCV under both phosphorus conditions. Heritability was moderate whereas high Genetic advance as per mean was observed under both the conditions for both phosphorus uptake and grain yield. Strong positive correlations were observed between days to flowering and various yield-related traits under both the phosphorus conditions. Positive correlation was observed between phosphorus uptake and grain yield under phosphorus-sufficient conditions, but a weaker correlation under phosphorus-deficient conditions.

Keywords: Augmented design, Correlation, Diversity, Heritability, Phosphorus

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1. INTRODUCTION

The world population is increasing and it is estimated to reach 10 billion by the end of this century [40]. However, the global population has already surpassed 8 billion by mid-November 2022 [50]. It is estimated that we would need 56% more food would needed to feed people by 2050 than in 2010 [31]. Therefore, it is important to increase food production

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to feed the growing population in upcoming years to ensure food security for the next generations.

Rice (*Oryza sativa* L.) is one of the major staple food for more than 50% of the world's population and an essential cereal crop for global food security [36]. Asia produces and consumes almost 90% of the world's rice [8]. India ranked second with more than 135 million metric tons of milled rice production [42]. However, the current production of rice grains is insufficient for a few years to come, and it must be increased at any cost. A variety of biotic and abiotic stresses affect rice production at every stage of the crop, making it difficult to increase production. One such barrier that affects the growth and development of rice is low nutrient availability in the soil [14].

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Among the macronutrients, phosphorus (P) is a crucial nutrient in ensuring world and Indian food security [35]. ~~–~~Phosphorous is an essential component of nucleic acids, enzymes, cell membranes, and biological activities such as photosynthesis, energy production, metabolism of carbohydrates, and ~~signaling~~signalling[1].Its absence from the soil might result in stunted growth, lower productivity, and generally weak plants [32]. The plant roots mostly take up phosphorus from the soil as H_2PO_4 or HPO_4^{2-}. The presence of phosphorus in the soil in the form of orthophosphate or inorganic phosphate inhibits plant absorption due to its low solubility and immobility [26]. Due to this, farmers are compelled to use additional phosphorus fertilizer to minimize the phosphate deficit, which raises the need for more fertilizer imports. Significant concerns arise over the availability of non-renewable rock phosphate sources in the future, which may affect the price and supply of phosphorus ~~P~~ fertilizer [45]. Hence, there is a need to breed rice cultivars adapted to low phosphorus levels. Several nations have effectively screened rice genotypes for low phosphorus tolerance, and phosphorus ~~P~~-efficient genotypes can be utilized as parents in breeding programs [49~~]~~, ~~[~~11]. However, as locally available germplasm differs from the germplasms utilized in those research in terms of variability, the information obtained from studies conducted in other countries cannot be directly applied to local breeding effort [5]. Hence, finding the genetic characteristics that allow rice plants to perform well in low-phosphorus conditions involves screening local rice genotypes and landraces for tolerance to low-phosphorus conditions. With this, ~~background, the purpose~~the aim of this study is to assess the genetic variability of the morpho-phenetic characteristics of ~~100~~ rice genotypes, including landraces and cultivars, in both phosphorus-sufficient and deficient field conditions to improve rice varieties under *Terai-agro* climatic condition.

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2. MATERIAL AND METHODOLOGY

The present study was carried out at the Agricultural Instructional Farm, UBKV, Pundibari, Cooch Behar during the Kharif season of 2021. The experimental material for the present study comprised 100 rice genotypes (Table 1) with fourchecks(C) *viz.,*Swarna Sub-1

(Check-1),), MTU 1153 (Check-2) MTU7029(Check-3), and UttarSona(Check-4) ~~,~~which were collected from the Agricultural Instructional Farm, Uttar BangaKrishi Vishwavidyalaya. Total available phosphorus was estimated in soils obtained from several fields. Two fields were ~~chosen~~ selected based on the availability of phosphorus i.e., one with a low phosphorus content (> 8 kg/ha) and the other with a high phosphorus content (>22 kg/ha). Rice seedlings were planted in both fields in ten blocks containing ten genotypes in which only four checks were replicated on each block, and observations were recorded as appropriate. The data were recorded for 14 traits such as days to 50% flowering, days to 100% flowering, plant height (cm), tillers per plant, flag leaf length (cm), flag leaf width (cm), panicles per plant, panicle length (cm), grains per panicle, spikelets per panicle, test weight (g), dry shoot weight (g/plant), phosphorus uptake (mg/plant) and grain yield (g/plant). Phosphorus concentration was estimated on flag leaf using tri acid digestion - ammonium metavanadate method [41].Variabilityanalysis was performed on both the field data separately. The data were recorded for five plants in each of the genotypes along with the checks and their means were used in statistical analysis using the *Augmented RCBD* package and the Pearson correlation was computed in the *Metan* package in R studio version 4.3.1. ~~The Pearsoncorrelation was computed in the *Metan*packagein R Studio version 4.3.1.~~

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3. RESULTS AND DISCUSSION

Analysis of Variance

The ANOVA ~~for augmented design~~ for both the phosphorous conditions concerning treatment adjusted were given in Table 2.The ANOVA ~~of augmented design~~ for both the phosphorous conditions concerning block adjusted were given in Table 3. The observed significant variance in these characteristics among the rice genotypes under phosphorus-deficient conditions implies that these genotypes may be attributed to various sources of tolerance, such as tolerance without phosphorus uptake genes, as well as recognized sources of tolerance, such as the presence of phosphorus uptake genes.The findings of this study show that, in phosphorus-deficient conditions, among all the 14 characters, there is variation in test weight, dry shoot weight and grain yield among the genotypes. This suggests that some of the genotypes could be used as donors to improve rice cultivars under phosphorus deficient soil. There is no much difference between the phosphorus sufficient and deficient condition. Similarly,[33] found that most of the lines under the phosphorus-deficient condition did not differ from the phosphorus-sufficient condition while selecting rice lines using pedigree selection.

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Table 1. List of 104 rice genotypes under study

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Sl.No	Genotypes	Sl.No.	Genotypes	Sl.No	Genotypes	S.No	Genotypes	Sl.No	Genotypes	Sl.No	Genotypes	Sl.No	Genotypes
1	Naveen	16	Chamaramani	31	Radhatilak	46	BPT 5204	61	NLR 33358	76	TKM 13	91	Uttar Lakshmi
2	Jayamati	17	Dehradun Gandeshwari	32	Radhunipagal	47	Indul Shall	62	NLR 33671	77	Govindabhog	92	MTU 1140
3	ChekaoSempak	18	Dudeswar	33	Tulaipanji	48	RP BIO 226	63	NLR 34242	78	Kalojira	93	MTU 1172
4	Ranjendra Bhagavati	19	Dudeswar-1	34	Zugal	49	MTU 1010	64	NLR 34449	79	Pual Sali	94	MTU 1121
5	Manipur Black Rice	20	Jhara	35	Padmini	50	Puspa	65	NLR 40024	80	Sial Negia Sali	95	MTU 1001
6	Ashnni Boro	21	JP-120	36	Geetanjali	51	Basmati 386	66	NLR 40054	81	Dhan Sali	96	BB I
7	SheetaBhog	22	Kalonunia	37	ketekijoha	52	RNR 19186	67	NLR 40058	82	Paolum Sali	97	BB II
8	Shanti Bhog	23	Kakri	38	CR Sugandh Dhan 907	53	BPT 2295	68	NLR 40065	83	Kala Mala Sali	98	GB 3
9	AC 35014	24	Kamal	39	CR Sugandh Dhan 908	54	NLR 145	69	ADT 43	84	Hari Powar Sali	99	IR 36
10	Lalna Kanada-41	25	KattariBhog	40	CR Sugandh Dhan 909	55	NLR 3041	70	ADR (R) 45	85	Tati Sali	100	Jamuna
11	Bipasha	26	Khara	41	GangavatiAgeti	56	NLR 3083	71	ADT (R)46	86	kanaklata	C1	Swarna Sub-1
12	Balam	27	Khalia Aush	42	Satabdi	57	NLR 3217	72	ASD 16	87	Mashuri	C2	MTU 1153
13	Baram Shall	28	Khalia Eulo	43	Parijat	58	NLR 3354	73	CR 1009	88	Satyaranjan	C3	MTU 7029
14	Baskathi	29	Kerala Sundari	44	Konark	59	NLR 4001	74	CR 1009 Sub-1	89	Ranjit	C4	Uttar Sona
15	Basmati	30	Patnai	45	Saket-4	60	NLR 30491	75	CO 51	90	Banga Bandhu (White)		

Table2. ANOVA for yield attributing characters for phosphorus sufficient and deficient field condition (Treatment adjusted)

Source	Df	Days to 50% flowering		Days to 100% flowering		Plant height (cm)		No. of productive tillers		Flag leaf length (cm)		Flag leaf width (cm)		No. of panicles per plant	
		P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-
Block (ignoring Treatments)	9	568.34**	607.44	645.85	742.92**	4465.34**	4433.13	8.5**	42.31**	5.7*	2.03**	0.34**	0.07**	16.7**	47.2*
Treatment (eliminating Blocks)	103	235.5	259.98**	243.44**	256.12**	1130.42**	1194.77**	13**	35.27	8.48	9.05**	0.24*	0.23	18.23**	20.09**
Treatment: Check	3	1937.7**	2534.17**	1803.62**	1784.17**	775.76	784.04**	11.77**	45.93**	10.67**	16.82	0.16	0.14**	49.7**	4.04*
Treatment: Test and Test vs. Check	100	184.43**	191.75**	196.64**	210.28**	1141.06**	1207.09**	13.04*	34.95**	8.42	8.82*	0.04*	0.03	17.29	20.58**
Residuals	27	0.26	29.69	23.87	0.43	28.85	92.69	15.42	38.95	3.61	7.23	0.02	0.02	28.39	3.34

*Significant at 5% probability level, ** Significant at 1% probability level, P^+ **-** Phosphorus sufficient field condition;P^- **-** Phosphorus deficient field condition

Table 2. (Continued)

Source	Df	Panicle length (cm)		No. of grains per panicle		No. of spikelet per panicle		Test weight (g)		Dry shoot weight (g/plant)		Phosphorus uptake (mg/plant)		Grain yield (g/plant)	
		P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-
Block (ignoring Treatments)	9	3.4	7.44	244.08**	340.34**	270.04**	330.19**	22.2**	21.1*	296.18**	219.63**	1.06*	3.8**	108.66**	264.07**
Treatment (eliminating Blocks)	103	3.13**	7.77	454.78**	930.44**	485.98**	977.99	19.35**	19.6*	123.03**	53.18**	1.41**	1.22*	192.09**	229.23
Treatment: Check	3	1.36*	1.35*	714.28**	972.05**	789.56**	1422.11**	6.42*	9.53*	17.88	59.22*	0.75*	0.79**	236.11**	257.66**
Treatment: Test and Test vs. Check	100	3.18**	7.96**	446.99	929.19**	476.87**	964.67**	19.74**	19.9	126.18**	53.00**	1.43**	1.23*	190.77**	228.37**
Residuals	27	2.99	5.35	468.08	267.86	619.25	380.46	4.46	4.06	105.01	35.07	0.41	1.02	78.78	106.56

*Significant at 5% probability level, ** Significant at 1% probability level, P^+ **-** Phosphorus sufficient field condition;P^- **-** Phosphorus deficient field condition

Table 3. ANOVA for yield attributing characters for phosphorus sufficient and deficient field condition (Block adjusted)

Source	Df	Days to 50% flowering		Days to 100% flowering		Plant height (cm)		No. of productive tillers		Flag leaf length (cm)		Flag leaf width (cm)		No. of panicles per plant	
		P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-
Treatment (ignoring Blocks)	103	285.07**	302.07	297.94**	321.00**	1442.82	1515.83**	12.96**	37.05**	8.56	8.47*	0.05**	0.03	18.16**	23.27**
Treatment: Check	3	1937.7**	2534.17**	1803.62	1784.17**	775.76**	784.04**	11.77**	45.93**	10.67**	16.82	0.36**	0.07*	49.7	4.04*
Treatment: Test vs. Check	99	234.13**	235.5**	241.28**	262.57	1285.1**	1282.02	13.13**	36.92	8.44**	8.26**	0.05**	0.03*	16.79	23.95
Treatment: Test	1	370.29	196.13	1390.02	1716.07**	19058.11**	26858.2**	2.23**	23.14**	14.26	4.22*	0.54**	0.10	59.33*	13.96**
Block (eliminating Treatments)	9	1.01	125.77**	22.12	0.43	890.2	758.79	8.99	21.89	4.76	8.71**	0.04	0.02*	17.45	10.81
Residuals	27	0.26	129.69	23.87	0.43	928.85	892.69	15.42	38.95	3.61	7.23	0.02	0.02	28.39	3.34

*Significant at 5% probability level, ** Significant at 1% probability level, P^+ - Phosphorus sufficient field condition;P^- - Phosphorus deficient field condition

Table 3. (Continued)

Source	Df	Panicle length (cm)		No. of grains per panicle		No. of spikelet per panicle		Test weight (g)		Dry shoot weight (g/plant)		Phosphorus uptake (mg/plant)		Grain yield (g/plant)	
		P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-	P^+	P^-
Treatment (ignoring Blocks)	103	3.00**	7.36**	456.65**	928.12**	494.21**	954.77**	20.77**	20.86**	133.5**	65.07**	1.43**	1.48**	190.38**	234.1**
Treatment: Check	3	1.36*	1.35*	714.28**	972.05**	789.56**	1422.11**	6.42*	9.53*	17.88*	59.22**	0.75*	0.79*	236.11	257.66**
Treatment: Test vs. Check	99	2.62*	7.49**	452.02**	890.9	489.69**	895.5**	13.34**	12.7	136.46**	65.83**	1.41**	1.51**	173.36**	210.07
Treatment: Test	1	45.83**	12.84	142.72*	4481.45**	56.23*	5420.66**	798.79**	863.19**	187.9	7.19*	5.3	0.26**	1738.29**	2542.6**
Block (eliminating Treatments)	9	4.84**	12.09**	222.6	366.89**	175.82	595.91**	5.95	6.59*	176.29**	83.57**	0.78*	0.83*	128.18**	208.3**
Residuals	27	2.99	5.35	468.08	267.86	619.25	380.46	4.46	4.06	105.01	35.07	0.41	1.02	78.78	106.56

*Significant at 5% probability level, ** Significant at 1% probability level, P^+ - Phosphorus sufficient field condition;P^- - Phosphorus deficient field condition

~~Similarly,[33]found that most of the lines under the phosphorus-deficient condition did not differ from the phosphorus-sufficient condition while selecting rice lines using pedigree selection.~~

Mean performance of rice genotypes

When comparing the overall mean value between the both phosphorus condition (Table 4), genotypes grown under phosphorus-deficient condition flowered later of at least two days than genotypes grown under phosphorus-sufficient condition. For ~~[44]~~, some of the genotypes did not even flower under a low phosphorus plot. This is a result of the plants not being phosphorus starved under typical soil phosphorus circumstances and their early acquisition of enough phosphorus due to sufficient soil phosphorus.The overall mean showed a reduction for most of the characters under the phosphorus deficient condition than the phosphorus sufficient condition. Similar to the present study, Swamy *et al*, [44] found a reduction in plant height, number ~~no~~. of productive tillers, flag leaf length, flag leaf width, and panicle length under phosphorus-deficient condition. According to [10], plant height is significantly influenced by phosphorus availability which is due to the high correlation between tissue expansion rate and tissue growth zone phosphorus status [24]. Under low phosphorus condition, a slower rate of tissue development could be due to a shorter region of cell division with lower cell production rates [6]. As a result, the plant and its parts could grow more slowly.According to [17] and [18] biomass and test weight are significant yield components in rice. With this context, in the present study, the rice genotype, Manipur black rice exhibited the highest mean value of 28.90 g and Baram Shall showed the highest dry shoot weight of 46.40 (g/ plant) under phosphorus deficient condition. Both Manipur black rice and Baram Shall are landraces and landraces are characterized by determinant tillering capacity, low yield and less number of tillers with large diameters. According to [22], photosynthetic rates in landraces were greater and corresponded with higher biomass, but they were unable to increase yield since tillering capacity is a determining factor.

The goal of breeding has always been to create cultivars that yield well even in conditions of low soil phosphorus levels [46]. Previous studies by [16], [48], [15] and [44] used the phosphorus content in different plant tissues as an indicator of poor soil phosphorus sensitivity or tolerance. In the present study, it is clearly indicated that there is a overall difference in phosphorus uptake in plant leaf cells among the genotypes under both the condition. Obviously, phosphorus uptake is more under phosphorus sufficient condition than the phosphorus deficient condition. The rice genotype, Pak. Basmati showed highest phosphorus uptake under phosphorus sufficient condition and Rajendra Bhagavathi exhibited high phosphorus uptake under phosphorus deficient condition. Therefore, it is suggested that

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Table 4. Highest and lowest mean performance of 104 rice genotypes.

Characters	Phosphorus sufficient field condition		Phosphorus deficient field condition	
	Highest	**Lowest**	**Highest**	**Lowest**
Days to 50% flowering	CO 51	Ketekijoha	Shanti bhog, CO51	Kala Mala Sali
Days to 100% flowering	CO 51	Ketekijoha	CO 51	CR SugandhDhan 909
Plant height (cm)	CO 51	RP BIO 226	CO 51	RP BIO 226
Tillers per plant	Pok. Basmati	Khalia Aush	BPT 5204	Khalia Aush
Flag leaf length (cm)	ASD 16	Kerala Sundari	BPT 2295	Bipasha
Flag leaf width (cm)	CR Sugandh Dhan 907	Jamuna, Kanaklata	Kamal	NLR 30491
Panicles per plant	CR 1009 sub-1	Khalia Aush	CR 1009 Sub-1	NLR 40054
Panicle length (cm)	MTU 1121	Kanaklata	Shanti Bhog	Kanaklata
Grains per panicle	BPT 5204	NLR 33358	TKM 13	Khalia Aush
Spikelets per panicle	BPT 5204	MTU 1172	Dehradun Gandheshwari	Khalia Aush
Test weight (g)	Manipur black rice	Patnai	Manipur Black RIce	ASD 16
Dry shoot weight (g/plant)	Pok. Basmati	Uttar Lakhsmi	Baram shall	NLR 33358
Phosphorus uptake (mg/plant)	Pok. Basmati	MTU 1121	Rajendra Bhagavati	BB II
Grain yield (g/plant)	MTU 1010	Konark	MTU 1010	Khalia Aush

genotypes such as Rajendra Bhagavathi which exhibited highest phosphorus uptake among all the genotypes can be used to develop new rice varieties with improved phosphorus deficiency tolerance.

Genotypic and phenotypic co-efficient of variation

The degree of variability contained in the available genotypes can be determined using the parameters of the genotypic and phenotypic coefficient of variation (GCV and PCV). Genetic advancement and heritability are useful in assessing how the environment affects a character's expression and how much improvement is achievable following selection [34]. The genetic variability analysis for both the phosphorus conditions are given in Table 5.

Characters like panicles per plant and grain yield showed high GCV and PCV in both phosphorus-sufficient and -deficient circumstances. This suggests that there is a broad range of genetic variability for these characteristics in the germplasm. This also showed that these characteristics have a wide genetic basis, are mostly unaffected by the environment, and are controlled by additive genes. As a result, there is a significant chance that these characteristics will be further enhanced by selection. High GCV and PCV for panicles per plant and grain yield were also reported by ~~[25],[9],[13]and [28]~~. [9,13, 25,28].

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Moderate levels of GCV and PCV were shown by traits like days to flowering, plant height, number of grains per panicle, and test weight. However, there were not many changes in the GCV and PCV. Environmental influences had a smaller impact on the traits under study, hence phenotypic performance-based selection will be reliable. Traits such as productive tillers per plant, dry shoot weight, and phosphorus uptake exhibited moderate GCV under phosphorus-sufficient conditions but high GCV under phosphorus-deficient conditions. This indicates direct selection will be rewarded for these characters under phosphorus deficient condition. Similarly, traits such as tillers per plant, grains per panicle, spikelets per panicle, and dry shoot weight exhibited moderate PCV under phosphorus-sufficient conditions but high PCV under phosphorus-deficient conditions. Similar kind of differences in GCV and PCV between different conditions were also reported by [30] between normal and heat stress conditions in wheat genotypes and by [39] between optimal and deficit irrigation conditions in upland cotton.

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Heritability [Broad sense (h^2_{bs})] and genetic advance as mean

While the selection is based on characteristics that contribute to yield, heritability and genetic advancement are significant selection factors. Genetic advancement combined with heritability estimates usually results in a more precise estimation of the gain under selection than heritability estimates alone. Under both phosphorus conditions, high heritability (broad sense) was noted for characters such as days to flowering, panicles per plant, grains per panicle and. test weight. High heritability values suggest that the environment has less of an impact on the expression of these characters. Therefore, by using direct selection techniques, the plant breeder can confidently base his selection on the phenotypic expression of these features in the specific plant in question. High heritability for days to flowering, panicles per plant, grains per panicle and test weight was also noted by [4],[20],[43] and [3] in rice.

Moderate heritability was exhibited by characters like spikelets per panicle and grain yield. Similar findings also reported by [4],[37] and [2]. Characters exhibiting moderate heritability can be still used for rice improvement. Tillers per plant and flag leaf length showed moderate heritability under phosphorus-sufficient condition but low heritability under phosphorus-deficient conditions. This indicates direct phenotypic selection of based on these characters may mislead the future progress.According to [23], heritability combined with genetic advancement would provide a more accurate estimate of selection value. High genetic advance was observed under both the phosphorus conditions for characters like days to flowering, tillers per plant, grains per panicle, test weight, phosphorus uptake, and grain yield. Among these, days to flowering and phosphorus uptake showed high heritability under phosphorus-sufficient condition and moderate heritability under phosphorus-deficient condition. This indicates, that these two characters have low environmental impact and selection may be rewarded in the further improvement in phosphorus deficiency tolerance in rice. Similarly, Moderate genetic advance was shown by plant height under both conditions. Panicles per plant, number of spikelet per panicle, and dry shoot weight exhibited moderate genetic advance under phosphorus-sufficient conditions but high genetic advance under phosphorus-deficient conditions.

Table 5. Variability analysis for phosphorous sufficient and deficient field condition

Characters	GCV	GCV. category	GCV	GCV. category	PCV	PCV. category	PCV	PCV. category	h^2_{bS}	h^2_{bS} category	h^2_{bS}	h^2_{bS} category	GAM	GAM. category	GAM	GAM. category
	P+		P-		P+		P-		P+		P-		P+		P-	
DFF	14.32	Medium	9.52	Low	14.33	Medium	14.20	Medium	99.89	High	44.93	Medium	29.52	High	13.16	Medium
DHF	13.19	Medium	14.21	Medium	13.89	Medium	14.23	Medium	90.11	High	99.84	High	25.82	High	29.30	High
PH	13.77	Medium	13.95	Medium	26.14	High	25.32	High	27.72	Low	30.37	Medium	14.95	Medium	15.86	Medium
NPT	15.46	Medium	34.76	High	18.39	Medium	36.68	High	36.14	Medium	20.48	Low	22.50	High	46.18	High
FLL	8.53	Low	3.92	Low	11.27	Medium	11.09	Medium	57.24	Medium	12.51	Low	47.66	Medium	2.86	Low
FLW	11.42	Medium	6.20	Low	14.64	Medium	12.00	Medium	60.84	High	26.71	Low	18.38	Medium	6.61	Low
NPP	25.47	High	35.64	High	29.44	High	38.42	High	70.26	High	86.04	High	12.87	Medium	68.20	High
PL	5.28	Medium	6.64	Low	6.98	Low	12.44	Medium	86.34	High	28.48	Low	33.42	High	7.31	Low
NGP	12.48	Medium	19.43	Medium	15.83	Medium	23.24	High	67.92	High	69.93	High	58.94	High	33.52	High
NSP	13.15	Medium	15.25	Medium	13.42	Medium	20.11	High	48.66	Medium	57.51	Medium	12.30	Medium	23.86	High
TW	16.36	Medium	16.71	Medium	20.05	High	20.26	High	66.59	High	67.99	High	27.54	High	28.42	High
DSW	12.41	Medium	23.73	High	25.84	High	34.71	High	23.05	Low	46.72	Medium	12.29	Medium	33.46	High
PU	19.39	Medium	25.12	High	23.07	High	44.18	High	70.68	High	32.32	Medium	33.63	High	29.46	High
GY	29.85	High	34.65	High	40.41	High	49.37	High	54.56	Medium	49.27	Medium	45.48	High	50.18	High

P^+ - Phosphorus sufficient field condition; **P^- -** Phosphorus deficient condition**,** **PV** - Phenotypic variance; **EV -** Environmental variance; **GV-**Genotypic variance; **PCV -** Phenotypic coefficient of variance; **GCV -** Genotypic coefficient of variance; **ECV -** Environmental coefficient of variance; **h^2_{bS}**- Heritability in broad sense; **GA-**Genetic advance; **GAM -** Genetic advance as mean; **,** DFF – Days to 50% of flowering; DHF - Days to 100% of flowering; PH-Plant height (cm); NPT-No. of productive tillers per plant; FLL – Flag leaf length (cm); FLW – Flag leaf width (cm); NPP- No. of panicles per plant; PL-Panicle length (cm); NGP – No. of grains per panicle; NSP- No. of spikelets per panicle; TW- Test weight (g); DSW – Dry shoot weight (g); PU-Phosphorus uptake (mg/plant); GY- grain yield (g/plant) than heritability estimates alone. Under both phosphorus conditions, high heritability (broad sense) was noted for characters such as days to flowering, panicles per plant, grains per panicle and. test weight. High heritability values suggest that the environment has less of an impact on the expression of these characters. Therefore, by using direct selection techniques, the plant breeder can confidently base his selection on the phenotypic expression of these features in the specific plant in question. High heritability for days to flowering, panicles per plant, grains per panicle and test weight was also noted by [4],[20],[43] and [3] in rice.

Moderate heritability was exhibited by characters like spikelets per panicle and grain yield. Similar findings also reported by [4],[37] and [2]. Characters exhibiting moderate heritability can be still used for rice improvement. Tillers per plant and flag leaf length showed moderate heritability under phosphorus-sufficient condition but low heritability under phosphorus-deficient conditions. This indicates direct phenotypic selection of based on these characters may mislead the future progress.According to [23], heritability combined with genetic advancement would provide a more accurate estimate of selection value. High genetic advance was observed under both the phosphorus conditions for characters like days to flowering, tillers per plant, grains per panicle, test weight, phosphorus uptake, and grain yield. Among these, days to flowering and phosphorus uptake showed high heritability under phosphorus-sufficient condition and moderate heritability under phosphorus-deficient condition. This indicates, that these two characters have low environmental impact and selection may be rewarded in the further improvement in phosphorus deficiency tolerance in rice. Similarly, Moderate genetic advance was shown by plant height under both conditions. Panicles per plant, number of spikelet per panicle, and dry shoot weight exhibited moderate genetic advance under phosphorus-sufficient conditions but high genetic advance under phosphorus-deficient conditions.

Phosphorus uptake and grain yield showed high variability and high to moderate heritability under both phosphorus-sufficient and deficient conditions. Genetic advance as a mean was high for phosphorus uptake and grain yield under both conditions, indicating the potential for genetic improvement of these traits through breeding. Therefore, rice cultivars with better performance in low-phosphorus conditions should be developed through breeding efforts aimed at improving phosphorus uptake efficiency and grain yield under phosphorus deficit.

Correlation analysis

The result of Pearson correlation analysis for both phosphorous sufficient and deficient conditions are given in Table 6.Under both phosphorus-sufficient and deficient conditions, a strong positive correlation was exhibited between days to 50% flowering and days to 100% flowering, indicating that genotypes with earlier flowering at 50% also tend to complete flowering earlier. Similarly, under both conditions, there was a strong positive correlation between the tillers per plant and grain yield, suggesting that genotypes with more tillers typically yield more grains. A similar kind of correlation was also observed by [38], [7], [47] and [21]. A novel concept about plant varieties is replacing the traditional belief that high-tillering rice plants give higher yields. To increase yields, tillering optimization is more crucial [27]. However, [29] stated, a higher percentage of heavier grains are produced by genotypes with fewer tillers. According to [12], there will be less yield loss under low-phosphorus conditions in rice cultivars with a large sink size and high tillering capacity.

Under phosphorus-sufficient condition, there was a significant positive correlation between phosphorus uptake and grain yield, indicating that higher phosphorus uptake leads to higher grain yields. However, under phosphorus-deficient conditions, although there was a positive correlation between phosphorus uptake and other characteristics, there was no significant correlation between phosphorus uptake and grain yield. The difference may be due to limiting availability of phosphorus which may diminish its direct impact on grain yield, resulting in weaker correlations. The availability of phosphorus in soil limits the plant [19]. Similarly, under phosphorus-sufficient condition, several characters such as test weight, dry shoot weight, and panicles per plant showed significant positive correlations with grain yield. However, under phosphorus-deficient conditions, these associations were weaker or non-significant.

4. Conclusion

Significant variation was observed between genotypes under both the phosphorus conditions. The rice genotype, Rajendra Bhagavathi, exhibited highest phosphorus uptake under phosphorus deficient condition which implies its potential in developing cultivar with improved phosphorus deficiency tolerance. Emphasize breeding for phosphorus uptake efficiency under phosphorus-deficient conditions to improve phosphorus utilization by plants.Grain yield displays considerable genetic and phenotypic variability irrespective of phosphorus availability. This suggests that focus on enhancing grain yield potential by selecting genotypes with high genetic variability and superior performance under both phosphorus conditions.Moderate heritability and high Consider indirect selection for traits positively correlated with grain yield, such as days to flowering, to improve overall performance under varying phosphorus availability.

Table 6. Pearson's correlation coefficient for both phosphorous sufficient and deficient field condition

Traits	P level	DFF	DHF	PH	NPT	FLL	FLW	NPP	PL	NGP	NSP	TW	DSW	PU	GY
DFF	P^+	1													
	P^-	1													
DHF	P^+	0.980^{**}	1												
	P^-	0.919^{**}	1												
PH	P^+	0.311^{**}	0.280^{**}	1											
	P^-	0.294	0.298	1											
NPT	P^+	0.240	0.262	0.149	1										
	P^-	0.115	0.122	-0.081	1										
FLL	P^+	-0.093	-0.108	0.116	-0.108	1									
	P^-	-0.023	0.086	0.042	0.066	1									
FLW	P^+	0.300	0.349	0.168	0.124	0.066	1								
	P^-	0.228	0.214	0.212^{*}	-0.090	-0.083	1								
NPP	P^+	0.166	0.192	0.094	0.590^{**}	-0.108	0.042	1							
	P^-	0.196	0.250	-0.036	0.579^{**}	-0.017	0.023	1							
PL	P^+	0.173	0.203	0.227	0.050	-0.069	0.212	-0.056	1						
	P^-	0.254	0.174	0.109^{**-}	0.002	0.152	0.065^{**}	-0.125	1						
NGP	P^+	0.034^{**}	0.069^{**}	0.086^{**}	0.067	-0.001	0.111	0.054	0.104	1					
	P^-	0.014	0.040	-0.112	0.191^{*}	0.099	-0.209	0.140^{*}	0.017	1					
NSP	P^+	0.031^{**}	0.070^{**}	0.036^{**}	0.058	-0.001	0.157	0.026	0.075	0.951^{**}	1				
	P^-	-0.022	-0.002	-0.137	0.219^{**}	0.040	-0.211	0.121^{*}	-0.038	0.943^{**}	1				
TW	P^+	-0.031	-0.090	0.018	0.220^{**}	-0.057	-0.250	0.238	-0.264	-0.057	-0.097	1			
	P^-	0.039	-0.045	0.052	0.032	0.112	0.019	-0.028	-0.050	0.023	-0.063	1			
DSW	P^+	0.045	0.066	0.139	0.623^{**}	-0.023	-0.067	0.461	-0.118	0.097	0.063	0.130	1		
	P^-	0.066	0.034	0.214^{*}	-0.102	0.014	0.060^{*}	-0.166	0.121^{*}	-0.027	-0.030	0.111	1		
PU	P^+	0.008	0.014	0.135	0.366^{**}	-0.174	-0.043	0.355	-0.054	-0.101	-0.131	0.042	0.521	1	
	P^-	0.199	0.123	0.127^{*}	-0.008	-0.056	0.047^{*}	-0.103	0.127^{**}	-0.043	-0.009	0.018	0.741^{**}	1	
GY	P^+	0.171	0.175	0.129	0.646^{**}	-0.178	0.044	0.562^{**}	0.020	0.439	0.397	0.561^{**}	0.472^{**}	0.763^{**}	1
	P^-	0.234	0.154	0.365	0.125^{*}	0.213	0.359	0.214^{*}	0.268	0.134^{*}	0.137^{*}	0.147	0.235	0.258	1

P+ **-** Phosphorus sufficient field condition;P- **-** Phosphorus deficient condition**,** DFF – Days to 50% of flowering; DHF - Days to 100% of flowering; PH-Plant height (cm); NPT-No. of productive tillers per plant; FLL – Flag leaf length (cm); FLW – Flag leaf width (cm); NPP- No. of panicle per plant; PL-Panicle length (cm); NGP – No. of grains per panicle; NSP- No. of spikelet per panicle; TW- Test weight (g); DSW – Dry shoot weight (g); PU-Phosphorus uptake (mg/plant); GY- grain yield (g/plant)

8. Disclaimer

The authors have stated that there are no conflicting interests. In our country and research location, the products utilized for this study are widely and often used. Since our goal is to enhance knowledge rather than use these products as a means of litigation, there is zero conflict of interest between the writers and the makers of the items. Additionally, the writers' own funds were used to fund the research rather than the producing corporation.

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