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Genetic Variability Analysis for Yield and Its Attributing Traits in Rice (*Oryza Sativa* L.) under Phosphorus-sufficient and Deficient Field Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: The present study aims to identify phosphorus deficiency tolerant rice genotypes under both phosphorus-sufficient and deficient conditions.

Materials and Methods: Two kinds of fields (high and low phosphorus content) were selected based on their soil phosphorus availability. Hundred diverse rice germplasm was 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 was recorded for 14 traits and subjected to different types of variability analysis.

Place and Season of Study: The experiment took place at instructional Farm of Uttar Banga Krishi Vishwavidyalaya, Cooch Behar, West Bengal, India during the Kharif season of 2021.

Results: The variability analysis revealed that phosphorus uptake showed a high genotypic coefficient of variation (GCV) under phosphorus-deficient condition and high phenotypic coefficient of variation (PCV) under both conditions. Grain yield showed high GCV and PCV under both the phosphorus conditions. Heritability was moderate whereas high Genetic advance as percentage of 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 conditions. Positive correlation was observed between phosphorus uptake and grain yield under phosphorus-sufficient condition, but a weaker correlation under phosphorus-deficient condition.

Keywords: Correlation; heritability; phosphorus; variability; rice.

1. INTRODUCTION

The world population is increasing and it is estimated to reach 10 billion by the end of 21st century [1]. However, the global population has already surpassed 8 billion by mid-November 2022 [2]. It is estimated that 56% more food would be needed to feed people by 2050 than in 2010 [3]. Therefore, it is important to increase food production to feed the growing population in upcoming years to ensure food security for the future 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 [4]. Asia produces and consumes almost 90% of the world's rice [5]. India ranked second with more than 135 million metric tonnes of milled rice production [6]. 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 [7].

Among the macronutrients, phosphorus (P) is a crucial nutrient in ensuring world and Indian food security [8]. Phosphorous is an essential component of nucleic acids, enzymes, cell membranes, and biological activities such as photosynthesis, energy production, metabolism of carbohydrates, and signalling [9]. Its absence from the soil might result in stunted growth, lower productivity, and generally weak plants [10]. The plant roots mostly take up P from the soil as H_2PO_4 or HPO_4^{2-}. The presence of P in the soil in the form of orthophosphate or inorganic phosphate inhibits plant absorption due to its low solubility and immobility [11]. 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 P fertilizer [12]. Hence, there is a need to breed rice cultivars adapted to low P levels. Several nations have effectively screened rice genotypes for low phosphorus tolerance, and P-efficient genotypes can be utilized as parents in breeding programmes [13,14]. However, as locally available germplasm differs from the germplasms utilized in the above said research in terms of variability, the information obtained from studies conducted in other countries cannot be directly applied to local breeding efforts [15]. Hence, finding the genetic traitistics that allow rice plants to perform well in low P conditions involves screening local rice genotypes and landraces for tolerance to low P conditions. With this, the aim of this study is to assess the genetic variability of the morpho-phenetic traitistics of rice genotypes, including landraces and cultivars, in both P sufficient and deficient field conditions to improve rice varieties under *Terai-agro* climatic condition.

2. MATERIALS AND METHODOLOGY

The present study was carried out at the Agricultural Instructional Farm, UBKV, Cooch Behar, West Bengal, India during the Kharif season of 2021. The experimental material for the present study comprised of 100 rice genotypes (Table 1) with four checks (C) including, Swarna Sub-1 (Check-1),), MTU 1153 (Check-2) MTU 7029 (Check-3), and Uttar Sona (Check-4), which were collected from the Agricultural Instructional Farm, Uttar Banga Krishi Vishwavidyalaya. Total available P was estimated in soil samples obtained from several fields. Two fields were selected based on the availability of P ie., one with a low P content (< 8 kg/ha) and the other with a high P content (>22 kg/ha). Twenty-four days old rice seedlings were transplanted in both the fields in an augmented design separately. Seedlings were planted in ten blocks each containing ten genotypes and four checks which were replicated in each block, and observations were recorded accordingly. The data was 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 [16]. Variability analysis such as genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV), heritability and genetic advance 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 *Metan* package in R studio version 4.3.1.

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance

The ANOVA for both the P conditions concerning treatment adjusted are given in Table 2. The ANOVA for both the P conditions concerning block adjusted are given in Table 3. The observed significant variance in these traitistics among the rice genotypes under P-deficient conditions implies that these genotypes may be attributed to various sources of tolerance, such as tolerance without P uptake genes, as well as recognized sources of tolerance, such as the presence of P uptake genes. The findings of this study show that, in P-deficient conditions, among all the 14 traits, 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 P deficient soil. There is no much difference between the P sufficient and deficient condition.

Similarly, [17] found that most of the lines under the P-deficient condition did not differ from the P-sufficient condition while selecting rice lines using pedigree selection.

3.2 Mean Performance of Rice Genotypes

When comparing the overall mean value between the both P condition (Table 4), genotypes grown under P-deficient condition flowered later of at least two days than genotypes grown under P-sufficient condition. For [18], some of the genotypes did not even flower under a low P plot. This is a result of the plants not being P starved under typical soil P circumstances and their early acquisition of enough P due to sufficient soil P. The overall mean showed a reduction for most of the traits under the P deficient condition than the P sufficient condition. Similar to the present study, [18] found a reduction in plant height, no. of productive tillers, flag leaf length, flag leaf width, and panicle length under P-deficient condition. According to Cancellier et al. [19], plant height is significantly influenced by P availability which is due to the high correlation between tissue expansion rate and tissue growth zone P status. Under low P condition, a slower rate of tissue development could be due to a shorter region of cell division with lower cell production rates [20]. As a result, the plant and its parts could grow more slowly. According to Fentie et al. [21] and Getachew and Birhan [22] 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 P-deficient condition. Both Manipur black rice and Baram Shall are landraces and landraces are traitized by determinant tillering capacity, low yield and less number of tillers with large diameters. According to Jahn et al. [23], 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.

Table 1. List of 104 rice genotypes under study

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	Chekao Sempak	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	Sheeta Bhog	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	Kattari Bhog	40	CR Sugandh Dhan 909	55	NLR 3041	70	ADR (R) 45	85	Tati Sali	100	Jamuna
11	Bipasha	26	Khara	41	Gangavati Ageti	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)		

Checks = C1, C2, C3 and C4

Table 2. ANOVA for yield attributing traits 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 traits 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

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

Traits	Phosphorus sufficient field condition				Phosphorus deficient field condition			
	Highest mean	Lowest mean	Coefficient of variation	Standard error	Highest mean	Lowest mean	Coefficient of variation	Standard error
Days to 50% flowering	Ketekijoha (131 days)	CO 51 (78 days)	0.48	1.47	Kala Mala Sali (132 days)	Shanti bhog, CO51 (80 days)	10.6	1.66
Days to 100% flowering	Ketekijoha (138 days)	CO 51 (86 days)	4.44	1.52	CR SugandhDhan 909 (141 days)	CO 51 (87 days)	0.58	1.58
Plant height (cm)	Patnai (186.60 cm)	CO 51 (86.40 cm)	23.31	3.48	Patnai (179.52 cm)	CO 51 (87.2 cm)	22.33	3.48
Tillers per plant	Pak. Basmati (33.40)	Khalia Aush (13.40)	19.94	0.37	BPT 5204 (38)	Khalia Aush (6.6)	18.19	0.61
Flag leaf length (cm)	ASD 16 (36.20 cm)	Kerala Sundari (17.80 cm)	7.42	0.30	BPT 2295 (38.2 cm)	Bipasha (20.7)	10.41	0.32
Flag leaf width (cm)	CR Sugandh Dhan 907 (2.20 cm)	Jamuna, Kanaklata (1.10 cm)	9.37	0.03	Kamal (2.1 cm)	NLR 30491 (0.9)	10.38	0.02
Panicles per plant	CR 1009 sub-1 (29.40)	Khalia Aush (5.60)	17.32	0.46	CR 1009 Sub-1 (28.4)	NLR 40054 (4.4)	14.55	0.50
Panicle length (cm)	MTU 1121 (26.40 cm)	Kanaklata (18.40 cm)	7.56	0.19	Shanti Bhog (28.1 cm)	Kanaklata (14.8 cm)	10.6	0.32
Grains per panicle	BPT 5204 (182.60)	NLR 33358 (81.20)	16.18	2.24	TKM 13 (185)	Khalia Aush (40)	12.44	3.04
Spikelets per panicle	BPT 5204 (213.80)	MTU 1172 (117.40)	15.13	2.30	Dehradun Gandheshwari (207)	Khalia Aush (73)	12.81	3.12
Test weight (g)	Manipur black rice (29.40 g)	Patnai (11.20 g)	10.81	0.37	Manipur Black Rice (28.90 g)	ASD 16 (10.70 g)	10.64	0.38
Dry shoot weight (g/plant)	Pok. Basmati (8.60 g)	Uttar Lakshmi (21.70 g)	22.99	1.16	Baram shall (46.40)	NLR 33358 (9.20 g)	25.47	0.91
Phosphorus uptake (mg/plant)	Pok. Basmati (10.66 mg)	MTU 1121 (3.73 mg)	12.75	0.12	Rajendra Bhagavati (6.08 mg)	BB II (0.56 mg)	16.62	0.12
Grain yield (g/plant)	MTU 1010 (63.50 g)	Konark (12 g)	25.72	1.40	MTU 1010 (55.40g)	Khalia Aush (3.50 g)	12.66	1.61

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

Traits	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)

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)*

The goal of breeding has always been to create cultivars that yield well even in conditions of low soil P levels [24]. Previous studies by Swamy et al. [18,25 and 26] and used the P content in different plant tissues as an indicator of poor soil P sensitivity or tolerance. In the present study, it is clearly indicated that there is a overall difference in P uptake in plant leaf cells among the genotypes under both the conditions. Obviously, P uptake is more under P- sufficient condition than the P-deficient condition. The rice genotype, Pak. Basmati showed highest P-uptake under P-sufficient condition and Rajendra Bhagavathi exhibited high P-uptake under phosphorus deficient condition. Therefore, it is suggested that genotypes such as Rajendra Bhagavathi which exhibited highest P-uptake among all the genotypes can be used to develop new rice varieties with improved P deficiency tolerance.

3.3 Genotypic and Phenotypic Co-Efficient of Variation

The degree of variability contained in the available genotypes can be determined using the genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV). Genetic advancement and heritability are useful in assessing how the environment affects a trait's expression and how much improvement is achievable following selection [27]. The genetic variability analysis for both the P conditions are given in Table 5.

Traits like panicles per plant and grain yield showed high GCV and PCV in both P-sufficient and -deficient circumstances. This suggests that there is a broad range of genetic variability for these traits in the germplasm. This also showed that these traitistics 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 traits will be further enhanced by selection. High GCV and PCV for panicles per plant and grain yield were also reported by Kumar et al. [28, 29, 30 and 31].

Moderate levels of GCV and PCV were shown by traits like days to flowering, plant height, 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 tillers per plant, dry shoot weight, and P-uptake exhibited moderate GCV under P-sufficient conditions but high GCV under P-deficient conditions. This indicates direct selection will be rewarded for these traits under P-deficient condition. Similarly, traits such as tillers per plant, grains per panicle, spikelets per panicle, and dry shoot weight exhibited moderate PCV under P-sufficient conditions but high PCV under P-deficient conditions. Similar kinds of differences in GCV and PCV between different conditions were also reported by Poudel et al. [32] between normal and heat stress conditions in wheat genotypes.

3.4 Heritability [Broad sense (h^2_{bs})] and Genetic Advance as Percentage of Mean

While the selection is based on traits 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 P conditions, high heritability (broad sense) was noted for traits 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 traits. 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 Akinwale et al. [33,34,35,36] in rice.

Moderate heritability was exhibited by traits like spikelets per panicle and grain yield. Similar findings also reported by Akinwale et al. [33,37,38]. Traits exhibiting moderate heritability can be still used for rice improvement. Tillers per plant and flag leaf length showed moderate heritability under P-sufficient condition but low heritability under P-deficient conditions. This indicates direct phenotypic selection of based on these traits may mislead future progress. According to Johnson et al. [39], heritability combined with genetic advancement would provide a more accurate estimate of selection value. High genetic advance was observed under both the P conditions for traits like days to flowering, tillers per plant, grains per panicle, test weight, P-uptake and grain yield. Among these, days to flowering and P-uptake showed high heritability under P-sufficient condition and moderate heritability under P-deficient condition. This indicates, that these two traits have low environmental impact and selection may be rewarded in the further improvement in P deficiency tolerance in rice. Similarly, Moderate genetic advance was shown by plant height under both conditions. Panicles per plant, number of spikelets per panicle, and dry shoot weight exhibited moderate genetic advance under P-sufficient conditions but high genetic advance under P-deficient conditions.

P-uptake and grain yield showed high variability and high to moderate heritability under both P-sufficient and deficient conditions. Genetic advance as a mean was high for P-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-P conditions should be developed through breeding efforts aimed at improving P uptake efficiency and grain yield under P deficit.

3.5 Correlation between the Rice Traits under Both P Conditions

The result of Pearson correlation analysis for both P sufficient and deficient conditions are given in Table 6. Under both P-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 Shahidullah [40,41,42,43]. 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 [44]. However, [45] stated, a higher percentage of heavier grains are produced by genotypes with fewer tillers. According to Deng [46], there will be less yield loss under low-P conditions in rice cultivars with a large sink size and high tillering capacity.

Under P-sufficient condition, there was a significant positive correlation between P uptake and grain yield, indicating that higher phosphorus uptake leads to higher grain yields. However, under P-deficient conditions, although there was a positive correlation between P uptake and other traitistics, there was no significant correlation between P uptake and grain yield. The difference may be due to the limiting availability of P which may diminish its direct impact on grain yield, resulting in weaker correlations. The availability of phosphorus P in soil limits the plant [47]. Similarly, under P-sufficient condition, several traits such as test weight, dry shoot weight, and panicles per plant showed significant positive correlations with grain yield. However, under P-deficient conditions, these associations were weaker or non-significant.

4. CONCLUSION

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

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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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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