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Studies on Root Traits through High Throughput Phenotyping in Rice (*Oryza Sativa* L.)

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Abstract

The present study was undertaken to characterize 15 rice genotypes for 16 quantitative and root characters under transplanted and direct sown conditions. The *per se* performance revealed that genotypes *viz.,* BPT 3050 and BPT 2766 under transplanted conditions and BPT 3114 and BPT 3050 under direct sown conditions exhibited superior grain yield. For root characters, the genotype BPT 2841 recorded high mean values for root growth angle and BPT 2846 exhibited high values for nodal root length under both transplanted and direct sown conditions. BPT 2846 and BPT 3050 recorded high mean values for root volume under transplanted and direct sown conditions, respectively. The traits namely number of nodal roots, nodal root length, root length density and seminal root length exhibited high heritability along with high genetic advance as per cent of mean under direct sown conditions, which show the preponderance of additive gene action. Under both transplanted and direct sown conditions, total root length had positive and significant relationship with root volume and grain yield, indicated the scope for simultaneous improvement. BPT 5204, BPT 3061, BPT 2766 and BPT 3291 are most divergent genotypes according to PCA biplot analysis under transplanted conditions. Under dry direct sown conditions, BPT 3061, BPT 2766, BPT 3082 and BPT 2841 were identified as diverse genotypes for most of the yield components and root traits.

Keywords: Rice, Direct sown, Root volume, Total root length, Root length density.

Introduction

Rice (*Oryza sativa* L.) is a staple food crop for over 3.5 billion people and an economic driver for many countries in South and Southeast Asia. India ranks first in area (44.6 M ha) and production (150.18 mtons) of rice in the world. In pursuit of boosting rice production, while maintaining economic feasibility within resource constraints, the shift from the traditional puddled-transplanted rice system to direct-seeded rice is gaining significance (Chang *et al.*, 1982 and Haefele *et al.,* 2014). Comparative yields in DSR can be obtained by adopting various cultural practices, selection of suitable cultivars, proper sowing time, optimum seed rate, proper weed and water management (Gill *et al.*, 2006). The root system is described as the "hidden half", because it performs a pivotal function in overall crop development as well as in advancement.

Root development and root activities are assumed to have mutual interactions with the shoots. In the last few decades, there has been shoot improvements but neglected the phenotypic variation of root architectural, morphological and anatomical traits. There are five root types in rice root architecture including the embryonic and the post-embryonic roots such as the radicle, the embryonic crown roots, the post-embryonic crown roots, the large lateral roots, and the small lateral roots (Rebouillat *et al.*, 2009). Genetic improvement for a large and deep root system is considered to be an important strategy for improving the water capture and yield stability of rice varieties (Mambani and Lal, 1983; Yoshida and Hasegawa, 1982). As the area under dry direct sowing is being increased every year, the study of root traits in different rice varieties is essential to identify suitable rice varieties for different types of sowing methods.

Materials and Methods

The experimental material consisted of 15 rice genotypes obtained from Agricultural Research Station, Bapatla. During *rabi* 2023, all the 15 genotypes were sown at the Floriculture Block of Agricultural College Farm on nursery beds raised separately. Twenty- five days old seedlings were transplanted with three replications in 5.0 m^2 plots in randomized block design (RBD).

Under dry direct seeded condition, planting was done by dibbling the seed in RBD with three replications of 5.0 m^2 plot size at Northern Block of Agriculture College Farm, Bapatla. Under both the conditions, a spacing of 20 cm and 15 cm was adopted between and within the rows, respectively. In dry direct seeded method, field was kept in moist condition for 3 days after sowing to promote good crop establishment, and then up to maturity stage, field was kept under saturation condition (Bouman *et al.,* 2007 and Shashidhar, 2007). Recommended package of practices were followed for raising the healthy crop. The sampling procedure for root traits was carried out at 60 DAS. Three plant samples per replication per genotype were collected in both the methods and stored at 4^{o}C for one day and analyzed for different root traits by image analysis with the help of digital camera (Canon FOS 70D DSLR Camera). Root images were captured and analyzed for various traits, *viz.,* total root length *i.e.,* sum of the lengths of all the roots in root system, root volume, root length density, root growth angle, number of nodal roots, seminal root length and nodal root length by using Win RHIZO Pro image analysis system (Tajima and Kato, 2013). An 8-bit grayscale image, after removing debris, was acquired by digital camera (Canon FOS 70D DSLR Camera). The root images were saved in TIFF format; 15 rice root images were collected for the analysis. By using the triangle thresholding algorithm as premeasured using ImageJ, the root images were transformed to binary images (Tajima and Kato, 2011). The morphological data on 5 plants/ replication/ genotype was also collected for nine characters *viz.,* days to 50% flowering, plant height, stem width, ear bearing tillers/ plant, total tillers/ m^2, panicle length, number of filled grains/ panicle, test weight and grain yield/plot. The mean data was utilized for the estimation of genetic parameters as per Johnson *et al.*, (1955) and Hanson *et al.,* (1956). The simple correlation coefficient was calculated by following Falconer (1964) while principal component analysis was carried out as described by Banfield (1978).

Results and Discussion

The analysis of variance results revealed significant differences among the genotypes for all the characters studied, indicating the existence of sufficient variation among the genotypes under study. The results of the mean performance of genotypes used in the present study revealed that genotypes *viz.,* BPT 3050, BPT 2846 and DRR Dhan 42 recorded superior grain yield per plot than the check variety BPT 5204 under transplanted conditions (**Table 1**), whereas under dry direct sown conditions, BPT 3114, BPT 2295 and BPT 2766 recorded superior grain yield per plot than the check variety BPT 5204 (**Table 2**). Among the genotypes studied, BPT 2766, Binadhan 16 and DRR Dhan 42 had desirable root traits like root growth angle, nodal root length, total root length, root length density, seminal root length and root volume compared to check variety BPT 5204. When both yield and root traits are considered, BPT 2766, BPT 3114 and BPT 2846 recorded high grain yield and desirable root characteristics under both transplanted and dry direct sown conditions. Under dry direct sown conditions, three genotypes *viz.,* BPT 2846, BPT 2841 and BPT 2295 manifested steep root growth angle suggesting that these genotypes had deeper root system hence, studies may be undertaken to test their tolerance to water stress conditions for their utilization in breeding programmes. DRR Dhan 42, Binadhan 16 and BPT 2858 had longer total root length while Binadhan 16, BPT 2846 and BPT 3291 had high root volume. Hence these genotypes can be recommended for the breeding programmes when aiming for development of above traits. The estimates of phenotypic coefficient of variation for all the characters under study were higher than the estimates of genotypic coefficient of variation. The difference between these two coefficients of variation is less. This close correspondence between two estimates of phenotypic coefficient of variation was also reflected by their high heritability values. Under transplanted condition, minimum phenotypic and genotypic coefficient of variation was observed for days to 50% flowering (9.09 and 8.73%) (**Table 3**) while maximum phenotypic and genotypic coefficient of variation was manifested by root length density (41.78 and 40.62%) indicating the existence of sufficient variation among the genotypes for potential yield improvement through selection. High PCV and GCV were observed for root volume (29.78 and 29.19%), total root length (28.16 and 27.39%) and test weight (24.98 and 24.80%) as well. Similar findings were earlier reported by Sridhar *et al*., (2011), Singh *et al*., (2020) and Devi *et al*., (2022). Heritability estimates were ranged from 31.54% (total number of tillers per m^2) to 98.60% (Test weight). Chandra Bose *et al.,* (2024) also reported high heritability estimates for test weight. Genetic advance as per cent of mean was varied from 6.72% (total number of tillers per m2) to 81.35% (root length density). Under DDSR condition, the genotypic coefficient of variation ranged from 6.51% (total number of tillers per m2) to 38.00% (root length density) (**Table 4**) while PCV varied from 8.89% (total number of tillers per m^2) to 40.01% (root length density). Maximum heritability was observed for stem width (95.25%) followed by seminal root length (95.04%) and test weight (92.97%). Genetic advance as per cent of mean manifested highest value for root length density (74.34%) while minimum was recorded by panicle length (7.31%).

Grain yield per plot manifested moderate GCV and PCV coupled with moderate heritability and genetic advance under both transplanted and DDSR conditions indicating that the prevalence of both non-additive and additive gene action in the inheritance of this trait. Under transplanted conditions, test weight, total root length, root length density and root volume exhibited high estimates for all the genetic parameters studied. Similarly, under dry direct sown conditions, test weight, stem width and root length density exhibited high estimates for all the genetic parameters studied suggesting the predominance of additive gene effects. Hence these traits can be improved through simple selection. Similar findings were previously reported by Shashidar *et al.,* (2007), Anandan *et al,.* (2022) and Faysal *et al.,* (2022).

Table 1: Mean performance for yield, yield components and root traits under transplanted condition in rice (*Oryza sativa* L.)

Genotype	DFF	PH (cm)	PL (cm)	EBT/ p lant	NT/ m2	NFG/ panicle	TW (g)	SW (mm)	NR	RGA (Degree)	NRL (cm)	TRL (cm)	RLD (cm/ cm3)	SRL (cm)	RV (CC)	GY (kg) /plot
BPT2231	115	95.5	21.7	17	468	192	15.5	3.6	18	38.9	16.8	243.7	0.276	8.4	0.88	3.3
BPT2295	121	101.1	23.0	14	442	207	13.5	4.2	23	43.8	17.5	179.5	0.268	11.3	0.67	3.1
BPT2766	116	102.1	22.2	12	429	248	15.4	7.5	25	46.9	15.4	154.7	0.100	8.2	1.54	3.8
BPT2841	92	114.5	21.4	10	445	251	12.4	5.5	16	37.3	18.6	215.1	0.227	11.6	0.95	3.0
BPT2846	112	100.4	24.0	17	464	251	13.6	4.6	22	55.7	16.7	125.3	0.071	8.4	1.75	3.8
BPT2858	102	118.6	28.6	13	430	329	12.2	3.8	16	30.5	16.3	235.9	0.323	11.7	0.73	2.8
BPT3050	102	98.3	25.6	17	512	177	22.6	3.5	20	47.1	14.5	325.5	0.260	9.5	1.25	4.4
BPT3061	105	130.3	24.1	20	508	226	17.2	6.8	17	46.5	11.2	271.3	0.199	9.3	1.36	3.8
BPT3082	102	96.9	23.5	14	437	272	13.3	5.1	26	36.1	13.7	316.5	0.458	10.6	0.69	3.0
BPT3114	104	121.4	22.4	19	488	173	17.3	4.6	22	39.3	12.9	196.4	0.204	11.9	0.96	3.6
BPT3291	103	99.8	22.2	12	452	211	22.7	4.1	19	49.0	15.3	278.7	0.244	8.5	1.14	3.3
BPT4358	105	102.1	22.8	13	452	224	13.5	5.7	21	50.6	15.6	308.1	0.285	9.6	1.08	3.6
BPT5204	112	87.6	19.4	19	510	181	13.1	4.3	15	41.1	13.5	268.7	0.395	8.8	0.68	3.0
Binadhan 16	75	102.8	22.7	9	415	156	23.5	5.5	25	48.5	14.6	360.8	0.474	12.1	0.76	2.9
DRRDhan 42	78	85.7	24.5	11	398	165	24.3	6.9	24	37.5	16.5	345.4	0.308	6.9	1.12	3.3
MEAN	102.9	104.4	23.2	14.8	457.0	206.8	16.6	5.0	20.6	43.2	15.2	255.0	0.272	9.7	1.03	3.1
Maximum	121	130.3	28.6	20	512	329	24.3	6.9	26	55.7	18.6	360.8	0.474	12.1	1.75	4.4
Minimum	75	85.7	19.4	9	398	156	12.2	3.5	15	30.5	11.2	125.3	0.071	6.9	0.67	2.4
SEm	3.7	3.8	0.6	1.0	10.3	20.7	0.5	0.2	1.8	3.3	0.7	9.4	0.5	0.4	0.2	0.2
CV	6.5	6.4	7.2	7.6	8.0	7.8	5.1	7.7	15.4	13.5	8.2	6.4	11.9	8.3	10.7	16.0
CD	10.8	15.1	1.8	2.9	29.9	60.0	1.4	0.8	5.3	9.7	2.1	27.3	1.5	1.3	0.6	0.8

DFF = Days to 50 per cent Flowering, PH = Plant Height (cm), PL = Panicle Length (cm), EBT/plant = Ear Bearing Tillers per plant, NT/m2 = No. of tillers/m2, NFG/panicle = No. of Filled grains per panicle, TW = Test weight, GY(kg)/plot = Grain yield (Kg) per plot, SW = Stem width (mm), NR = No. of nodal roots, RGA (Degree) = Root growth angle (Degree), NRL = Nodal root length (cm), TRL = Total root length (cm), RLD = Root length density, SRL = Seminal root length (cm), RV = Root volume.

Table 2: Mean performance of rice genotypes for yield components and root traits under dry direct seeded condition in rice (*Oryza sativa* L.)

Genotype	DFF	PH (cm)	PL (cm)	EBT/ plant	NT/ m^2	NFG/ pancile	TW (g)	SW (mm)	NR	RGA (Degree)	NRL (cm)	TRL (cm)	RLD (cm/cm^3)	SRL (cm)	RV (CC)	GY (Kg)/ plot
BPT2231	108	93.2	22.0	15	461	180	15.3	4.3	21	37.3	22.7	321.5	0.171	9.5	1.79	3.0
BPT2295	113	107.5	21.0	13	404	192	14.1	4.6	26	47.4	25.5	325.6	0.282	13.6	1.12	3.8
BPT2766	111	102.0	22.3	12	458	248	14.4	6.1	25	39.4	18.5	288.2	0.189	11.2	1.55	3.2
BPT2841	87	109.2	22.5	12	508	255	11.8	5.7	23	48.6	24.7	342.5	0.271	15.6	1.23	2.8
BPT2846	108	106.5	24.3	11	527	261	14.2	5.6	28	55.4	28.5	306.9	0.155	9.2	1.90	3.4
BPT2858	95	112.9	29.7	13	493	341	12.4	3.2	25	37.5	21.0	410.5	0.308	12.4	1.25	2.7
BPT3050	98	90.5	24.2	13	506	158	19.7	3.8	29	53.0	19.5	420.1	0.456	16.8	0.72	4.1
BPT3061	105	124.4	22.8	14	529	212	15.4	5.6	22	34.2	26.8	387.3	0.284	15.3	1.28	2.9
BPT3082	103	105.4	23.2	16	456	195	13.4	5.4	26	44.1	22.7	350.6	0.241	14.2	1.38	3.2
BPT3114	97	111.9	24.0	15	525	168	15.0	4.2	27	37.7	23.2	360.2	0.216	13.6	1.56	4.2
BPT3291	97	93.3	21.4	14	470	185	21.3	4.8	31	35.2	20.6	309.8	0.397	12.5	0.78	3.1

Genotype	DFF	PH (cm)	PL (cm)	EBT/ plant	NT/ m^2	NFG/ pancile	TW (g)	SW (mm)	NR	RGA (Degree)	NRL (cm)	TRL (cm)	RLD (cm/cm^3)	SRL (cm)	RV (CC)	GY (Kg)/ plot
BPT4358	104	95.3	21.3	15	474	204	13.9	4.9	26	52.0	21.4	420.8	0.217	9.8	1.86	3.9
BPT5204	107	94.6	20.0	15	514	153	14.0	4.3	22	46.8	23.7	395.6	0.203	9.6	1.77	2.8
Binadhan 16	81	100.9	19.9	13	469	160	21.9	5.1	35	47.2	26.2	438.4	0.223	13.4	1.93	2.8
DRRDhan 42	82	85.1	19.6	14	448	165	26.6	5.8	32	46.2	23.9	460.5	0.243	11.7	1.77	3.0
MEAN	100.0	102.4	22.5	14	483	195	16.4	4.9	26.7	44.1	23.2	369.2	0.270	12.5	1.46	3.1
Maximum	113	124.4	29.7	16	529	341	26.6	6.1	35	55.4	28.5	460.5	0.456	16.8	1.93	4.2
Minimum	81	85.1	19.6	11	404	153	11.8	3.2	21	34.2	18.5	306.9	0.155	9.2	0.72	2.7
CV (%)	4.1	5.0	8.0	8.2	6.0	6.3	7.1	5.8	9.2	7.8	9.6	5.3	12.4	4.1	6.0	8.1
Sem	2.4	3.2	1.0	0.6	16.8	8.2	0.6	0.0	1.4	2.0	1.2	11.3	0.01	0.3	51.4	0.1
CD	6.9	9.5	2.9	1.9	48.8	23.8	2.0	0.1	4.1	5.8	3.7	32.8	0.05	0.8	0.7	0.4

DFF = Days to 50 per cent Flowering, PH = Plant Height (cm), PL = Panicle Length (cm), EBT/plant = Ear Bearing Tillers per plant, NT/m^2 = No. of tillers/m^2, NFG/panicle = No. of Filled grains per panicle, TW = Test weight, GY(kg)/plot = Grain yield (Kg) per plot, SW = Stem width (mm), NR = No. of nodal roots, RGA (Degree) = Root growth angle (Degree), NRL = Nodal root length (cm), TRL = Total root length (cm), RLD = Root length density, SRL = Seminal root length (cm), RV = Root volume.

Table 3: Genetic parameters for yield components and root characters under transplanted and dry direct sown conditions in rice (*Oryza sativa* L.)

S. No	Characters	GCV (%)		PCV (%)		Genetic Advance		Heritability (Broad Sense) (%)		Genetic Advance as % of Mean	
		Trans-planted	Direct sown	Trans-planted	Direct sown	Trans-planted	Direct sown	Trans-planted	Direct sown	Transplanted	Direct sown
1	DFF	8.73	8.80	9.09	9.65	17.18	18.59	92.15	84.70	17.26	18.58
2	PH (cm)	13.53	10.97	14.00	11.61	28.20	9.59	93.34	36.09	26.93	8.63
3	PL (cm)	10.97	7.61	11.13	9.34	2.65	1.67	51.32	28.75	11.77	7.31
4	EBT/Plant	10.14	7.78	11.26	9.35	2.16	1.54	55.72	47.01	15.77	10.99
5	NT/m^2	8.81	6.51	9.35	8.89	30.73	47.57	31.54	53.75	6.72	9.84
6	NFG/pancile	17.57	19.61	18.80	19.72	77.72	22.88	87.31	23.11	33.82	9.52
7	TW (g)	24.80	25.90	24.98	26.87	8.60	8.46	98.60	92.97	50.74	51.46
8	SW (mm)	18.20	26.46	18.67	27.11	1.86	0.78	95.04	95.25	36.55	53.19
9	NR	14.62	14.35	16.26	16.27	4.28	6.05	47.28	67.40	20.70	22.59
10	RGA (degrees)	13.39	14.78	19.04	16.74	8.39	11.87	49.46	77.98	19.40	26.89
11	NRL (cm)	11.70	11.58	14.33	13.32	3.00	3.75	66.69	54.57	19.69	16.10
12	TRL (cm)	27.39	12.41	28.16	14.48	139.86	59.30	94.59	54.36	54.87	17.33
13	RLD (cm/cm3)	40.62	38.00	41.78	40.01	0.22	0.20	94.53	90.16	81.35	74.34
14	SRL (cm)	16.02	18.32	18.06	18.79	2.86	4.63	78.72	95.04	29.29	36.79
15	RV (cc)	29.19	12.96	29.78	15.51	610.54	203.67	96.10	34.02	58.95	14.37
16	GY (kg) per plot	13.53	11.90	19.22	12.80	0.61	0.33	44.76	38.13	18.65	10.06

PCV-Phenotypic Coefficient of Variation; GCV-Genotypic Coefficient of Variation

DFF = Days to 50 per cent Flowering, PH = Plant Height (cm), PL = Panicle Length (cm), EBT/plant = Ear Bearing Tillers per plant, NT/m^2 = No. of tillers/m2, NFG/panicle = No. of Filled grains per panicle, TW = Test weight, GY(Kg)/plot = Grain yield (Kg) per plot, SW = Stem width (mm), NR = No. of nodal roots, RGA (Degree) = Root growth angle (Degree), NRL = Nodal root length (cm), TRL = Total root length (cm), RLD = Root length density, SRL = Seminal root length (cm), RV = Root volume.P- Phenotypic G-Genotypic

Table 4: Correlation coefficients (Phenotypic and Genotypic) for yield contributing characters and root traits under transplanted and dry direct sown conditions in rice (*Oryza sativa* L.)

		DFF	PH	PL	EBT	NT/m2	NFG	TW	SW	NR	RGA	NRL	TRL	RLD	SRL	RV	GYP
DFF	G	1.0000	0.2902	0.5703*	0.4136**	0.3137*	-0.1369	-0.4491**	-0.1893	-0.0354	-0.0938	0.1265	0.2827	-0.4106**	0.0016	0.5226**	0.4552**
	P	1.0000	0.2675	0.4298**	0.3541*	0.0800	-0.1171	-0.4215**	-0.1729	-0.0030	-0.0928	0.0666	0.0662	-0.3869**	-0.0100	0.2420	0.2669
PH	G	0.2528	1.0000	0.5160*	0.4347**	0.1615	0.3833*	-0.2433	-0.1454	-0.3794*	-0.2798	-0.3997*	0.3300	-0.2292	0.5176**	0.6098**	0.5101**
	P	0.0878	1.0000	0.3643**	0.3038*	0.0877	0.3597*	0.2461	-0.1189	-0.2958*	-0.2164	-0.1977	0.1383	0.2180	0.4770**	0.3522*	0.3338*
PL	G	0.1707	0.9205**	1.0000	0.5960**	0.4746**	0.4679**	-0.1726	-0.5435**	-0.0788	0.1352	0.2248	0.5630**	-0.4561**	-0.1554	0.8471**	0.6867**
	P	0.1263	0.6329**	1.0000	0.5788**	0.1363	0.3901**	-0.1063	-0.3817**	-0.1323	-0.0115	0.3298*	0.5305**	-0.3387*	-0.0821	0.5316**	0.6442**
EBT	G	0.1674	0.2805	-0.1598	1.0000	0.9502**	0.0279	-0.2553	-0.4772**	-0.4675**	-0.1512	-0.1179	0.8030**	0.0287	-0.1984	0.6714**	0.6982**
	P	0.0957	0.1074	0.1150	1.0000	0.1981	-0.0048	-0.1656	-0.3895**	-0.2204	-0.2670	0.0196	0.4286**	-0.0266	-0.1427	0.2714	0.5217**
NT/ m2	G	-0.1422	0.1235	0.4827*	-0.1487	1.0000	-0.3076	-0.1815	-0.5345**	-0.8239**	0.3046*	-0.4096**	0.4288**	-0.2454	-0.0875	0.3692	0.0956
	P	-0.0126	0.0873	0.1657	-0.1039	1.0000	-0.1446	-0.1123	-0.2443	-0.2959*	0.1309	-0.2446	0.0511	-0.1530	0.0011	0.0352	0.0945
NFG	G	-0.4181*	0.8780**	0.6722**	-0.4983*	0.0032	1.0000	0.0511	-0.1957	-0.3076*	-0.1830	0.5018*	0.6541**	-0.2616	-0.0820	0.7863**	0.5514**
	P	-0.1959	0.5790**	0.5876**	-0.1455	0.0976	1.0000	0.0407	-0.1796	-0.2954*	0.0374	0.4272**	0.3649*	-0.2694	-0.0358	0.5052**	0.4037**
TW	G	- 0.5855**	-0.2101	-0.1674	0.0927	-0.2970	0.3359*	1.0000	0.1192	0.3528	0.2912	0.0590	0.2997	0.1215	-0.2738	0.1782	0.1619
	P	- 0.5419**	-0.1279	-0.0991	0.0606	-0.2426	0.1333	1.0000	0.1184	0.2416	0.2088	0.0497	0.1596	0.1187	-0.2420	0.0959	0.1420
SW	G	0.0098	- 0.5356**	-0.5677**	0.1438	0.0743	-0.6284**	-0.1448	1.0000	0.4203**	0.1969	-0.5913**	-0.5432**	-0.1424	-0.2269	-0.2090	-0.5487**
	P	0.0107	-0.3232*	-0.2949*	0.0834	0.0716	-0.2174	-0.1514	1.0000	0.2763	0.1634	-0.3504*	-0.2307	-0.1432	-0.2160	-0.0459	-0.3415*
NR	G	- 0.6780**	-0.2503	-0.2149	-0.2838	-0.2708	0.6999**	0.8544**	-0.0736	1.0000	0.5034**	0.2864	-0.0976	0.1204	0.0263	-0.3689*	-0.1468
	P	- 0.4947**	-0.0991	-0.0455	-0.1854	-0.1388	0.1821	0.6454**	-0.0651	1.0000	-0.0040	0.0118	-0.0998	0.1007	-0.1102	-0.1171	-0.1119
RGA	G	-0.4049*	-0.5042*	-0.1809	-0.4225*	-0.1018	0.1485	0.3492*	-0.4543*	0.4546**	1.0000	0.0266	-0.2143	-0.4622*	-0.3796*	0.1092	-0.2070
	P	-0.2598	-0.2344	-0.0329	-0.3279*	0.0217	0.0899	0.3269*	-0.3832*	0.3404*	1.0000	-0.0203	-0.1795	-0.3433*	-0.2060	0.1464	-0.1739
NRL	G	-0.0660	- 0.8218**	-0.4614*	-0.1251	0.3150*	-0.7575**	-0.0606	0.4874**	0.0558	0.0766	1.0000	0.0198	-0.0068	-0.3393	0.0791	0.1770
	P	-0.1112	-0.2361	-0.2316	-0.2673	0.0881	-0.2506	0.0077	0.3498*	-0.0029	0.1297	1.0000	0.5133**	-0.0330	-0.1214	0.3244*	0.5318**
TRL	G	-0.1900	0.6825**	0.3376*	0.6501**	0.2322	0.5016**	0.2168	-0.2585	0.0115	-0.1959	-0.4824**	1.0000	0.3599*	-0.2506	0.6994**	0.8987**
	P	-0.0610	0.6307**	0.3746*	0.2803	0.1325	0.3438*	0.1755	-0.2329	0.0194	-0.1334	-0.2303	1.0000	0.1555	-0.0752	0.4489**	0.8358**
RLD	G	-0.2361	0.5528**	0.5498**	-0.0700	0.1000	0.8323**	0.3829	-0.8854**	0.2966	0.4657**	-0.4793**	0.6001**	1.0000	0.3141	-0.7910**	-0.1723
	P	-0.1851	0.3461*	0.2891	0.0110	0.0421	0.3370*	0.3333*	-0.8482**	0.2217	0.3739*	-0.3053*	0.4644**	1.0000	0.2852	-0.4969**	-0.1110
SRL	G	-0.3892	0.3060	0.2561	-0.1473	0.1490	0.3662*	0.0788	-0.6746**	0.1097	0.2968*	-0.0517	0.2010	0.6140**	1.0000	-0.4404**	-0.0926
	P	-0.3358*	0.2090	0.2072	-0.1606	0.1044	0.1905	0.0643	-0.6408**	0.1130	0.2956*	-0.0090	0.1819	0.5669**	1.0000	-0.3073*	-0.0450
RV	G	0.1140	0.6800**	0.5309*	0.2651	-0.0315	0.6955**	0.1683	0.0809	-0.1756	-0.1212	-0.3954*	0.6196**	0.1381	-0.2259	1.0000	0.9233**
	p	-0.0033	0.3908**	0.4241**	0.0879	0.0953	0.3506*	0.1040	0.0306	-0.1135	-0.0821	-0.2479	0.3733*	0.0206	-0.0874	1.0000	0.6257**
GYP	G	0.2953	0.9293**	0.6439**	0.4724**	-0.2843	0.5294*	0.2371	-0.6095*	-0.0051	-0.2090	-0.6735**	0.7113**	0.7196**	0.1407	0.6455**	1.0000
	P	0.1707	0.7583**	0.6545**	0.2617	-0.0105	0.5696**	0.1669	-0.3754*	-0.0349	-0.0878	-0.2681	0.6941**	0.4048**	0.1171	0.5956**	1.0000

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

DFF = Days to 50 per cent Flowering, PH = Plant Height (cm), PL = Panicle Length (cm), EBT/plant = Ear Bearing Tillers per plant, NT/m^2 = No. of tillers/m2, NFG/panicle = No. of Filled grains per panicle, TW = Test weight, GY(Kg)/plot = Grain yield (Kg) per plot, SW = Stem width (mm), NR = No. of nodal roots, RGA (Degree) = Root growth angle (Degree), NRL = Nodal root length (cm), TRL = Total root length (cm), RLD = Root length density, SRL = Seminal root length (cm), RV = Root volume. P- Phenotypic G-Genotypic

The estimates of phenotypic correlation for all the characters under study were higher than the estimates of genotypic correlation. From the correlation studies it may be concluded that yield contributing characters *viz.,* days to 50 per cent flowering (rg=0.4552 and rp=0.2669), plant height (rg=0.5101 and rp=0.3338), panicle length (rg=0.6867 and rp=0.6442), ear bearing tillers per plant (rg=0.6982 and rp=0.5217), number of filled grains per panicle (rg=0.5514 and rp=0.4037), nodal root length (rg=0.1770 and rp=0.5318), total root length (rg=0.8987 and rp=0.8358) and root volume (rg=0.9233 and rp=0.6257) were positively correlated with grain yield per plot under transplanted conditions indicating that the above traits can be considered for improvement of grain yield. Under dry direct sown conditions, characters *viz.,* plant height (rg=0.9293 and rp=0.7583), ear bearing tillers per plant (rg=0.4724 & rp=0.2617), panicle length (rg=0.6439 and rp=0.6545), number of filled grains per panicle (rg=0.5294 and rp=0.5696), total root length (rg=0.7113 and rp=0.6941), root length density (rg=0.7196 and rp=0.4048) and root volume (rg=0.6455 and rp=0.5956) were positively correlated with grain yield per plot indicating that these traits can be considered for improvement of grain yield. Stem width was negatively correlated with grain yield per plot under both transplanted and dry direct sown conditions. Days to 50 per cent flowering exhibited negative and significant association with test weight (rg=-0.4491** and rp=-0.4215** and rg=- 0.5855** and rp=-0.5419**I) under both transplanted and dry direct sown conditions respectively suggesting that the genotypes with short duration recorded more test weight in this study. Earlier studies by Deepthi *et al.,* (2022), Heera *et al*., (2023), Farheen *et al*., (2023) and Satish Chandra *et al*., (2024) are in accordance with the present results. Positive correlation of grain yield with total root length and root volume were previously reported by Yogameenakshi *et al*., (2012) and Quadri *et al.,* (2023). Among the root traits, nodal root length, total root length and root volume were positively correlated with each other and can be improved simultaneously whereas root length density and seminal root length were negatively correlated with each other under transplanted conditions. Under dry direct sown conditions, among the root traits, total root length, root length density and root volume were positively correlated with each other and can be improved simultaneously. Whereas negative and significant association was observed between nodal root length with total root length, root length density and root volume. Under both transplanted and direct sown conditions total root length has positive and significant relationship with root volume and grain yield indicating the scope for simultaneous improvement. Positive and significant relationship of total root length and root volume with grain yield was previously reported by Yogameenakshi *et al*., (2012), Haider *et al.,* (2012) and Quadri *et al*., (2023).

From PCA analysis genetic divergence was assessed for yield and root characters in 15 genotypes to identify diverse germplasm by using Principal Component Analysis (PCA). The first principal component explained 50.769 per cent while, the second, third and fourth principal component explained 22.52 per cent, 13.44 per cent and 8.95 per cent variability, respectively among the genotypes for the traits under transplanted conditions (**Figure 1**). The first principal component explained 41.042 per cent while, the second, third and fourth principal component exhibited 28.60 per cent, 12.29 per cent and 8.67 per cent variability, respectively among the germplasm lines for the traits under dry direct sown conditions (**Figure 2**). A perusal of the results revealed that BPT 5204, BPT 2766, BPT 3061 and BPT 3291 are most divergent genotypes according to PCA biplot analysis under transplanted conditions. Hence, hybridization between these diverse genotypes may result in isolation of transgressive segregants with higher grain yield, higher total root length, and more root volume. Under dry direct sown conditions, BPT 3061, BPT 2766, BPT 3082 and BPT 2841 were identified as diverse genotypes for most of the yield components and root traits. Hence, using these genotypes in hybridization programme may result in the development and selection of genotypes with higher grain yield, and desirable root traits *viz*., total root length, root volume, nodal root length and thus making the isolated selected genotypes suitable for dry direct sown conditions.

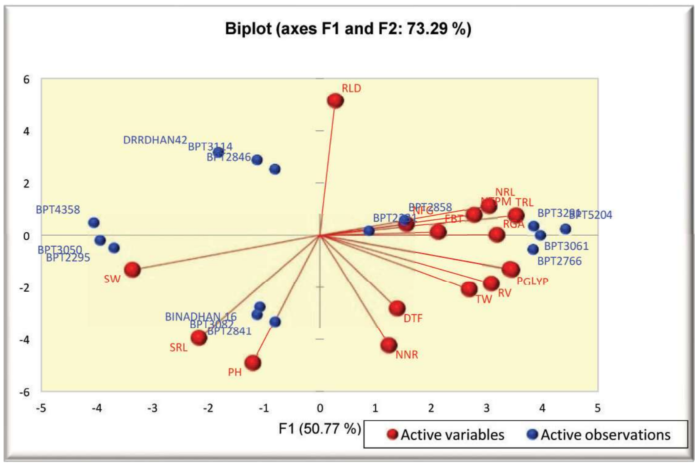

Figure 1: Biplot graph of different traits for first two principal components under transplanted conditions

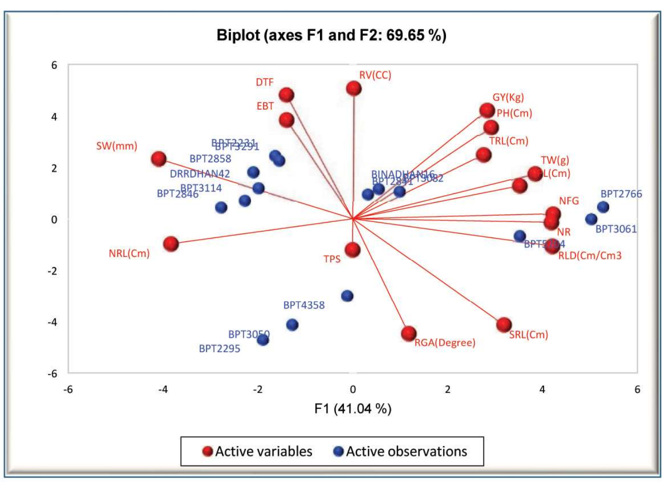

Figure 2: Biplot graph of different traits for first two principal components under dry direct sown conditions

Conclusion

From the present study, it may be concluded that BPT 3050, BPT 3114, BPT 2846 and BPT 2766 recorded high grain yield under both transplanted and dry direct sown conditions. These genotypes also manifested superior values for yield components and desirable root characters. Hence, all these genotypes may be recommended for dry direct sown conditions. BPT 3050 and BPT 2846 were released varieties and can be popularized under dry direct sown conditions. The other genotypes *viz.*, BPT 3114 and BPT 2766 are advanced breeding lines. These two genotypes may be evaluated under multilocation testing in future for identification of their stability in different locations.

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