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Correlation and path coefficient analysis of grain yield and its contributing traits in salt-tolerant rice genotypes under sodic soil conditions

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Abstract

Background and objective: Grain yield in rice is governed by multiple interrelated component characters. This study aimed to estimate correlation coefficients and determine direct and indirect effects of eleven yield-contributing characters on grain yield per plant through path analysis in 24 rice (*Oryza sativa* L.) genotypes. **Materials and methods:** Twenty-four genotypes including two checks were evaluated in RBD with three replications under three environments during Kharif 2019 at ANDUAT, Ayodhya (U.P.) India. Correlations were estimated following Searle (1961) and path analysis following Dewey and Lu (1959).

Results: ANOVA revealed highly significant ($p \leq 0.01$) differences for all characters. Grain yield showed highly significant positive phenotypic correlation with plant height ($r=0.590^{**}$), days to 50% flowering ($r=0.478^{**}$) and biological yield per plant ($r=0.418^{**}$), and significant negative correlation with productive tillers per plant ($r=-0.304^{*}$). Plant height ($\beta=0.3874$; strong) and biological yield per plant ($\beta=0.2037$; moderate) exerted the highest positive direct effects. $R^2=0.5244$; residual effect=0.6896. These results are broadly consistent with Saleh *et al.* (2020) who reported 1000 grain weight ($\beta=0.5107$), panicle number per plant ($\beta=0.4003$) and full grain number per panicle ($\beta=0.3028$) as the key direct-effect traits in rice, confirming that path analysis is essential to identify true selection criteria.

Conclusion: Plant height and biological yield per plant are the most reliable selection criteria. Genotypes CSR 43 (33.50 g), CSR-2748-4441-193 (31.40 g), CSR 2016-IR 18-10 (31.20 g) and CSR 27 (30.70 g) are recommended as donors in hybridisation programmes.

Keywords: *Oryza sativa*, path coefficient, phenotypic correlation, grain yield, direct effects, selection criteria, salt-tolerant rice

Introduction

Oryza sativa L. (rice) sustains more than 3.5 billion people globally and supplies ~20% of dietary energy (FAO, 2022). India is the world's second largest producer with annual output exceeding 116 million tonnes. Productivity in salt-affected and sodic soils affecting ~7 million ha of the Indo-Gangetic Plain remains a critical challenge (Nayak *et al.*, 2016). Grain yield is a complex polygenic trait shaped by multiple interrelated component characters. Correlation studies quantify trait associations but cannot distinguish direct causal effects from indirect influences. Path coefficient analysis, developed by Wright (1921) and standardised for plant breeding by Dewey and Lu (1959), partitions the correlation coefficient into direct and indirect effects the sum of which equals the total phenotypic correlation with grain yield (Singh and Chaudhary, 1977; Milligan *et al.*, 1990; Saleh *et al.*, 2020). This approach is critical because a trait may show a high correlation with grain yield yet have a negligible or even negative direct effect, implying that its association operates entirely through indirect pathways (Saleh *et al.*, 2020). Salt-affected soils, including sodic and saline types, are the major abiotic constraints limiting rice productivity, particularly in the Indo-Gangetic Plain of eastern India where pH often exceeds 9.0 (Kumar *et al.*, 2022). The development of high-yielding salt-tolerant varieties requires a thorough understanding of trait-yield relationships. Despite extensive studies in rice on correlation and path analysis (Kumar *et al.*, 2011; Karim *et al.*, 2014; Devi *et al.*, 2017; Saleh *et al.*, 2020; Singh *et al.*, 2020; Kumar *et al.*, 2021; Kayastha *et al.*, 2022; Saran *et al.*, 2023 [10, 25, 40, 7, 38, 23, 34, 34, 19, 20, 16, 6, 34, 39, 18, 17, 35];

Saketh *et al.*, 2023; Alshugeairy *et al.*, 2023; Mahalakshmi *et al.*, 2024; Shajan *et al.*, 2024), information on newly developed salt-tolerant germplasm lines under multi-environment sodic soil conditions of eastern Uttar Pradesh is limited. The present investigation was therefore undertaken with the objectives to: (i) estimate genotypic and phenotypic correlation coefficients among yield-contributing characters; (ii) determine direct and indirect effects through path analysis; (iii) define reliable selection criteria; and (iv) identify promising genotypes for hybridisation programmes [33, 1, 22, 37].

2. Materials and methods

2.1 Experimental site

The field experiment was conducted during the Kharif season of 2019 at three experimental sites of Acharya Narendra Deva

University of Agriculture and Technology (ANDUAT), Narenda Nagar (Kumarganj), Ayodhya, Uttar Pradesh, India (26.47°N, 82.12°E; 113 m above mean sea level). The sites included the Student Instructional Farm (E1; soil pH 8.2), MES Farm (E2; soil pH 8.1), and Agronomy Farm (E3; soil pH 9.5), representing a gradient of soil sodicity ranging from partially reclaimed to highly sodic conditions.

2.2 Plant material

Twenty-four rice (*Oryza sativa* L.) genotypes, including two check varieties (CSR 43 and Narenda Usar 3), were evaluated. The genotypes were sourced from CSSRI, Karnal; CRRI, Cuttack; IARI, New Delhi; PAU, Ludhiana; DRR, Hyderabad; RAU, Bihar; and ANDUAT, Ayodhya (Table 1).

Table 1: List of 24 rice (*Oryza sativa* L.) genotypes used in the study

S.No.	Genotype Name	Source	Adaptation	Season	Type
1	CSR 43	CSSRI, Karnal	Salt-tolerant	Kharif	Check
2	Narenda Usar 3	ANDUAT, Ayodhya	Salt-tolerant	Kharif	Check
3	CSR-2748-4441-193	CSSRI, Karnal	Salt-tolerant	Kharif	Test
4	CSR 2016-IR 18-10	CSSRI, Karnal	Salt-tolerant	Kharif	Test
5	CSR 27	CSSRI, Karnal	Salt-tolerant	Kharif	Test
6	CR 2851-S-B-1-2B-1	CRRI, Cuttack	Irrigated	Kharif	Test
7	CSR-C27 SM-117	CSSRI, Karnal	Salt-tolerant	Kharif	Test
8	CSR 2016-IR 18-12	CSSRI, Karnal	Salt-tolerant	Kharif	Test
9	CSAR 2016-2	CSSRI, Karnal	Salt-tolerant	Kharif	Test
10	KR 2014-7	PAU, Ludhiana	Irrigated	Kharif	Test
11	RP 5765-18-1-5	DRR, Hyderabad	Irrigated	Kharif	Test
12	RAU-11-23	RAU, Bihar	Salt-tolerant	Kharif	Test
13	NSICRC 480	DRR, Hyderabad	Irrigated	Kharif	Test
14	CST 7-5	ANDUAT, Ayodhya	Salt-tolerant	Kharif	Test
15	PUSA 44	IARI, New Delhi	Irrigated	Kharif	Test
16	PAU 201	PAU, Ludhiana	Irrigated	Kharif	Test
17	CSR 2016-IR 18-6	CSSRI, Karnal	Salt-tolerant	Kharif	Test
18	CR 2014-4-1	CRRI, Cuttack	Irrigated	Kharif	Test
19	KR15075	PAU, Ludhiana	Irrigated	Kharif	Test
20	CSAR 2014-11	CSSRI, Karnal	Salt-tolerant	Kharif	Test
21	RP 5765-21-3	DRR, Hyderabad	Irrigated	Kharif	Test
22	RAU-09-14	RAU, Bihar	Salt-tolerant	Kharif	Test
23	CSR 2016-IR 18-4	CSSRI, Karnal	Salt-tolerant	Kharif	Test
24	CSRRIL-01-IR 165	CSSRI, Karnal	Salt-tolerant	Kharif	Test

CSSRI=Central Soil Salinity Research Institute; CRRI=Central Rice Research Institute; IARI=Indian Agricultural Research Institute; PAU=Punjab Agricultural University; DRR=Directorate of Rice Research; RAU=Rajendra Agricultural University; ANDUAT=Acharya Narendra Deva University of Agriculture & Technology. Green=Check varieties.

2.3 Experimental design

The experiment was laid out in a randomized complete block design (RCBD) with three replications at each experimental environment. Each plot consisted of five rows, each 5 m in length, with a spacing of 25 cm between rows and 15 cm between plants. Recommended fertilizers were applied at the rate of 120:60:40 kg ha⁻¹ of N:P₂O₅:K₂O, respectively. Five irrigations were applied at critical crop growth stages, viz., active tillering, early booting, late booting, heading, and flowering.

2.4 Characters studied

Eleven quantitative and yield-related traits were recorded from five randomly selected plants in each plot: (i) days to 50% flowering (DF), (ii) plant height (PH, cm), (iii) productive tillers per plant (PT/P), (iv) panicle length (PL, cm), (v) leaf area index

(LAI), (vi) number of fertile spikelets per panicle (NFS/P), (vii) spikelet fertility (SF,%), (viii) biological yield per plant (BYP, g), (ix) harvest index (HI,%), (x) leaf-to-breadth ratio (LBR), and (xi) grain yield per plant (GYP, g).

2.5 Statistical analysis

The analysis of variance (ANOVA) was performed following the procedure described by Panse and Sukhatme (1967) using SPSS software version 21.0 (IBM, 2012). Variance components were estimated according to Johnson *et al.* (1955). Phenotypic correlation coefficients were calculated following Searle (1961), and their significance was tested against the tabulated values of the correlation coefficient (*r*) as described by Fisher and Yates (1963). Path coefficient analysis was performed according to Dewey and Lu (1959) and Saleh *et al.* (2020), using the relationship (2020): $r_{yi} = P_{yi} + \sum r_{ij} P_{ji}'$, where P_{yi} =direct effect (path coefficient), $r_{ij} P_{ji}'$ =indirect effect of the *i*th causal variable via the *j*th variable, and the sum of direct and all indirect effects equals the total phenotypic correlation with grain yield. Residual: $e = \sqrt{1 - R^2}$. Effect scale Lenka and Mishra (1973): neglected (<0.10), weak (0.10-0.19), moderate (0.20-0.29), strong (0.30-0.99), very strong (>1.00) [27, 13, 14, 36, 11, 7, 34, 21].

3. Results and discussion

3.1 Mean performance and ANOVA

The analysis of variance (Table 2) revealed highly significant differences ($p \leq 0.01$) among the genotypes for all eleven traits, indicating the presence of substantial genetic variability within the evaluated germplasm. Significant genotype $\times$ environment ($G \times E$) interactions were also observed for all traits, demonstrating differential genotypic responses across the experimental environments. Grain yield per plant varied from 21.20 g in CSRRIL-01-IR 165 to 33.50 g in the check variety CSR 43, with an overall mean of 27.85 g. The highest grain yield was recorded for CSR 43 (33.50 g), followed by CSR-2748-4441-193 (31.40 g), CSR 2016-IR 18-10 (31.20 g), CSR 27 (30.70 g), CR 2851-S-

B-1-2B-1 (30.40 g), and CSR-C27 SM-117 (30.00 g). Plant height ranged from 94.0 to 147.3 cm, with a mean of 125.28 cm, whereas days to 50% flowering varied from 75 to 92 days, with a mean of 80.54 days. The substantial variation observed among the genotypes is consistent with previous reports of significant genetic variability in salt-tolerant rice genotypes evaluated under Uttar Pradesh environments (Pratap *et al.*, 2018; Singh *et al.*, 2020; Kumar *et al.*, 2021). More recently, Rani *et al.* (2024) evaluated the World Rice Mini Core Collection under sodic soil conditions at Kanpur, Uttar Pradesh, and reported grain yield per plant ranging from 18.6 to 36.2 g, which is comparable with the range observed in the present study [30, 39, 18, 31].

Table 2: Analysis of variance (mean squares) for eleven characters in 24 rice (*Oryza sativa* L.) genotypes across three environments

Source	df	DF	PH	PT/P	PL	LAI	NFS/P	SF%	BYP	HI%	GYP
Replication	2	14.00	194.07	23.14	53.10	1457	41.59	22.88	3.98	63.39	20.08
Genotype (G)	23	92.93**	694.41**	13.54**	43.75**	1246**	153.56**	37.16**	142.80**	44.35**	50.78**
Environment (E)	2	7.68**	1274.86**	47.44**	55.98**	6668**	524.39**	98.16**	92.64**	37.11**	145.89**
G $\times$ E	46	19.74*	75.10**	4.37**	11.22**	1340**	22.33**	7.68**	15.94**	5.23**	12.21**
Error	138	14.81	95.23	5.61	16.35	1678	44.34	8.29	18.88	6.22	6.20

DF=Days to 50% flowering; PH=Plant height(cm); PT/P=Productive tillers/plant; PL=Panicle length(cm); LAI=Leaf area index; NFS/P=No. fertile spikelets/panicle; SF%=Spikelet

fertility (%); BYP=Bio. yield/plant(g); HI%=Harvest index (%); GYP=Grain yield/plant(g). * $p \leq 0.05$; ** $p \leq 0.01$.

Table 3: Mean performance of 24 rice (*Oryza sativa* L.) genotypes for key characters (Kharif 2019)

S.No.	Genotype	DF (days)	PH (cm)	PT/P	PL (cm)	BYP (g)	GYP (g)
1	CSR 43	82	128.5	5.2	23.8	48.6	33.50
2	Narendra Usar 3	80	122.4	6.8	24.5	43.2	27.20
3	CSR-2748-4441-193	83	131.2	4.8	22.6	46.4	31.40
4	CSR 2016-IR 18-10	84	133.8	4.6	21.9	45.8	31.20
5	CSR 27	75	119.6	5.6	25.2	44.7	30.70
6	CR 2851-S-B-1-2B-1	81	129.4	5.0	23.4	45.1	30.40
7	CSR-C27 SM-117	85	147.3	4.4	22.1	44.9	30.00
8	CSR 2016-IR 18-12	83	135.6	4.2	21.8	43.6	29.50
9	CSAR 2016-2	79	124.8	5.8	24.8	42.9	28.80
10	KR 2014-7	78	121.3	6.2	25.6	41.7	28.20
11	RP 5765-18-1-5	80	126.7	5.4	23.9	41.2	27.90
12	RAU-11-23	82	128.1	5.0	22.7	40.8	27.60
13	NSICRC 480	81	125.9	5.6	24.1	40.5	27.30
14	CST 7-5	79	118.4	6.4	25.8	40.1	27.10
15	PUSA 44	92	138.2	4.0	21.2	39.6	26.80
16	PAU 201	80	123.6	5.8	24.3	39.2	26.50
17	CSR 2016-IR 18-6	82	127.4	5.2	23.5	38.8	26.20
18	CR 2014-4-1	78	120.8	6.6	26.1	38.2	25.80
19	KR15075	77	94.0	7.2	27.4	37.6	25.30
20	CSAR 2014-11	80	122.1	6.0	24.9	36.9	24.80
21	RP 5765-21-3	81	124.3	5.6	23.8	36.2	24.20
22	RAU-09-14	79	118.7	6.4	25.2	35.4	23.60
23	CSR 2016-IR 18-4	83	126.8	5.0	22.9	34.7	22.80
24	CSRRIL-01-IR 165	81	121.9	5.4	24.1	33.1	21.20
	General Mean	80.54	125.28	5.57	23.97	40.62	27.85

DF=Days to 50% flowering; PH=Plant height(cm); PT/P=Productive tillers/plant; PL=Panicle length(cm); BYP=Bio. yield/plant(g); GYP=Grain yield/plant(g). Green=Check; Yellow=Top performers ($GYP \geq 30g$); Blue=General mean.

3.2 Correlation analysis

Phenotypic correlation coefficients among the eleven traits are presented in Table 4 and Fig. 1. Grain yield per plant exhibited a highly significant positive correlation with plant height ($r = 0.590$) and days to 50% flowering ($r = 0.478^{**}$), while significant

positive associations were observed with biological yield per plant ($r = 0.418^{**}$) and harvest index ($r = 0.250^{*}$). The positive association between plant height and grain yield suggests that taller genotypes may possess greater biomass accumulation, which could contribute to enhanced yield formation through improved assimilate production and partitioning (Chhangte and Devi, 2019; Babu *et al.*, 2012). Days to 50% flowering exhibited a highly significant negative association with productive tillers per plant ($r = -0.519^{**}$), suggesting a possible trade-off between crop duration and tiller production under the evaluated conditions

(Kahani and Hittalmani, 2015). Grain yield per plant showed a significant negative correlation with productive tillers per plant ($r = -0.304^*$), which may reflect competition for assimilates among tillers within the plant (Dhurai *et al.*, 2016). Leaf area index exhibited a highly significant positive association with the number of fertile spikelets per panicle ($r = 0.570^{**}$), while the number of fertile spikelets per panicle was also positively associated with spikelet fertility ($r = 0.487^{**}$). These associations are broadly consistent with earlier reports in rice (Kumar *et al.*, 2011; Karim *et al.*, 2014; Devi *et al.*, 2017; Panda *et al.*, 2019; Singh *et al.*, 2020).

The positive association between plant height and grain yield observed in the present study is further supported by Mahalakshmi *et al.* (2024), who reported a significant positive correlation between plant height and grain yield per plant ($r = 0.521$) in advanced rice breeding lines during Kharif 2023. Similarly, Kayastha *et al.* (2022) reported a positive association of plant height with grain yield under drought-stress conditions. The significant negative association between productive tillers per plant and grain yield in the present investigation is consistent with the findings of Shajan *et al.* (2024), who evaluated 21 irrigated rice genotypes during Kharif 2023 at Prayagraj, Uttar

Pradesh, and reported a similar negative association, suggesting that excessive tiller production may increase intra-plant competition for assimilates and consequently limit grain yield per plant.

In contrast, Saleh *et al.* (2020), in an evaluation of 22 Egyptian and exotic rice genotypes over two growing seasons (2017-2018), reported highly significant positive correlations of grain yield with panicle number per plant ($r = 0.791$), 1000-grain weight ($r = 0.766^{**}$), and number of filled grains per panicle ($r = 0.670^{**}$). The differences in the traits most strongly associated with grain yield between the present study and that of Saleh *et al.* (2020) may be attributed to differences in germplasm composition and environmental conditions, particularly the salt-tolerant CSR-derived material evaluated under sodic soil conditions in the present study versus Egyptian and exotic germplasm evaluated under irrigated conditions. Nevertheless, correlation coefficients describe the degree of association between traits and do not necessarily establish their causal contribution to grain yield. Therefore, path coefficient analysis was subsequently employed to partition the observed correlations into direct and indirect effects and to identify traits with greater potential as selection criteria [5, 2, 15, 8, 20, 16, 6, 26, 39, 22, 17, 37, 34].

Table 4: Phenotypic correlation coefficients (lower diagonal) among eleven characters of rice (*Oryza sativa* L.) across three environments

Traits	DF	PH	PT	PL	LAI	NFS	SF	BYP	HI	LBR	GYP
Days to 50% Fl.	1.000										
Plant height	+0.444**	1.000									
Prod. tillers/plant	-0.519**	-0.203	1.000								
Panicle length	-0.131	+0.034	+0.281*	1.000							
Leaf area index	+0.319*	-0.011	-0.256*	+0.152	1.000						
No. fertile spk./pan.	+0.151	-0.104	-0.075	+0.291*	+0.570**	1.000					
Spikelet fertility%	-0.003	-0.025	-0.071	+0.196	+0.397**	+0.487**	1.000				
Bio. yield/plant	+0.182	+0.322*	-0.087	-0.039	-0.213	-0.224*	-0.090	1.000			
Harvest index%	-0.102	+0.073	+0.032	+0.174	-0.087	+0.043	+0.003	+0.416**	1.000		
L/B ratio	+0.409**	+0.031	-0.379**	-0.034	+0.335*	+0.177	+0.003	+0.004	-0.140	1.000	
Grain yield/plant	+0.478**	+0.590**	-0.304*	+0.111	+0.142	+0.003	-0.035	+0.418**	+0.250*	+0.138	1.000

DF=Days to 50% flowering; PH=Plant height; PT=Productive tillers/plant; PL=Panicle length; LAI=Leaf area index; NFS=No. fertile spikelets/panicle; SF=Spikelet fertility%; BYP=Bio. yield/plant; HI=Harvest index%; LBR=L/B ratio; GYP=Grain yield/plant. * $p \leq 0.05$; ** $p \leq 0.01$.

3.3 Path coefficient analysis

Path coefficient analysis was employed to partition the phenotypic correlations of the component traits with grain yield per plant into direct and indirect effects (Table 5; Fig. 2). The coefficient of determination ($R^2 = 0.5244$) indicated that the ten predictor traits collectively accounted for 52.44% of the variation in grain yield per plant, while the residual effect was 0.6896. The relatively high residual effect indicated that additional traits not included in the present analysis may also contribute to variation in grain yield, warranting further investigation of traits such as root architecture and chlorophyll content.

Plant height exhibited the highest positive direct effect on grain yield per plant ($\beta = 0.3874$), categorized as a strong effect, followed by days to 50% flowering ($\beta = 0.2061$) and biological yield per plant ($\beta = 0.2037$), both showing moderate positive direct effects. Plant height also exhibited positive indirect effects through days to 50% flowering (0.0915) and biological yield per plant (0.0656). The relatively high direct effect of plant height contributed substantially to its strong positive overall correlation with grain yield ($r = 0.590$), indicating that plant height may have

considerable importance in determining grain yield under the conditions of the present study. In contrast, Saleh *et al.* (2020) reported a negligible direct effect of plant height ($\beta = 0.0501$) on grain yield in Egyptian and exotic rice genotypes, suggesting that the relative contribution of plant height to grain yield may vary with germplasm and growing environment. Babu *et al.* (2012) and Herawati *et al.* (2019) likewise reported positive but negligible direct effects of plant height, in agreement with Saleh *et al.* (2020). The comparatively larger direct effect observed in the present study may therefore reflect the response of the evaluated salt-tolerant germplasm under sodic soil conditions.

Days to 50% flowering exhibited a positive indirect effect through plant height (0.1720) and a negative indirect effect through productive tillers per plant (-0.1070). Its moderate positive direct effect ($\beta = 0.2061$) contributed substantially to the overall positive correlation with grain yield ($r = 0.478$), indicating that flowering time may also have relevance for yield improvement under the evaluated conditions. This observation is consistent with the findings of Singh *et al.* (2020).

Biological yield per plant exhibited a moderate positive direct effect on grain yield ($\beta = 0.2037$), together with a positive indirect effect through plant height (0.1247), contributing to its significant positive overall correlation with grain yield ($r = 0.418$). These results suggest that total dry matter production may play an important role in grain yield formation, in agreement with Saha *et al.* (2019), Saran *et al.* (2023), and Saketh *et al.* (2023). Further

support was provided by Prasanth *et al.* (2026), who, in an association study involving 24 elite salt-tolerant rice lines under direct-seeded conditions in Andhra Pradesh, reported positive associations of biological yield and harvest index with grain yield at both phenotypic and genotypic levels, highlighting their potential utility as selection criteria under salt-stress conditions [2, 12, 34, 39, 32, 35, 33, 29].

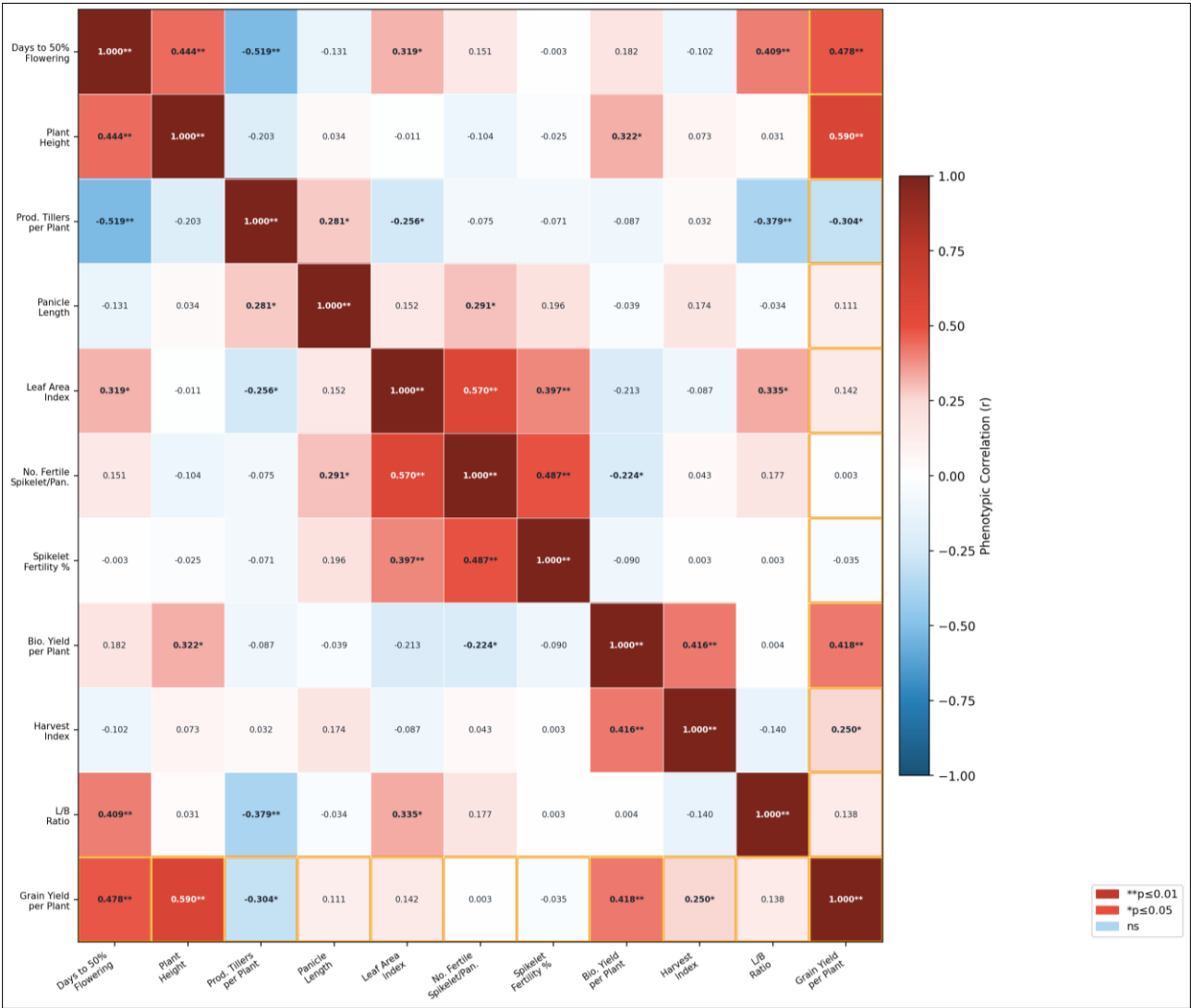


Fig 1: Phenotypic correlation heatmap among eleven yield-contributing traits in rice (*Oryza sativa* L.). Orange borders = correlations with GYP. ** $p \leq 0.01$; * $p \leq 0.05$.

Productive tillers per plant exhibited a weak negative direct effect on grain yield ($\beta = -0.1274$), consistent with its significant negative overall correlation ($r = -0.304$). Its indirect effects through plant height and biological yield per plant were also negative, further contributing to the observed negative association. This finding differs from the results of Shajan *et al.* (2024), who, in a path analysis study conducted at Prayagraj, Uttar Pradesh, during Kharif 2023, reported a positive association of productive tillers with grain yield, although its direct contribution was largely mediated through biomass. Alshugeairy *et al.* (2023) similarly emphasized the environment-dependent nature of direct effects in rice, highlighting the importance of path analysis for identifying appropriate selection criteria. The number of fertile spikelets per panicle (NFS/P; $\beta = -0.0390$), spikelet fertility (SF%; $\beta = -0.0832$), and leaf-to-breadth ratio (LBR; $\beta = -0.0230$) exhibited negligible negative direct effects on grain yield. The occurrence of negative direct effects despite positive associations among some component traits highlights the importance of partitioning correlation coefficients into direct and indirect effects before making selection decisions (Minnie *et al.*,

2013; Devi *et al.*, 2017; Saleh *et al.*, 2020). A comparable pattern was reported by Saleh *et al.* (2020), who observed that although several traits showed significant positive associations with grain yield, some traits had negligible direct effects. In their study, plant height ($\beta = 0.0501$) and panicle length ($\beta = 0.0726$) exhibited negligible direct effects despite their associations with other yield-related traits. Similarly, the present study revealed negligible direct effects for spikelet fertility, fertile spikelets per panicle, and LBR [37, 1, 24, 6, 34]. Overall, the path analysis indicated that plant height, days to 50% flowering, and biological yield per plant made comparatively larger positive direct contributions to grain yield than the other traits evaluated. Therefore, these traits may be considered promising selection criteria for grain yield improvement in the salt-tolerant rice genotypes evaluated under sodic soil conditions. However, the relatively high residual effect also indicates that grain yield is influenced by additional traits not included in the present analysis, and further multi-environment evaluation would be valuable for validating the stability of these selection criteria.

Table 5: Direct (bold, underlined, blue diagonal) and indirect effects of ten characters on grain yield per plant in rice (*Oryza sativa* L.). R²=0.5244; Residual e=0.6896

Traits	DF	PH	PT	PL	LAI	NFS	SF	BYP	HI	LBR	r (GYP)
Days to 50% Fl.	0.2061	0.1720	0.0661	-0.0194	0.0461	-0.0059	0.0002	0.0371	-0.0151	-0.0094	+0.478**
Plant height	0.0915	0.3874	0.0259	0.0050	-0.0016	0.0041	0.0021	0.0656	0.0108	-0.0007	+0.590**
Prod. tillers/plant	-0.1070	-0.0786	-0.1274	0.0415	-0.0370	0.0029	0.0059	-0.0177	0.0047	0.0087	-0.304*
Panicle length	-0.0270	0.0132	-0.0358	0.1478	0.0220	-0.0113	-0.0163	-0.0079	0.0257	0.0008	+0.111
Leaf area index	0.0658	-0.0043	0.0326	0.0225	0.1446	-0.0222	-0.0330	-0.0434	-0.0128	-0.0077	+0.142
No. fertile spk./pan.	0.0311	-0.0403	0.0096	0.0430	0.0824	-0.0390	-0.0405	-0.0456	0.0063	-0.0041	+0.003
Spikelet fertility%	-0.0006	-0.0097	0.0090	0.0290	0.0574	-0.0190	-0.0832	-0.0183	0.0004	-0.0001	-0.035
Bio. yield/plant	0.0375	0.1247	0.0111	-0.0058	-0.0308	0.0087	0.0075	0.2037	0.0614	-0.0001	+0.418**
Harvest index%	-0.0210	0.0283	-0.0041	0.0257	-0.0126	-0.0017	-0.0002	0.0847	0.1477	0.0032	+0.250*
L/B ratio	0.0843	0.0120	0.0483	-0.0050	0.0484	-0.0069	-0.0002	0.0008	-0.0207	-0.0230	+0.138

Bold underlined blue cells=direct effects. Scale (Lenka and Mishra, 1973): <0.10 neglected; 0.10-0.19 weak; 0.20-0.29 moderate; 0.30-0.99 strong; >1.00 very strong. Abbreviations same as Table 4. **p*≤0.05; ***p*≤0.01.

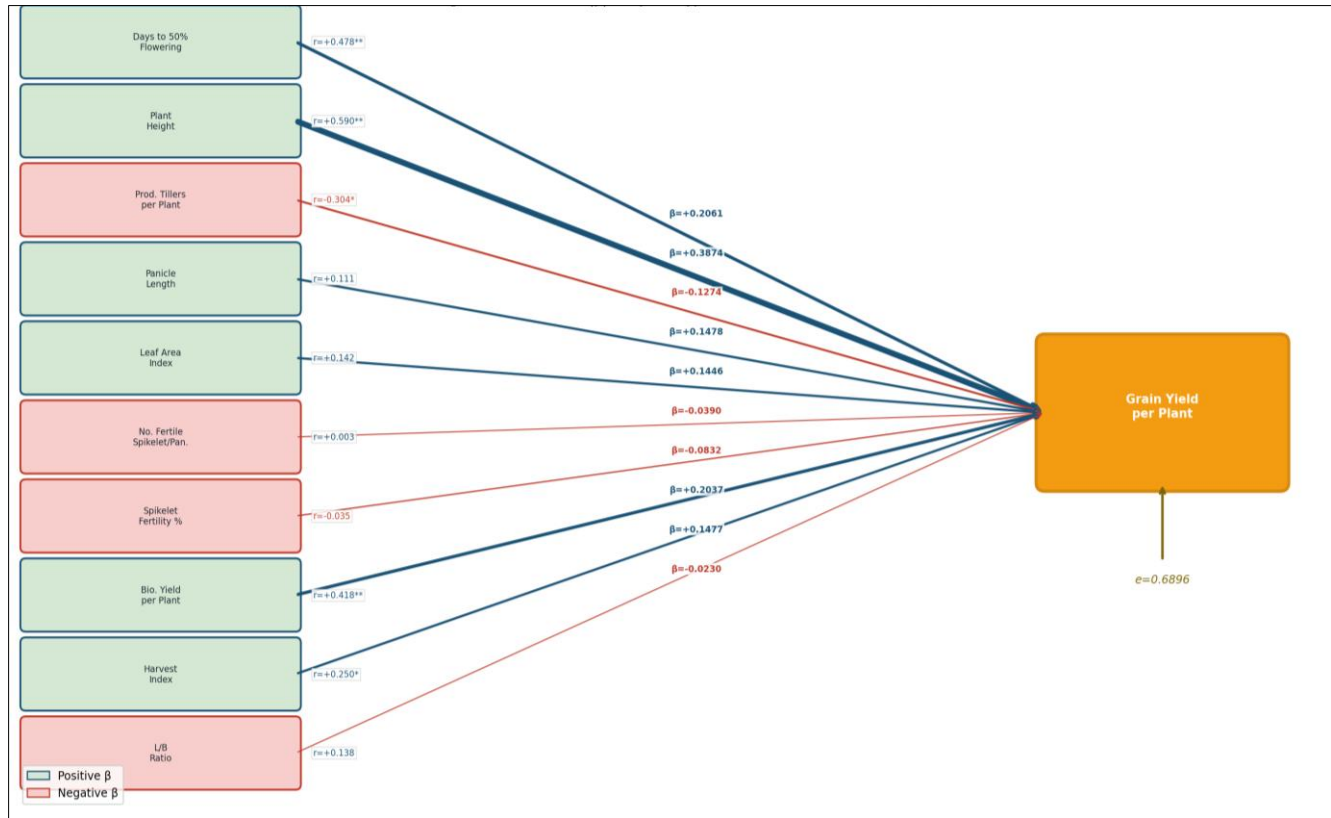


Fig 2: Path coefficient diagram: direct effects (β) of ten traits on grain yield in rice (*Oryza sativa* L.). Arrow width ∝|β|. r=phenotypic correlation with GYP. R²=0.5244; Residual e=0.6896.

3.4 Selection strategy

Based on the combined correlation and path coefficient analyses, plant height (β = 0.3874; r = 0.590) emerged as the most important selection criterion for grain yield, owing to its comparatively high positive direct effect. Biological yield per plant (β = 0.2037; r = 0.418**) and days to 50% flowering (β = 0.2061; r = 0.478**) also exhibited moderate positive direct effects and significant positive associations with grain yield, indicating their potential importance in selection for yield improvement. The negative direct effect of productive tillers per plant suggests that selection based solely on tiller number may not be effective under the evaluated sodic soil conditions. Among the evaluated genotypes, CSR 43, CSR-2748-4441-193, CSR 2016-IR 18-10, and CSR 27 exhibited comparatively higher grain yield and may serve as promising donor genotypes for future breeding programmes aimed at developing high-yielding, salt-tolerant rice.

4. Conclusion

Significant genetic variability was observed among the 24 rice genotypes for all eleven traits evaluated. The coefficient of determination (R² = 0.5244) indicated that the ten predictor traits collectively accounted for 52.44% of the variation in grain yield per plant, while the residual effect (0.6896) suggested the contribution of additional traits not included in the present analysis, warranting further investigation. Plant height (β = 0.3874), days to 50% flowering (β = 0.2061), and biological yield per plant (β = 0.2037) exhibited the highest positive direct effects and may therefore be considered important selection criteria for grain yield improvement under the evaluated conditions. In contrast, productive tillers per plant (β = -0.1274), spikelet fertility (β = -0.0832), and number of fertile spikelets per panicle (β = -0.0390) exhibited negative direct effects, highlighting the importance of path analysis in distinguishing direct effects from

associations mediated through other traits. The present findings are broadly consistent with Saleh *et al.* (2020), who emphasized the importance of direct effects in identifying effective selection criteria, although the traits showing the largest direct contributions differed between studies, presumably reflecting differences in germplasm and growing environments. While Saleh *et al.* (2020) identified 1000-grain weight ($\beta = 0.5107$), panicle number per plant ($\beta = 0.4003$), and full grain number per panicle ($\beta = 0.3028$) as major contributors to grain yield in Egyptian and exotic rice genotypes, the present study identified plant height ($\beta = 0.3874$), days to 50% flowering ($\beta = 0.2061$), and biological yield per plant ($\beta = 0.2037$) as important selection criteria in salt-tolerant germplasm evaluated under sodic soil conditions in eastern Uttar Pradesh. Accordingly, simultaneous consideration of plant height, flowering duration, and biological yield may be useful for improving grain yield under sodic soil conditions. Among the evaluated genotypes, CSR 43, CSR-2748-4441-193, CSR 2016-IR 18-10, and CSR 27 exhibited superior grain yield and may serve as promising donor parents in future breeding programmes aimed at developing high-yielding, salt-tolerant rice varieties for the Indo-Gangetic Plain.

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