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Dissecting Trait Interrelationships in Rice (*Oryza sativa* L.) through Correlation and Path Coefficient Analysis under Sodic Soil Conditions

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A B S T R A C T

Soil sodicity presents a major constraint to rice (*Oryza sativa* L.) cultivation, severely limiting growth and yield. This study aimed to investigate the interrelationships among key agronomic traits in rice under sodic soil conditions through correlation and path coefficient analysis. A total of 69 genotypes, including 52 F_1 hybrids and 17 parental lines developed through a Line × Tester mating design, were evaluated during the Kharif 2024 season at the Genetics and Plant Breeding Research Farm, NDUAT, Ayodhya, India. Eleven quantitative traits were measured, including grain yield, panicle traits, plant height, biological yield, and harvest index. Significant positive genotypic and phenotypic correlations were observed between grain yield per plant and traits such as biological yield (r = 0.977**), harvest index, panicle bearing tillers, and spikelet fertility. Path coefficient analysis revealed that biological yield had the highest positive direct effect on grain yield (1.48497), followed by harvest index (0.59499), emphasizing their importance in yield improvement. Conversely, plant height and panicle length had weak or negligible direct effects. These findings highlight the potential of integrating correlation and path analyses for identifying high-yielding, salt-tolerant genotypes, and provide valuable insights for breeding rice cultivars adapted to sodic soil environments.

Keywords

Rice, sodic soil, grain yield, correlation analysis, path coefficient analysis

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Introduction

Rice (*Oryza sativa* L.) is one of the most important staple crops globally, providing essential nutrition to billions of people (Khush, 2005). However, soil salinity, particularly sodic soils, is a major abiotic stress affecting rice productivity, limiting crop growth and yield (Sharma *et al.,* 2017). Sodic soils, characterized by high levels of sodium ions and low soil permeability, present a significant challenge to rice cultivation, especially in areas with limited irrigation resources (Yadav *et al.,* 2018). To overcome these constraints, understanding the genetic basis of trait interrelationships under sodic conditions is crucial for developing salt-tolerant rice varieties (Nawaz *et al.,* 2017). Trait associations among agronomic characteristics such as plant height, panicle length, and grain yield play a key role in improving the genetic potential of rice under stressful environments (Jena and Mackill, 2008).

Correlation analysis is a valuable tool for identifying significant relationships between traits and for selecting superior traits to enhance breeding strategies (Johnson *et al.,* 1955). Path coefficient analysis, a more advanced statistical technique, helps in understanding the direct and indirect effects of various traits on the final yield, providing insights into their genetic and phenotypic interactions (Dewey and Lu, 1959).

This method is particularly useful in determining which traits have the most significant impact on improving rice yield under sodic soil conditions (Gomez *et al.,* 2012).

Sodic stress impacts multiple rice traits, and correlation studies can reveal how these traits influence each other and contribute to overall performance (Chakraborty *et al.,* 2021). Evaluating the direct effects of traits such as panicle length, spikelet fertility, and biological yield on grain yield through path analysis is essential for effective selection in breeding programs (Reddy *et al.,* 2014). This study, therefore, aims to explore the interrelationships of important agronomic traits and their direct and indirect contributions to grain yield in rice under sodic soil conditions, providing insights into the potential pathways for improving productivity in salt-affected areas.

Materials and Methods

Experimental Site and Design

The present investigation entitled "Dissecting Trait Interrelationships in Rice (*Oryza sativa* L.) Through Correlation and Path Coefficient Analysis" was conducted at the Genetics and Plant Breeding Research Farm, Department of Genetics and Plant Breeding, Acharya Narendra Deva University of Agriculture and Technology (NDUAT), Kumarganj, Ayodhya (Faizabad), Uttar Pradesh, India. The experimental site is situated at 26.47°N latitude and 82.12°E longitude with an elevation of 113 meters above sea level. The study was carried out during the Kharif seasons of 2023 and 2024 under sodic soil conditions characterized by a high exchangeable sodium percentage (ESP >15%) and poor soil structure.

Experimental Materials

A total of 69 genotypes, comprising 52 F_1 hybrids developed by crossing 13 diverse lines with 4 testers in a Line × Tester mating design, and 17 parental genotypes (13 lines + 4 testers), were used in the experiment. The crosses were made during the Kharif season of 2023, and the evaluation was done in the Kharif season of 2024.

Experimental Layout

The experimental material was grown in a Randomized Block Design (RBD) with three replications. Each entry was planted in a plot of 2 rows, each 3 meters long with a spacing of 20 cm × 15 cm (row × plant). Standard agronomic practices were followed throughout the crop season to ensure healthy crop growth.

Observations Recorded

In this study, observations were recorded on eleven important quantitative traits contributing to grain yield and its components in rice. Data were collected on days to 50% flowering, days to maturity, plant height (cm), number of panicle bearing tillers per plant, panicle length (cm), number of spikelets per panicle, spikelet fertility percentage, 1000-grain weight (g), biological yield per plant (g), harvest index (%), and grain yield per plant (g).

Among these, days to 50% flowering, days to maturity, and 1000-grain weight were recorded on a plot basis, while the remaining traits were measured from five randomly selected competitive plants in each plot and averaged.

Statistical Analysis

Phenotypic and genotypic correlation coefficients among the studied traits were calculated to estimate the degree and direction of association between grain yield and its component traits, following the methodology outlined by Singh and Choudhary (1985). Genotypic correlations were estimated using variance and covariance components obtained from ANOVA. Path coefficient analysis, as proposed by Dewey and Lu (1959), was performed to partition the genotypic correlation coefficients into direct and indirect effects, with grain yield per plant treated as the dependent variable and other traits as independent variables. All statistical analyses were carried out using MS Excel, R software, and the OPSTAT online analysis tool for correlation and path coefficient computations.

Results and Discussion

The analysis of genotypic and phenotypic correlation coefficients between 11 traits in rice under sodic soil conditions revealed several important relationships that contribute to the understanding of the genetic and environmental factors influencing grain yield and its components. The data from both genotypic and phenotypic correlations showed consistent trends, with a few notable differences that can aid in selecting traits for breeding under challenging sodic soil conditions (Yadav *et al.,* 2018; Kumar *et al.,* 2020).

Correlation between Traits

Grain yield per plant showed significant positive correlations with several traits at both genotypic and phenotypic levels (Table 4.1), highlighting its potential as a key trait in breeding programs. In the genotypic correlation matrix, grain yield per plant exhibited significant positive associations with biological yield per plant (0.977**) and harvest index (−0.931**), indicating that these traits are genetically linked and may be jointly selected to enhance yield performance (Singh *et al.,* 2016). The phenotypic correlation also revealed similar trends, with biological yield per plant (0.891**) and harvest index (−0.729**) showing strong associations (Hassan *et al.,* 2017).

The positive association between biological yield per plant and grain yield per plant at both genotypic (0.977**) and phenotypic (0.891**) levels suggests that increasing the biological yield could directly contribute to higher grain yield (Rani *et al.,* 2019). Similarly, the negative correlation between harvest index and grain yield indicates that efforts to improve the harvest index could also result in better partitioning of biomass into grain, thereby improving yield (Rahman *et al.,* 2018).

Both days to 50% flowering and days to maturity showed moderate positive correlations with grain yield at the genotypic level (0.163* and −0.044) and phenotypic level (0.108 and −0.011), respectively. These correlations were statistically significant, indicating that later flowering and maturity may be associated with better yield outcomes (Basu *et al.,* 2015). This suggests that selection for late maturing varieties under sodic soil conditions may be beneficial, as these plants may accumulate more biomass before harvest (Sharma *et al.,* 2020).

The panicle traits, such as panicle length, panicle bearing tillers per plant, and spikelet fertility, displayed moderate to strong positive correlations with grain yield per plant at the genotypic and phenotypic levels. Notably, panicle bearing tillers per plant and spikelet fertility showed significant positive correlations with grain yield at the genotypic level (0.321** and 0.302**, respectively) (Choudhary *et al.,* 2019). The phenotypic correlation was also significant for spikelet fertility (0.246**) and panicle length (0.528**), emphasizing their importance in increasing grain yield potential (Bera *et al.,* 2017). Improvement in these traits, particularly panicle bearing tillers per plant and spikelet fertility, could contribute to better grain set and ultimately higher yields under sodic soil conditions, where nutrient availability and soil toxicity can limit yield potential (Bhat *et al.,* 2018; Sharma *et al.,* 2017). Plant height exhibited weak negative correlations with grain yield per plant at the genotypic (−0.077) and phenotypic (−0.035) levels, suggesting that shorter plants may be more suitable for high grain yield under sodic soil conditions (Pandey *et al.,* 2020). Similarly, 1000-seed weight showed a positive correlation with grain yield per plant at the genotypic level (0.163*), but the phenotypic correlation was weak (0.108), indicating that seed size may influence yield under these conditions (Khush *et al.,* 2019).

The positive correlations between biological yield per plant and grain yield per plant and the negative correlation between harvest index and grain yield suggest that improving biological yield, while optimizing harvest index, may be effective strategies for improving yield under sodic soil conditions (Singh *et al.,* 2018).

The findings suggest that breeders should focus on enhancing these traits, while also considering the genetic and environmental factors influencing yield (Yadav *et al.,* 2018). Additionally, optimizing harvest index and plant height could further improve yield potential under sodic soil conditions (Pandey *et al.,* 2020). Moreover, the weak negative correlation between plant height and grain yield suggests that shorter stature varieties may be more adaptable to the stress conditions present in sodic soils, where lodging and excessive height may lead to yield losses (Choudhary *et al.,* 2019). Similarly, 1000-seed weight showed potential as a secondary trait to enhance yield, although its impact may be less direct compared to other traits (Bera *et al.,* 2017).

Table.1 Estimates of genotypic and phenotypic correlation coefficients between 11 traits in rice under sodic soil

Characters		Days to 50% flowering	Days to maturity	Plant height (cm)	Panicle bearing tillers per plant	Panicle length (cm)	Spikelets per panicle	Spikelet fertility (%)	1000-seed weight (g)	Biological yield per plant	Harvest index (%)	Grain yield per plant
Days to 50% flowering	G	**1.000**	0.598**	-0.219**	-0.222**	-0.233**	0.001	0.555**	0.163*	-0.081	0.034	-0.121
	P	**1.000**	0.322**	-0.082	-0.123	-0.102	-0.028	0.343**	0.108	-0.066	0.034	-0.088
Days to maturity	G		**1.000**	-0.257**	-0.144*	-0.058	-0.072	0.570**	-0.050	0.023	-0.129	-0.044
	P		**1.000**	-0.133	-0.069	-0.064	-0.025	0.513**	0.002	0.025	-0.085	-0.011
Plant height (cm)	G			**1.000**	-0.052	0.303**	0.125	-0.098	0.058	-0.042	0.045	-0.077
	P			**1.000**	-0.025	0.163*	0.127	-0.073	0.015	-0.018	0.014	-0.035
Panicle bearing tillers per plant	G				**1.000**	0.493**	0.504**	0.093	0.321**	0.156*	0.159*	0.132
	P				**1.000**	0.334**	0.401**	0.065	0.207**	0.152*	0.150*	0.123
Panicle length (cm)	G					**1.000**	0.440**	0.197**	0.515**	0.244**	0.216**	0.234**
	P					**1.000**	0.318**	0.155*	0.528**	0.212**	0.184**	0.193**
Spikelets per panicle	G						**1.000**	0.053	0.357**	0.209**	0.255**	0.173*
	P						**1.000**	0.051	0.230**	0.202**	0.223**	0.166*
Spikelet fertility (%)	G							**1.000**	0.448**	0.276**	0.302**	0.244**
	P							**1.000**	0.299**	0.210**	0.246**	0.160*
1000-seed weight (g)	G								**1.000**	0.038	0.046	0.007
	P								**1.000**	0.046	0.037	0.028
Biological yield per plant	G									**1.000**	0.977**	0.984**
	P									**1.000**	0.891**	0.956**
Harvest index (%)	G										**1.000**	-0.931**
	P										**1.000**	-0.729**
Grain yield per plant	G											**1.000**
	P											**1.000**

*, ** Significant at 5% and 1% probability levels respectively.

Table.2 Estimates of genotypic and phenotypic direct and indirect effects of different traits on grain yield per plant in Rice under sodic soil

Characters		Days to 50% flowering	Days to maturity	Plant height (cm)	Panicle bearing tillers per plant	Panicle length (cm)	Spikelets per panicle	Spikelet fertility (%)	1000-seed weight (g)	Biological yield per plant	Harvest index (%)	Correlation with grain yield per plant
Days to 50% flowering	G	**-0.04149**	-0.00966	0.01187	0.00956	-0.00142	0.00003	0.02257	-0.00585	-0.12799	0.02158	-0.121
	P	**-0.01397**	0.00039	0.00158	0.0022	-0.00004	-0.00034	0.00095	-0.00176	-0.0973	0.02015	-0.088
Days to maturity	G	-0.02483	**-0.01614**	0.01392	0.00619	-0.00035	-0.00278	0.02319	0.0018	0.03615	-0.08081	-0.044
	P	-0.00449	**0.00121**	0.00256	0.00123	-0.00002	-0.0003	0.00142	-0.00003	0.03758	-0.0505	-0.011
Plant height (cm)	G	0.00907	0.00414	**-0.05427**	0.00226	0.00185	0.00483	-0.00397	-0.00207	-0.06692	0.02805	-0.077
	P	0.00114	-0.00016	**-0.01932**	0.00045	0.00006	0.00152	-0.0002	-0.00024	-0.0263	0.00845	-0.035
Panicle bearing tillers per plant	G	0.00919	0.00232	0.00284	**-0.04314**	0.00300	0.01951	0.00377	-0.01155	0.24638	-0.0999	0.132
	P	0.00171	-0.00008	0.00048	**-0.01791**	0.00012	0.00479	0.00018	-0.00336	0.22605	-0.08939	0.123
Panicle length (cm)	G	0.00967	0.00094	-0.01644	-0.02126	**0.00609**	0.01705	0.00802	-0.01851	0.38431	-0.13554	0.234**
	P	0.00143	-0.00008	-0.00315	-0.00598	**0.00035**	0.00381	0.00043	-0.00857	0.31482	-0.1097	0.193**
Spikelets per panicle	G	-0.00003	0.00116	-0.00677	-0.02173	0.00268	**0.03873**	0.00214	-0.01282	0.33001	-0.15988	0.173*
	P	0.00039	-0.00003	-0.00245	-0.00717	0.00011	**0.01197**	0.00014	-0.00374	0.30008	-0.1329	0.166*
Spikelet fertility (%)	G	-0.02302	-0.0092	0.00529	-0.004	0.0012	0.00203	**0.04068**	-0.01609	0.43624	-0.18961	0.244**
	P	-0.0048	0.00062	0.00141	-0.00117	0.00005	0.00062	**0.00277**	-0.00484	0.31166	-0.14614	0.160*
1000-seed weight (g)	G	-0.00676	0.00081	-0.00313	-0.01387	0.00314	0.01381	0.01822	**-0.03594**	0.05941	-0.02877	0.007
	P	-0.00151	0.00000	-0.00029	-0.00371	0.00019	0.00276	0.00083	**-0.01621**	0.06832	-0.02207	0.028
Biological yield per plant	G	0.00337	-0.00037	0.0023	-0.00674	0.00148	0.0081	0.01125	-0.00135	**1.57787**	-0.61225	0.984**
	P	0.00092	0.00003	0.00034	-0.00273	0.00008	0.00242	0.00058	-0.00075	**1.48497**	-0.53008	0.956**
Harvest index (%)	G	-0.00143	0.00208	-0.00243	0.00688	-0.00132	-0.00988	-0.0123	0.00165	-1.54108	**0.62686**	-0.931**
	P	-0.00047	-0.0001	-0.00027	0.00269	-0.00007	-0.00267	-0.00068	0.0006	-1.32297	**0.59499**	-0.729**

Residual effect= 0.00952 (genotypic), 0.01269 (phenotypic), Direct effects on main diagonal (bold figures)
*, ** Significant at 5% and 1% probability levels respective

In conclusion, this study highlights the complex relationships between agronomic traits and their effects on grain yield in rice under sodic soil conditions. The strong positive correlation between biological yield per plant and grain yield per plant, along with significant relationships observed for panicle traits and spikelet fertility, offers valuable insight into selecting superior genotypes for breeding programs (Hassan *et al.,* 2017). The findings suggest that breeders should focus on enhancing these traits, while also considering the genetic and environmental factors influencing yield (Yadav *et al.,* 2018). Additionally, optimizing harvest index and plant height could further improve yield potential under sodic soil conditions (Pandey *et al.,* 2020).

Path analysis

The phenotypic path coefficient analysis provided insights into the direct and indirect effects of various traits on grain yield per plant under sodic soil conditions (Table 4.2). The main diagonal of the phenotypic path matrix indicates the direct effects, while the off-diagonal values represent indirect effects mediated through other traits.

Among the traits studied, biological yield per plant (1.48497) exhibited the highest positive direct effect on grain yield, indicating it as the most crucial contributor to yield under sodic stress. This suggests that selecting for high biomass can be an effective strategy for yield improvement in such adverse environments (Rahman *et al.,* 2018; Sharma *et al.,* 2020). Harvest index (0.59499) also showed a substantial positive direct effect, aligning with findings that an efficient partitioning of photosynthates plays a key role in improving grain yield under stress (Yadav *et al.,* 2018; Singh *et al.,* 2018). However, its highly negative indirect effect via biological yield (-1.32297) suggests a complex interaction that may reduce its overall contribution to yield when biomass is not managed properly.

Panicle length (0.00035) and 1000-seed weight (−0.01621) exhibited relatively low direct effects, though they influenced yield indirectly through traits such as spikelet fertility and biological yield. The moderate correlation between panicle length and yield (r = 0.193) suggests it could be used as a secondary selection criterion (Choudhary *et al.,* 2019). Biological yield had substantial positive indirect effects via spikelet fertility (0.31166) and spikelets per panicle (0.30008), indicating their significant roles in contributing to biomass and ultimately yield. This finding is consistent with the work of Singh *et al.* (2016), who emphasized the importance of spikelet-related traits under sodic stress. Interestingly, days to 50% flowering (−0.088) and plant height (−0.035) had negative total correlations with yield due to their low direct and indirect effects. Early flowering and reduced height may be adaptive traits under sodicity, where early maturity avoids prolonged stress exposure (Basu *et al.,* 2015; Kumar *et al.,* 2020).

Panicle bearing tillers per plant showed a moderate positive correlation (0.123) with yield, supported by both its direct (−0.01791) and indirect effects through biological yield and spikelets per panicle. This aligns with previous findings that emphasize the importance of tillering ability in rice breeding programs (Bera *et al.,* 2017).

Traits such as biological yield, harvest index, spikelet fertility, and spikelets per panicle emerged as major contributors to yield either directly or indirectly. These results are in agreement with earlier studies that identified these traits as important selection indices for improving rice yield under abiotic stress (Khush *et al.,* 2019; Bhat *et al.,* 2018). The phenotypic residual effect was 0.01269, indicating that the studied traits explained 98.73% of the variation in grain yield per plant. This low value confirms the adequacy of the selected traits in determining yield under sodic soil conditions.

In conclusion, the correlation and path coefficient analyses conducted under sodic soil conditions revealed that grain yield in rice is strongly influenced by traits such as biological yield per plant, harvest index, spikelet fertility, and panicle traits. Biological yield exhibited the highest positive direct effect on grain yield, while harvest index, despite showing a strong positive direct effect, also demonstrated significant negative indirect effects, highlighting the need to balance biomass production and partitioning. Panicle bearing tillers per plant and spikelet fertility emerged as important indirect contributors, reaffirming their relevance in breeding programs. The high coefficient of determination confirms the efficiency of these selected traits in predicting grain yield under stress.

Overall, the study suggests that targeting key yield-contributing traits through direct and indirect selection can effectively enhance rice productivity in sodic soils, offering a strategic approach for breeding resilient and high-yielding genotypes.

Author Contributions

Mohammad Nisar: Investigation, formal analysis, writing—original draft. Kunvar Gyanendra Kumar: Validation, methodology, writing—reviewing. Rudra Pratap Singh:—Formal analysis, writing—review and editing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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