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Deciphering path coefficient analysis in rice (*Oryza sativa* L.) under saline soils

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ABSTRACT

The combination of many yield-contributing factors results in the expression of complex traits like yield. In the current study, 86 rice genotypes participated in an experiment to assess seed yield and its component qualities using path coefficient analysis to determine direct and indirect effects. Through direct positive impacts and indirect positive effects through various yield-attributing features, the path analysis results indicated that the number of productive tillers, total number of grains per panicle, panicle length, and test weight were the most important factors in determining the rice seed yield. As a result, during the selection process, it is imperative to prioritize features that show notable and considerable direct consequences. The phenotypical residual value was 0.614. The influence of other characteristics is the cause of high residual effect levels. The development of high-yielding cultivars appropriate for salt conditions will be a fruitful outcome of this strategy.

Keywords: *Rice, Path coefficient, Salinity, Seed yield*

Introduction

One of the most vital grains for world dietary intake, rice (*Oryza sativa* L.) serves as the main energy source for people in Asia, Africa, and Latin America (Fukagawa and Ziska 2019). Over 3% of the world's agricultural land (162 million hectares) was used for rice cultivation, yielding 755 million tons (FAOSTAT 2021). India, the world's second-largest producer of rice, possesses about 25% of the world's rice cultivation land. India's food supply and food security are significantly influenced by this crop as well. (Rathna Priya *et al*. 2019).

Agricultural landscapes are changing as a result of abiotic stressors and climate change. In regions of the world where rice is grown, salinity is the second most common abiotic stressor after drought. In India, saline-affected soils cover around 6.73 million hectares of land (Krishnamurthy *et al*. 2014). Low precipitation, high surface evaporation, weathering of native rocks, saline irrigation, and poor cultural practices are all contributing factors to the growing area under salinization (Shrivastava and Kumar 2015). Although secondary inland salinization is also anticipated to affect irrigated fields, climate change-induced sea level rise is likely to make situations worse (Wassman *et al*. 2004). It has been estimated that more than 50% of the arable land will be

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affected by salinity by the end of 2050 (Jamil *et al*. 2011).

In general terms, salt hinders agricultural plants' ability to absorb water through their roots, which impacts the plant's metabolic functions. It affects cell development and expansion right away since a high salt concentration is harmful. Osmotic stress and oxidative damage are minor causes of salt damage, whereas ion toxicity is the main reason. Over the course of the crop, the rice crop is negatively impacted by saline stress, which results in low seed germination, delayed seedling growth, seedling mortality, low biomass accumulation, decreased main root length and several lateral roots, decreased tillering ability, fewer spikelets per panicle, increased spikelet sterility percentage, and decreased panicle weight, all of which significantly reduce grain yield. It is recommended for a future recombinant breeding program to comprehend the direct and indirect consequences among its components and yield, since these interactions are crucial for using them to acquire desired alteration.

Selecting preferred lines to be incorporated into a breeding program and releasing new varieties would require an understanding of the relationships between phenotypic traits and how they affect yield (Dhavaleshvar *et al.,* 2019). Although the direct and indirect effects on yield and yield-related components may be favorable or unfavorable, it is possible to identify the direct influence of that specific character and the indirect influence through other components. Determining the path coefficient is therefore essential in order to partially detect the association of these influences and uncover the relationship and root between yield-related factors and yield. In the present investigation, seed yield per plant was considered as a resultant variable and mortality percentage, days to 50% flowering, plant height (cm), panicle length (cm), number of productive tillers/ m^2, total number of grains per panicle, number of un-filled grains per panicle, sterility percentage (%) and 1000 grain weight (g) are the causal (independent) variables.

Material and Methods

Plant materials

The plant materials used in the study consisted of 80 genotypes and 6 checks of rice, including advanced breeding lines, released varieties, and elite lines generated through various breeding procedures, collected from various sources and maintained at the Agricultural Research Station in Kampasagar, Telangana Table 1.

Experimental layout

The 80 genotypes along with four tolerant checks (FL 478, CSR 23, CSR 36, RNR 11718), one susceptible check (Pusa-44), and one local yield check (KPS

Table 1. List of rice genotypes and checks utilized in the experiment

Sources	Germplasm lines
Germplasm collection	IR78222-20-7-148-2-B-B-B-B, IRRI 104, URAIBOOL IRGC 52785, Oryzica 1, CT118911-2-2-7-M, Kinandang patong, OM4900, IR6, Zanton:IRGC 31248-1, SUPA, M 202, MINGHU 163, ZHENSHAN 97B, IRRI 147, SANHUANGZHAN-NO2, IR10M 300, Manaw thukha, BR 28, Fedearroz 50, NSIC RC 240, GSRIR2-9-RI-Su3-Y2, IR13F 167, IR69726-116-1-1, IR77186-122-2-2-3, IRRI 154, IRBB 66, IR64-21, IR77298, N22 IRGC 19379-1, IR 93340, IR 93354, Khao Hlan on, IR 84984-83-15-481-B, IR10F 360, DJ123, TEQING, UPLR17:IRTP9897-C1, Jamir.
Varieties	MTU1010, Nanhi, Jasmine 85, Sambha mahsuri+sub1, Swarna, SADRI, TN1, Sahel 177.
Advanced breeding lines	KPS 13576, KPS 13577, KPS 13580, KPS 13584, KPS 10667, KPS 10672, KPS 13582, KPS 10628, KPS 10640, KPS 10656, KPS 10676, KPS 10683, KPS 10633, KPS 10658 KPS 10631, KPS 10642, KPS 10651, KPS 10654, KPS 10657, KPS 10661, KPS 10669, KPS 10316, KPS 10319, KPS 10321, KPS 10329, KPS 13575, KPS 13578, KPS 13579, KPS 13581, KPS 13583, KPS 13585, KPS 13586, KPS 13587, KPS 13588.
Checks	CSR 23 (Alkalinity and salinity tolerant check) CSR 36 (Alkalinity tolerant check) RNR 11718 (Local alkalinity and salinity check) FL 478 (Salinity tolerant check) KPS 2874 (Local yield check) PUSA 44 (Susceptible check)

2874) were sown in Randomized Complete Block Design with three replications in the *Rabi*, 2020-2021. The spacing of 25 cm between rows and 15 cm between plants was followed. The main field is a stress block for inland salinity with a pH of 9.3, E.C of 4.68 dSm^{-1} and an ESP value of 88.0. For the trait mortality percentage based on IRRI SES 2013 injury was calculated Table 2.

Data analysis

The formula given by given by Dewey and Lu (1959) is used for computation of path analysis.

Results and Discussion

The results of the path coefficient analysis of growth and yield characters on grain nutrients under aerobic conditions are presented in Table 3 and Fig. 1. The highest positive direct effect on the seed yield per plant was number of productive tillers (0.2241) whereas, the lowest positive direct effect on grain yield per plant was 1000 grain weight (0.0542). Among studied traits, the highest negative direct effect on grain yield per plant was mortality percentage (0.2232) whereas, the lowest negative direct effect on grain yield per plant was days to 50% flowering (0.0918). The highest positive indirect effect on grain yield per plant via number of productive tillers was mortality percentage (0.0986), whereas the lowest positive indirect effect was panicle length via days to 50% flowering (0.0026). The mortality percentage on grain yield had the highest negative indirect effect via number of productive tillers (0.0990), while via sterility percentage on grain yield via panicle length was at the bottom of the indirect negative effect (0.0028).

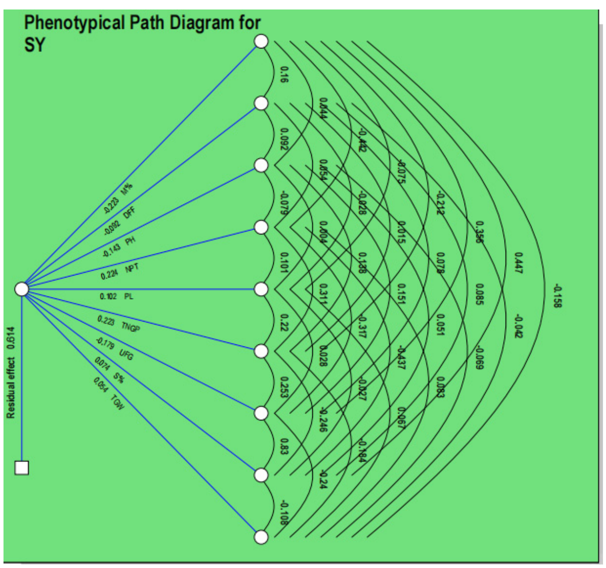

Fig. 1. Phenotypic path diagram of rice genotypes for yield and its attributing traits

The trait mortality percent had a positive indirect effect on number of productive tillers/m^2 (0.0986), panicle length (0.0167), total number of grains per panicle (0.0473), and 1000 grain weight (0.0354). The direct effect on seed yield per plant was negative (-0.2232). Its indirect effects were negative through days to 50% flowering (-0.0358), plant height (-0.0098), number of un-filled grains per panicle (-0.0795) and sterility percentage (-0.0998). Touhiduzzaman *et al.* (2016) reported similar findings for this trait with seed yield per plant.

For days to 50% flowering negative and lowest (-0.0918) direct effect on yield and negative indirect effects were seen through mortality percentage (-0.0147), plant height (-0.0084), number of productive tillers/m^2 (-0.0049), total number of grains per panicle (-0.0014), number of un-filled grains per panicle (-0.0072), and sterility percentage (-0.0078). Positive indirect effects were seen through panicle length (0.0026), and 1000 grain weight (0.0039). These results of days to 50 % flowering having a negative direct effect on seed yield per plant are in line with the findings of Dushyanthakumar (2008), Nandan *et al*. (2010), Shrivatsav *et al.* (2020) and Hasan-Ud-Daula and Sarker (2020).

Plant height (cm) exhibited a negative direct effect on seed yield per plant (-0.1428). These results are in agreement with the findings of Sumithra *et al.* (2019), Muthuvijayaragavan and Murugan (2020),

Table 2. Scoring of damage for salt injury in field conditions in rice standard evaluation system scale (IRRI-SES 2013)

Score	Growth Scale	Salinity-induced reaction
1	Normal growth, no leaf symptoms	Highly tolerant
3	Nearly normal growth, but leaf tips of few leaves whitish and rolled.	Tolerant
5	Growth severely retarded, most leaves rolled, only a few are elongating	Moderately tolerant
7	Complete cessation of growth, most leaves dry, some plants drying	Susceptible
9	Almost all plants dead or drying	Highly susceptible

and Shrivatsav *et al.* (2020). The negative direct effect of plant height on yield was met through positive indirect effects through number of productive tillers/m^2 (0.0112), and 1000 grain weight (0.0099). But negative indirect effects on plant height was through mortality (%) (-0.0063), days to 50% flowering (-0.0131), panicle length (cm) (-0.0005), total number of grains per panicle (-0.0197), number of un-filled grains per panicle (-0.0215) and sterility percentage (%) (-0.0072). Senguttuvel *et al*. (2010) and Akinwale *et al*. (2011) reported the same results for plant height.

Number of productive tillers showed a positive direct effect on seed yield per plant (0.2241). Positive direct effect on seed yield per plant was also reported by Karthikeyan *et al*. (2019), and Saha *et al*. (2019). Number of productive tillers/m^2 showed positive indirect effects through days to 50% flowering (0.0121), panicle length (0.0226), panicle length (cm) (0.0226), total number of grains per panicle (0.0697), and 1000 grain weight (g) (0.0187). But negative indirect effects on number of productive tillers/m^2 were seen through mortality percentage (-0.0990), plant height (-0.0177), number of un-filled grains per panicle (-0.0711), and sterility per cent (-0.0980). These results are in accordance with the work of Kranto *et al.* (2016).

Panicle length (cm) reported positive direct effect on seed yield per plant (0.1017). Positive indirect effects on PL through plant height (cm) (0.0004), number of productive tillers/m^2 (0.0103), total number of grains per panicle (0.0224) and number of unfilled grains per panicle (0.0079). But negative indirect effects were seen in the case of the mortality percentage (-0.0076), days to 50% flowering (-0.0028), and sterility percentage (-0.0028). Similar results were reported by Krishnamurthy *et al*. (2013), Karthikeyan *et al*. (2019) and Kiruthikadevi *et al*. (2020).

Total number of grains per panicle has a positive direct effect on seed yield per plant (0.2226). NGP showed negative indirect effects were seen through mortality per cent (-0.0472), sterility percentage (-0.0548), and 1000 grain weight (g) (-0.0409). But positive indirect effects were seen in case of days to 50 % flowering (0.0033), plant height (cm) (0.0307), panicle length (cm) (0.0490), number of productive tillers/m^2 (0.0692), and number of un-filled grains per panicle (0.0563). These findings confirm with the reports of Aarthi *et al.* (2019), Saha *et al.* (2019).

Un-filled grains showed negative direct effect on seed yield per plant (-0.1785) and negative indirect effects was seen through mortality percentage (-0.0636), days to 50 % flowering (-0.0139), plant height (-0.0269), panicle length (-0.0050), total number of grains per panicle (-0.0452) and sterility percentage (-0.1481). But positive indirect effects were seen through number of productive tillers/m^2 (0.0566), and 1000 grain weight (0.0428). These results of a negative direct effect on seed yield per plant were also reported by Sarawgi *et al.* (1997) and Saha *et al.* (2019).

Sterility percentage showed a positive direct effect on seed yield per plant (0.0737) and positive in-

Table 3. Direct and indirect effects of different traits on yield as partitioned by path analysis along with three checks evaluated under saline field conditions

	M %	DFF	PH (cm)	NPT/m^2	PL (cm)	NGP	UFG	S%	TW (g)
M %	-0.2232	-0.0358	-0.0098	0.0986	0.0167	0.0473	-0.0795	-0.0998	0.0354
DFF	-0.0147	-0.0918	-0.0084	-0.0049	0.0026	-0.0014	-0.0072	-0.0078	0.0039
PH (cm)	-0.0063	-0.0131	-0.1428	0.0112	-0.0005	-0.0197	-0.0215	-0.0072	0.0099
NPT/m^2	-0.0990	0.0121	-0.0177	0.2241	0.0226	0.0697	-0.0711	-0.0980	0.0187
PL (cm)	-0.0076	-0.0028	0.0004	0.0103	0.1017	0.0224	0.0029	-0.0028	0.0068
NGP	-0.0472	0.0033	0.0307	0.0692	0.0490	0.2226	0.0563	-0.0548	-0.0409
UFG	-0.0636	-0.0139	-0.0269	0.0566	-0.0050	-0.0452	-0.1785	-0.1481	0.0428
S%	0.0329	0.0062	0.0037	-0.0322	-0.0020	-0.0181	0.0611	0.0737	-0.0079
TW (g)	-0.0086	-0.0023	-0.0038	0.0045	0.0036	-0.0099	-0.0130	-0.0058	0.0542

Residual Effect = 0.614
Bold values indicate direct effects
M% - Mortality percentage
DFF- Days to 50 % flowering
PH (cm) - Plant height
PL (cm) - Panicle length
NPT/m^2 - Number of Productive tillers/m^2
NGP - Total number of grains/panicle
UFG - Number of un-filled grains/panicle
S % - Sterility percentage
TW (g) – 1000 grain weight
SY (g) - Seed yield/plant

direct effect through mortality percentage (0.0329), days to 50 per cent flowering (0.0062), plant height (0.0037), and number of un-filled grains per panicle (0.0611). Negative indirect effects were seen through number of productive tillers/m^2 (-0.0322), panicle length (cm) (-0.0020), total number of grains per panicle (-0.0181), and 1000 grain weight (g) (-0.0079). A similar case of sterility percentage (%) having a positive direct effect on yield was reported by Sarawgi *et al*. (1997).

1000 grain weight showed a positive direct effect on seed yield per plant with a value of 0.0542. Its negative indirect effects were seen in case of mortality percentage (-0.0086), days to 50 % flowering (-0.0023), plant height (cm) (-0.0038), total number of grains per panicle (-0.0099), number of un-filled grains per panicle (-0.0130) and sterility percentage (-0.0058). But positive indirect effects were seen through panicle length (cm) (0.0036) and number of productive tillers/m^2 (0.0045). A similar case was reported it to have a positive direct effect on yield by Karthikeyan *et al.* (2019), and Shrivatsav *et al.* (2020).

In the present study, path coefficient analysis was carried out at the phenotypic level for ten traits which showed a significant correlation with grain yield per plant. Among the characters studied, number of productive tillers, total number of grains per panicle, panicle length, sterility percentage and 1000 grain weight affected directly, positively, and significantly grain yield per plant. Therefore, choosing those traits could result in an increase in rice grain production. The current study's findings on the positive direct effects of several features on grain yield are consistent with those of Yadav *et al.* (2017) regarding the number of tillers per plant, Faysal *et al.* (2022), and Saleh *et al.* (2020) regarding test weight. Our research supports the findings of Chandra and Nilanjaya (2017), who demonstrated that under aerobic and normal conditions, a variety of characteristics, such as the number of tillers per plant and the number of spikelets per panicle, had a direct and detrimental impact on desired qualities.

Based on path coefficient analysis, the relationship between two elements might be separated into direct and indirect impact through other components (Wright, 1921). Our findings concurred with those of Reetisana *et al.* (2022), who found that panicle length, a measure of days to 50% flowering, had a detrimental indirect effect on grain output per plant. Additionally, Saleh *et al.* (2020) found that the analyzed parameters of panicle length, quantity per plant, and days to heading all had a negative and omitted indirect effect on the yield of grain as a result of plant height.

The direct and indirect effects of yield contributing components and yield were computed in this study. The genuine relationship was explained and plant breeders were able to select directly through these traits since the relationship between the effect and a causal factor was comparable to its direct effect. However, if the direct influence were small or negative, the positive correlation might be the result of indirect effects. In that instance, all of the other factors were used at the same time during the selection process.

Additionally, when the direct effect was high and positive but the correlation was negative, additional limits may be employed to reduce the unexpected indirect consequences in order to exploit the direct effect. Based on the path coefficient data, the number of productive tillers, total number of grains per panicle, panicle length, and test weight were critical characteristics that should be taken into consideration as selection criteria in order to improve grain production. The findings also showed that the number of tillers per plant had the greatest positive direct and indirect effects on other qualities, indicating that the best method would be to select for grain yield based on this attribute.

Residual effect

The phenotypical residual value was 0.614. High values of residual effect are due to the influence of other traits. The association of different component characters among themselves and with yield is quite important for devising an efficient selection criterion for yield. The total correlation between yield and component characters may be sometimes misleading, as it might be an over-estimate or under-estimate because of its association with other characters. Hence, indirect selection by correlated response may not be sometimes fruitful, when many characters are affecting a given character, splitting the total correlation into direct and indirect effects of cause as devised by Wright (1921) would give more meaningful interpretation to the cause of the association between the dependent variable like yield and independent variables like yield components.

This kind of information will help formulate the selection criteria, indicate the selection for these characters is likely to bring about an overall improvement in single plant yield directly. Path analysis revealed that direct effect on seed yield per plant by number of productive tillers, total number of grains and panicle length. This indicates that if other factors are held constant, an increase in number of productive tillers will also contribute to greater panicle length results in increase in total number of grains per plant and reflect increased seed yield.

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Declarations

Conflict of interest: The authors declare that they have no competing interests.

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