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Quantitative Trait Relationship Modelling for Yield and Biofortification Traits in Rice (*Oryza sativa* L.)

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Abstract

The present investigation was undertaken to estimate the direct and indirect effects of yield contributing, grain quality and biofortification traits on grain yield through path coefficient analysis in the rice cross Swarna × Madhukar. Six generations namely P_1, P_2, F_1, F_2, BC_1 and BC_2 were evaluated during kharif 2012 under irrigated conditions at DRR Farm, ICRISAT campus, Hyderabad. Observations were recorded for plant height, days to 50% flowering, panicle length, productive tillers per plant, filled grains per panicle, test weight, kernel dimensions, grain iron content, grain zinc content and grain yield per plant. Path coefficient analysis revealed that productive tillers per plant exerted the highest positive direct effect on grain yield followed by filled grains per panicle and test weight, indicating their major contribution toward productivity. Zinc content also exhibited positive direct influence on yield, suggesting the possibility of simultaneous improvement of productivity and nutritional quality. In contrast, panicle length, kernel traits and iron content recorded negative direct effects on yield. The residual effect (0.4186) indicated that the studied traits contributed substantially toward grain yield variation. The results suggest that emphasis on productive tillers per plant, filled grains per panicle and test weight would be effective for identifying superior high yielding and nutritionally improved rice genotypes.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most extensively cultivated cereal crops and serves as the principal source of food for more than half of the global population. In Asia, rice contributes substantially to daily caloric intake and plays a crucial role in ensuring food and nutritional security. According to FAOSTAT (2015), rice ranks as the third highest produced crop worldwide after maize and sugarcane with an annual production of 758.8 million tonnes. Therefore, continuous improvement in grain yield along with grain quality traits has become a major objective in rice breeding programmes. However, grain yield is a complex quantitative trait governed by several interrelated component characters and strongly influenced by environmental conditions, making direct selection for yield less effective.

In plant breeding, understanding the nature and magnitude of association among yield and its component characters is essential for effective selection. Although correlation analysis provides useful information regarding interrelationships among traits, it does not clearly distinguish the direct and indirect contribution of individual characters toward grain yield. To overcome this limitation, path coefficient analysis, originally proposed by Wright (1921) and later applied in crop improvement by Dewey and Lu (1959), has been widely used to partition correlation coefficients into direct and indirect effects and thereby establish cause-and-effect relationships among traits. This approach enables breeders to identify the most influential characters contributing directly to yield and facilitates the formulation of efficient selection strategies.

Several studies have demonstrated the usefulness of path coefficient analysis in identifying important yield determining traits in rice. Padmaja et al. (2011) reported that productive tillers per plant and filled grains per panicle exhibited positive direct effects on grain yield in rice germplasm. Similarly, Babu et al. (2012) and Nagaraju et al. (2013) observed strong positive direct effects of productive tillers, panicle length and panicle related traits on grain yield, indicating their importance in selection programmes. Seyoum et al. (2012) further reported that filled grains per panicle, productive tillers and test weight contributed substantially toward grain yield through positive direct effects. In addition, Nagesh et al. (2013) emphasized the importance of grain iron and zinc contents along with yield contributing traits for simultaneous improvement of productivity and nutritional quality in rice. These findings indicate that identification of characters having substantial direct contribution toward grain yield is essential for developing superior rice genotypes possessing both high yield and desirable grain quality traits. Hence, the present investigation was undertaken to estimate the direct and indirect effects of yield contributing and grain quality traits on grain yield through path coefficient analysis in the rice cross

MATERIALS AND METHODS

The experimental material for the present study consisted of six generations namely P_1, P_2, F_1, F_2, BC_1 and BC_2 derived from the rice cross Swarna × Madhukar. The experiment was conducted during kharif 2012 at the DRR Farm, ICRISAT campus, Hyderabad under irrigated conditions in a randomized complete block design (RCBD) with two replications. Observations were recorded on five randomly selected plants for plant height, days to 50% flowering, panicle length, productive tillers per plant, filled grains per panicle, test weight, kernel dimensions, grain iron content, grain zinc content and grain yield per plant. Grain iron and zinc concentrations were estimated using Energy Dispersive X-ray Fluorescence (EDXRF) spectrometry. Path coefficient analysis was carried out to estimate the direct and indirect effects of different traits on grain yield per plant following the method of Dewey and Lu (1959).

RESULTS AND DISCUSSION

Path coefficient analysis in the cross *Swarna* × *Madhukar*

The partitioning of genotypic correlations into direct and indirect effects revealed considerable variation in the contribution of yield, grain quality and biofortification traits towards single plant yield in *Swarna* × *Madhukar*. The residual effect (0.4186) indicated that the selected characters accounted for a substantial proportion of the variability associated with grain yield, confirming the adequacy of the path model employed.

Yield expression in the present cross was predominantly governed by **productive tillers per plant**, which registered a remarkably high direct effect (0.7032) together with a strong positive association with yield (0.7867**). The superiority of this character was further strengthened by favourable secondary influences transmitted through panicle length, filled grains, test weight, kernel breadth and zinc content. The cumulative contribution of these interactions suggests that enhanced tillering efficiency creates a stronger framework for assimilate production and partitioning towards grain development. Similar results identifying productive tillers as a major determinant of rice yield were reported by Hasan *et al.* (2013), Nagaraju *et al.* (2013) and Nagesh *et al.* (2013). Therefore, selection pressure directed towards productive tillering would substantially improve yield performance in segregating populations.

A substantial contribution to yield formation also originated from **filled grains per panicle**. The high positive direct effect (0.4493) and significant positive correlation with yield indicate the decisive role of grain filling capacity in determining final productivity. Positive transmission of effects through productive tillers, kernel breadth, panicle length and plant height additionally reinforced its influence on yield realization. The results demonstrate that efficient grain filling and enhanced sink establishment remain crucial physiological requirements for obtaining superior grain productivity. Comparable findings were previously documented by Yugandhar Reddy *et al.* (2008), Sharma *et al.* (2012) and Nagaraju *et al.* (2013).

The contribution of **test weight** to grain yield was also noteworthy. Its positive direct effect (0.1284) accompanied by significant positive association with yield indicates that grain mass contributed meaningfully toward productivity under the present genetic background. Indirect enhancement through productive tillers, panicle length and grain quality traits further improved its cumulative effect. Similar observations were reported by Sankar *et al.* (2006), Ekka *et al.* (2011) and Padmaja *et al.* (2011). These findings suggest that heavier grain phenotype may complement yield improvement when simultaneously combined with favourable yield components.

Traits associated with plant architecture and crop duration exerted comparatively smaller but biologically relevant influences. **Plant height** maintained a positive direct effect (0.0227), while its positive relationship with yield appeared to arise mainly from supportive interactions involving flowering behaviour, panicle length and productive tillers. Seyoum *et al.* (2012), Bekele *et al.*

(2013) and Nagaraju *et al.* (2013) reported similar trends for plant stature in rice. Likewise, **days to 50% flowering** exhibited a small positive direct effect despite a weak negative association with yield, indicating that unfavourable indirect influences obscured its actual contribution. Such responses reflect the complex balance between crop duration and productivity.

From the nutritional standpoint, **zinc concentration** displayed encouraging behaviour by recording a positive direct effect (0.0304) along with positive association with yield. Indirect support through productive tillers, flowering duration and panicle length strengthened its contribution. The coexistence of favourable yield response and improved zinc accumulation suggests the possibility of simultaneously improving productivity and micronutrient enrichment in this cross. Similar relationships between zinc content and grain yield were described by Bekele *et al.* (2013)

Conversely, several characters exerted suppressive direct influences on yield. **Panicle length** expressed a negative direct effect (−0.0029) despite maintaining significant positive association, implying that its relationship with yield was largely mediated by other contributing characters rather than by intrinsic effect. Grain quality traits including **kernel length, kernel breadth and L/B ratio** also recorded negative direct effects, suggesting limited independent contribution towards productivity improvement. Similar observations regarding negative direct influences of grain quality parameters have been reported by Krishna *et al.* (2008), Madhavilatha (2002) and Garg *et al.* (2010).

An unfavourable trend was evident for **iron content**, which exhibited a negative direct effect (−0.0474) and significant negative association with yield. Although positive secondary effects were observed through several component traits, these were inadequate to compensate for its adverse direct influence. This outcome highlights the difficulty of simultaneously maximizing yield and iron enrichment and indicates the necessity for balanced breeding strategies during biofortification programmes. Similar findings were reported by Bekele *et al.* (2013).

The present analysis therefore identifies **productive tillers per plant, filled grains per panicle and test weight** as the principal contributors governing yield enhancement in *Swarna* × *Madhukar*, while **zinc content** emerges as a promising nutritional attribute that can be improved without severe yield penalty. In contrast, characters exhibiting negative direct effects may require restricted or compensatory selection approaches. Accordingly, simultaneous emphasis on highly influential yield components and favourable micronutrient traits would facilitate the recovery of superior recombinants combining productivity, grain quality and nutritional value.

CONCLUSION

The present investigation demonstrated the effectiveness of path coefficient analysis in identifying important yield contributing and biofortification traits in the rice cross Swarna × Madhukar. Among the characters studied, productive tillers per plant, filled grains per panicle and test weight exerted strong positive direct effects on grain yield, indicating their major role in determining productivity. Zinc content also showed favourable direct influence on yield, suggesting the feasibility of simultaneous improvement of grain yield and nutritional quality. In contrast, panicle length, kernel traits and iron content exhibited negative direct effects, indicating the need for cautious and balanced selection strategies during breeding. Overall, the study revealed that selection based on productive tillers per plant, filled grains per panicle and test weight would be effective for developing high yielding rice genotypes with desirable grain quality and micronutrient characteristics.

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Table 1. Estimates of direct and indirect effects of yield contributing traits and grain quality parameters on yield in rice for Swarna X Madhukar

Trait	Days to 50% Flowering	Plant Height	Panicle Length	Productive Tillers/ Plant	Filled Grains	Test Weight	Kernel Length	Kernel Breadth	L/B Ratio	Iron Content	Zinc Content	Yield / Plant
Days to 50% Flowering	**0.0113**	0.0009	0.0012	-0.0004	-0.0002	-0.0003	0.0002	0.0001	0.0001	-0.0002	0.0015	**-0.0192**
Plant Height	0.0019	**0.0227**	0.0014	0.0009	0.0014	0.0003	0.0005	0.0016	-0.0006	-0.0026	-0.0023	**0.0771**
Panicle Length	-0.0003	-0.0002	**-0.0029**	-0.0004	-0.0002	-0.0003	-0.0001	-0.0003	0.0000	0.0007	-0.0004	**0.1460***
Productive Tillers/ Plant	-0.0245	0.0267	0.0989	**0.7032**	0.0770	0.1504	0.0628	0.0782	0.0203	-0.1176	0.1820	**0.7867****
Filled Grains	-0.0077	0.0271	0.0277	0.0492	**0.4493**	0.0075	-0.0145	0.0935	-0.0811	0.0118	-0.0698	**0.5131****
Test Weight	-0.0040	0.0020	0.0113	0.0274	0.0021	**0.1284**	0.0003	0.0073	0.0084	-0.0159	-0.0149	**0.2823****
Kernel Length	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000	**-0.0014**	0.0006	-0.0006	0.0001	0.0001	**0.0684**
Kernel Breadth	-0.0006	-0.0051	-0.0073	-0.0082	-0.0153	-0.0042	0.0305	**-0.0735**	0.0594	-0.0024	0.0031	**0.1265**
L/B Ratio	-0.0001	0.0007	0.0004	-0.0008	0.0049	-0.0018	-0.0113	0.0218	**-0.0270**	0.0023	-0.0017	**-0.0151**
Iron Content	0.0010	0.0055	0.0108	0.0079	-0.0012	0.0059	0.0035	-0.0015	0.0041	**-0.0474**	0.0093	**-0.1772***
Zinc Content	0.0040	-0.0031	0.0045	0.0079	-0.0047	-0.0035	-0.0021	-0.0013	0.0019	-0.0059	**0.0304**	**0.1372**

Genotypic residual effect = 0.4186 **Bold values**- direct effects Normal values-indirect effects

*Significant at 5 per cent level ** Significant at 1 per cent level

Fig.1. Path diagram depicting the direct and indirect effects of yield in the cross Swarna X Madhukar.