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Correlation Dynamics for Yield, Yield-Contributing Traits and Grain Micronutrient Parameters in Rice (*Oryza sativa* L.)

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ABSTRACT

Rice serves as the primary dietary source for over half of the world's population and contributes significantly to global food and nutritional security, particularly in developing countries. However, polished rice grains are deficient in essential micronutrients such as iron and zinc, resulting in widespread micronutrient malnutrition. Biofortification through plant breeding has emerged as a sustainable strategy to improve the nutritional quality of rice. The present study was conducted to evaluate and analyze the nature of association among grain yield, yield contributing traits and grain micronutrient parameters in the rice cross 'RP Bio-226 × Jalmagna'. The experimental material consisted of six generations namely P_1, P_2, F_1, F_2, BC_1 and BC_2 evaluated during kharif 2012 under irrigated conditions at the Directorate of Rice Research (DRR), Hyderabad. Observations were recorded on twelve quantitative and quality traits including grain iron and zinc contents. Genotypic correlation coefficients were estimated using the method suggested by Al-Jibouri et al. (1958). The results revealed that grain yield per plant exhibited significant positive association with plant height, panicle length, productive tillers per plant, filled grains and test weight. Productive tillers per plant and filled grains showed the highest positive correlation with grain yield, indicating their major contribution towards productivity. Iron and zinc contents showed negative but non-significant association with grain yield, suggesting the possibility of simultaneous improvement of yield and micronutrient concentration through appropriate selection strategies. The study indicated that productive tillers per plant, filled grains, panicle length and test weight may serve as effective selection criteria for improving grain yield along with nutritional quality in rice biofortification breeding programmes.

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Introduction

Rice is a short-day, monocotyledonous and predominantly self-pollinated annual cereal belonging to the family Poaceae, It is cultivated widely across diverse agro-climatic regions and constitutes the principal food source for a large proportion of the world's population (Bhargava *et al*., 2021). Due to its major contribution to human nutrition and daily caloric intake, rice is often regarded as a "global grain" (Sadhana *et al*., 2022). More than 40 per cent of the world's population depends on rice as a primary source of dietary energy (Resham *et al*., 2023). In India, rice plays a crucial role in ensuring food and nutritional security and supports the livelihood of millions of rural households. Its economic and nutritional significance is particularly evident in Asian countries, where rice constitutes a major component of the daily diet (Kumar *et al*., 2020). Micronutrient malnutrition, commonly referred to as "hidden hunger," has become a major global nutritional concern affecting billions of people, particularly women and children (Cakmak, 2002; White and Broadley, 2009). Among various micronutrient deficiencies, iron deficiency is considered one of the most prevalent nutritional disorders worldwide and is associated with anaemia, impaired cognitive development, weakened immunity and increased maternal health risks (Frossard *et al*., 2000). Since rice is the principal food source for a large segment of the population, enhancing its nutritional quality through biofortification has gained considerable attention in recent years.

Significant progress has been achieved in rice biofortification research with the development of genotypes possessing elevated grain iron and zinc concentrations without substantial reduction in grain yield (Sanjeeva Rao *et al*., 2020; Wairich *et al*., 2022). Furthermore, the integration of genomics-assisted breeding, physiological approaches and marker-assisted selection has accelerated the development of micronutrient-rich rice cultivars (Dixit *et al*., 2019). However, simultaneous improvement of grain yield and micronutrient content remains a major challenge because grain yield is a complex quantitative trait governed by several interrelated component characters and strongly influenced by environmental conditions. Understanding the association among grain yield, yield-attributing traits and micronutrient parameters is essential for effective selection in rice breeding programmes. Correlation analysis helps in determining the magnitude and direction of association among different traits and assists in identifying

characters contributing towards grain yield (Singh *et al*., 2020). However, correlation analysis alone cannot clearly distinguish the direct and indirect contributions of component traits. In this context, path coefficient analysis provides a better understanding of cause-and-effect relationships by partitioning correlation coefficients into direct and indirect effects (Dewey and Lu, 1959).

Therefore, the present investigation was undertaken in the rice cross 'RP Bio-226 × Jalmagna' to study the association among grain yield, yield-contributing traits and grain micronutrient parameters through correlation analysis. The findings of the study are expected to facilitate the identification of important component traits associated with yield and nutritional quality, thereby contributing to efficient selection strategies in rice biofortification breeding programmes.

Materials and Methods

The research material for the current study comprised the rice cross RP Bio-226 × Jalmagna developed from two genetically diverse parents contrasting for grain yield, grain quality and micronutrient concentration. RP Bio-226 (Improved Samba Mahsuri), derived from BPT 5204 × SS1113 and released in 2007, is a high-yielding semi-dwarf variety possessing superior grain quality but relatively low grain iron and zinc content. In contrast, Jalmagna, a traditional genotype released in 1969, is characterized by high grain iron and zinc concentration, longer crop duration and distinct plant architecture. The parental lines were raised during *rabi* 2010-2011 at the Directorate of Rice Research (DRR), Hyderabad, and hybridization was carried out through clipping emasculation followed by hand pollination. The F_1 plants were selfed to produce the F_2 generation, while backcrossing with the respective parents generated BC_1 and BC_2 populations. Thus, six generations namely P_1, P_2, F_1, F_2, BC_1 and BC_2 were developed for the study.

The six generations were evaluated during kharif 2012 at DRR Farm, ICRISAT, Hyderabad under irrigated conditions in a RCBD with two replications. Transplanting was done using 26-30 day old seedlings at a spacing of 20 × 10 cm in rows of 3 m length. Recommended agronomic practices and plant protection measures were followed uniformly throughout the crop growth period. Observations were recorded on five randomly selected plants from each replication for traits including plant height (PH), days to 50% flowering (DFF), panicle length (PL), productive tillers per plant (PTP), filled grains per panicle (FGP), grain yield per plant (GYP), test weight (TW), kernel dimensions (KD), grain iron (GI) and grain zinc (GZ) content. Grain iron and zinc concentrations were estimated using Energy Dispersive X-ray Fluorescence (EDXRF) spectrometry.

Statistical analysis

Pearson's correlation coefficients among trait combinations were estimated based on genotype mean values in Microsoft Excel at significance levels of $P < 0.05$ and $P < 0.01$. The significance of correlation coefficients was denoted by * and ** for the 5% and 1% probability levels, respectively.

Results and Discussion

Days to 50 % Flowering (DFF)

DFF exhibited a highly significant positive association with zinc content (0.1880**), whereas its association with yield per plant was negative and non-significant (-0.0141). The negative relationship with grain yield indicated that early flowering genotypes may possess slight yield advantage under the present experimental conditions.

The positive association with zinc content suggested the possibility of improving micronutrient concentration without adversely affecting flowering behaviour. Similar observations for yield per plant were earlier reported by Meenakshi *et al*. (1999) and Nagaraju *et al*. (2013)

Plant Height

Plant height showed highly significant positive association with panicle length (0.6902**), productive tillers per plant (0.3718**), filled grains per panicle (0.4589**), test weight (0.5215**) and yield per plant (0.2633**). The strong association between plant height and panicle length indicated that taller plants tended to possess well-developed reproductive structures capable of supporting higher grain number. Positive correlation with productive tillers and filled grains suggested improved assimilate production and partitioning efficiency in vigorous genotypes. The positive association with test weight further reflected better grain filling capacity. These results indicated that moderate plant height may contribute favourably towards yield improvement. Similar findings were reported by Suman (2003), Sravan *et al*. (2012) and Reddy *et al*. (2013) for yield per plant and panicle length; Chandra *et al*. (2009) and Rahman *et al*. (2014) for productive tillers and filled grains; and Krishna *et al*. (2008) and Babu *et al*. (2012) for test weight.

Panicle Length

Panicle length exhibited significant positive association with yield per plant (0.2118**), productive tillers per plant (0.3674**), filled grains per panicle (0.3838**) and test weight (0.4512**). Longer panicles generally accommodated more spikelets and grains, thereby contributing directly towards increased grain production. Its positive relationship with test weight also indicated better grain development and efficient translocation of assimilates during grain filling. Therefore, panicle length may serve as an important selection criterion for improving grain yield. Similar results were reported by Sravan *et al*. (2012) and Reddy *et al*. (2013) for single plant yield, Yadav *et al*. (2011) and Nagaraju *et al*. (2013) for productive tillers, Eradasappa *et al*. (2007), Chandra *et al*. (2009) and Padmaja *et al*. (2011) for filled grains, and Babu *et al*. (2012) for test weight.

Productive Tillers per Plant

Productive tillers per plant exhibited a highly significant positive correlation with yield per plant (0.4940**), filled grains per panicle (0.4106**) and test weight (0.1961**). A higher number of productive tillers increased the number of effective panicle-bearing stems, thereby contributing substantially to enhanced grain yield per plant. Its positive association with filled grains per panicle and test weight also indicated improved grain filling and efficient partitioning of assimilates in genotypes possessing greater tillering ability. Similar positive associations with yield per plant were earlier reported by Babu *et al.* (2012), Gangashetty *et al.* (2013) and Nagesh *et al.* (2013). Likewise, Janardhanam *et al.* (2001), Padmaja *et al.* (2011), Nagaraju *et al.* (2013) and Rahman *et al.* (2014) also observed a positive relationship between productive tillers and test weight.

Filled Grains per Panicle

Filled grains per panicle exhibited highly significant positive association with yield per plant (0.4330**) and test weight (0.3163**). The results indicated that plants with higher number of filled grains possessed superior sink capacity and consequently produced higher grain yield.

Positive association with test weight suggested that increase in grain number did not adversely influence grain development. Therefore, simultaneous improvement of grain number and grain weight appears feasible in the present material. Similar observations were reported by Garg *et al*. (2010), Mohanty *et al*. (2012), Nagesh *et al*. (2013) and Sarker *et al*. (2014) for yield per plant, and Krishna Naik *et al*. (2005) and Anbumalarmathi and Nadarajan (2008) for test weight.

Test Weight

Test weight showed significant positive association with yield per plant (0.2033**), indicating that heavier grains contributed positively towards productivity. The positive relationship between these traits reflected efficient grain filling and better partitioning of assimilates towards developing grains. Hence, improvement in grain boldness may favourably influence grain yield. Similar findings were reported by Basavaraja *et al*. (2011) and Chakraborty and Chaturvedi (2014).

Kernel Length

Kernel length exhibited highly significant positive association with kernel breadth (0.7541**) and highly significant negative association with L/B ratio (-0.5527**). However, its association with yield per plant was negative and non-significant (-0.0898). The positive relationship between kernel length and kernel breadth indicated simultaneous increase in grain dimensions, whereas the negative association with L/B ratio suggested proportionately greater increase in breadth than length. Since kernel length exhibited negligible association with yield, direct selection for this trait alone may not substantially improve productivity. Similar results were reported by Krishna Veni and Shobha Rani (2006) and Krishna *et al*. (2008) for kernel breadth.

Kernel Breadth

Kernel breadth exhibited a negative but non-significant correlation with yield per plant (-0.0943), whereas a highly significant negative association was observed with the L/B ratio (-0.8582**). The inverse relationship with the L/B ratio was anticipated, as an increase in kernel breadth proportionally lowers the length-to-breadth ratio of the grain. The non-significant correlation with yield per plant indicated that kernel breadth had only a minor direct influence on grain productivity in the present cross. Comparable results for yield per plant were earlier documented by Krishna *et al.* (2008). Similarly, negative and significant association of kernel breadth with the L/B ratio was also reported by Khatun *et al.* (2003) and Subudhi *et al.* (2007).

Length/Breadth Ratio

Length/breadth ratio exhibited positive but non-significant association with yield per plant (0.1334). Although the association was low, the positive direction suggested that relatively slender grains may contribute marginally towards yield improvement. However, due to the non-significant nature of association, this trait may not be considered as an effective criterion for direct selection. Similar observations were reported by Garg *et al*. (2010) and Nagaraju *et al*. (2013).

Iron and Zinc Content

Iron (-0.1104) and zinc (-0.0274) contents exhibited negative but non-significant association with yield per plant.

These results indicated that enhancement of micronutrient concentration may not necessarily lead to reduction in grain yield. The absence of strong negative association between yield and micronutrient traits suggested the possibility of simultaneous improvement of productivity and nutritional quality through appropriate breeding strategies. Zinc content also exhibited positive association with days to 50 per cent flowering and iron content, indicating the feasibility of improving both micronutrients simultaneously in the present material. Similar observations were reported by Nagesh *et al*. (2013), who observed negative non-significant association for zinc content and negative significant association for iron content.

Yield per Plant

Single plant yield exhibited highly significant positive association with plant height (0.2633**), panicle length (0.2118**), productive tillers per plant (0.4940**), filled grains per panicle (0.4330**) and test weight (0.2033**), indicating the importance of these traits in determining grain productivity. Therefore, these characters may serve as reliable selection criteria for improving grain yield. Positive but non-significant association was observed between yield per plant and L/B ratio (0.1334). In contrast, negative but non-significant association was recorded with days to 50 per cent flowering (-0.0141), kernel length (-0.0898), kernel breadth (-0.0943), iron content (-0.1104) and zinc content (-0.0274). According to Newall and Eberhart (1961), simultaneous improvement of negatively associated traits becomes difficult in breeding programmes. Hence, careful selection strategies are required to achieve concurrent improvement in yield and associated characters.

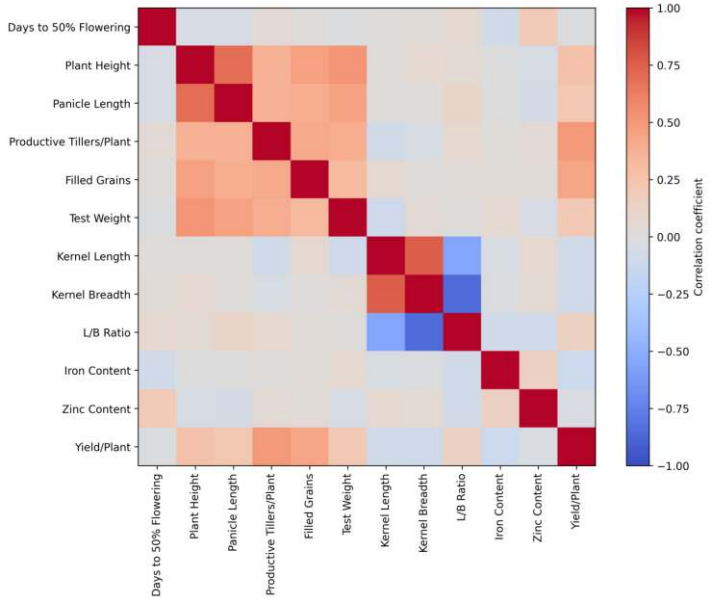

Fig.1: The figure below represents the graphical visualization of the correlation matrix.

Table 1: Estimates of genotypic correlation coefficients

Trait	Correlation with Yield/Plant	Nature
Days to 50% Flowering	-0.0141	Negative
Plant Height	0.2633	Positive
Panicle Length	0.2118	Positive
Productive Tillers/Plant	0.494	Positive
Filled Grains	0.433	Positive
Test Weight	0.2033	Positive
Kernel Length	-0.0898	Negative
Kernel Breadth	-0.0943	Negative
L/B Ratio	0.1334	Positive
Iron Content	-0.1104	Negative
Zinc Content	-0.0274	Negative

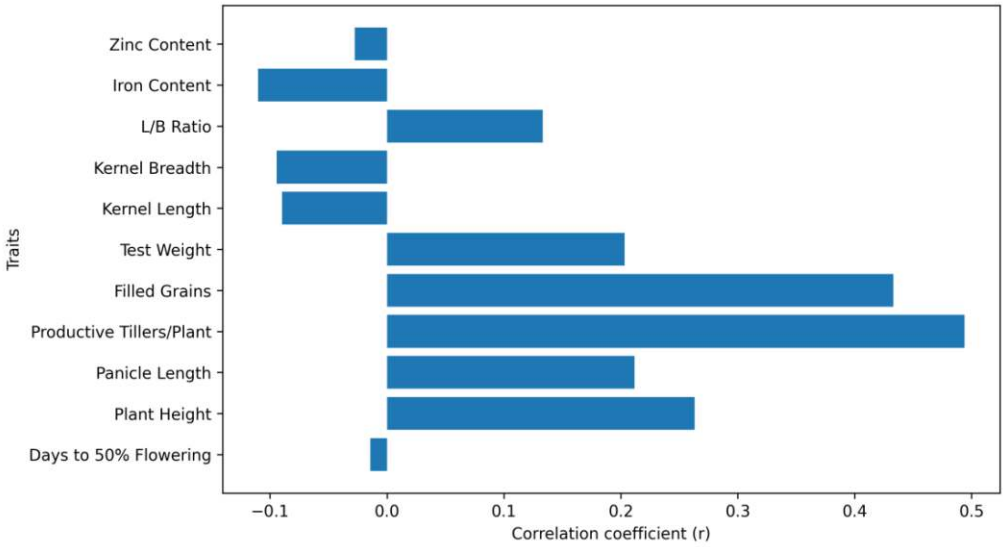

Fig. 2: Correlation of different traits with grain yield per plant

Table.2: Estimates of genotypic correlation coefficients among yield, its contributing characters and grain quality parameters for Rpbio-226 X Jalmagna

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	1.0000	-0.0475	-0.0537	0.0392	0.0076	-0.0139	0.0163	0.0277	0.0556	-0.0866	0.1880	-0.0141
Plant Height		1.0000	0.6902**	0.3718**	0.4589**	0.5215**	0.0207	0.0681	0.0485	-0.0075	-0.0533	0.2633**
Panicle Length			1.0000	0.3674**	0.3838**	0.4512**	0.0204	0.0116	0.1136	-0.0019	-0.0575	0.2118**
Productive Tillers/ Plant				1.0000	0.4106**	0.3907**	-0.0799	-0.0403	0.0773	0.0160	0.0414	0.4940**
Filled Grains					1.0000	0.3163**	0.0581	0.0108	0.0310	0.0288	0.0319	0.4330**
Test Weight						1.0000	-0.1023	0.0429	0.0070	0.0653	-0.0525	0.2033**
Kernel Length							1.0000	0.7541**	-0.5527**	-0.0441	0.0565	-0.0898
Kernel Breadth								1.0000	-0.8582**	-0.0165	0.0512	-0.0943
L/B Ratio									1.0000	-0.0932	-0.0859	0.1334
Iron Content										1.0000	0.1340	-0.1104
Zinc Content											1.0000	-0.0274

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

CONCLUSION

The present investigation on correlation analysis in the rice cross 'RP Bio-226 × Jalmagna' revealed that grain yield per plant exhibited significant positive association with plant height, panicle length, productive tillers per plant, filled grains per panicle and test weight. Among these traits, productive tillers per plant and filled grains per panicle showed comparatively stronger positive association with grain yield, indicating their important role in determining productivity.

Iron and zinc contents exhibited negative but non-significant association with grain yield, suggesting the absence of strong adverse relationship between yield and micronutrient accumulation. This indicates the possibility of simultaneous improvement of grain yield and nutritional quality through appropriate breeding strategies.

Overall, the results of the present study suggest that productive tillers per plant, filled grains per panicle, panicle length, plant height and test weight may serve as important selection criteria for the development of high-yielding and micronutrient-rich rice genotypes in biofortification breeding programmes.

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