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PATH ANALYSIS AND CORRELATION STUDIES FOR IDENTIFYING SUPERIOR RESTORER LINES IN HYBRID RICE BREEDING

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ABSTRACT

The current study was conducted on 129 genotypes at ICAR-Indian Institute of Rice Research (IIRR), Hyderabad, during Kharif 2024 and Rabi 2024-2025, to determine the interrelationship and direct and indirect effects of yield component traits on grain rice grain yield for future breeding activities to improve yield. Eleven parameters were evaluated to assess the interrelationship among yield and yield attributed traits and their effects on grain yield, ANOVA revealed significant differences among the treatments for all the traits studied. Grain yield showed positive and significant association with panicle length (0.14), number of productive tillers (0.14), test weight (0.25) and per day productivity (0.99) while, the traits such as days to 50% flowering, panicle length, spikelet fertility, test weight and per day productivity showed positive effects on grain yield per plant. This study concludes that that improvement in yield can be achieved by increasing the productive tillers, test weight and panicle length.
Keywords **:** Hybrid rice, phenotypic association, direct and indirect effects

Introduction

Rice is an important source of food, and more than 50% percent of people rely on rice to fulfil their hunger needs globally (Maurya *et al*., 2022). Hybrid rice production has been a significant breakthrough in this regard, and the floral traits play a major role in the development of hybrid rice (Ashraf *et al*., 2024). Hybrid rice technology has provided a significant contribution to food security and employment opportunities. The phenomenon in which hybrid progenies often perform better than their homozygous parents is known as heterosis (or hybrid vigor) and is widespread in crops such as rice and maize (Moll *et al*., 1962).

The commercial use of heterosis has benefited from the successful matching of sterile lines and restorer lines, which has dramatically increased crop production in the past several decades. Heterosis in the first generation (F_1) derived from hybrid rice parental lines provided 15–30% higher advanced yield than inbred varieties. In addition, heterosis means superior hybrid vigor in agronomic traits, grain yield, and other traits compared to their parents, as well as being more tolerant to stresses than inbred parents (Gaballah *et al*., 2022).

Hybrid rice has superior grain yield to inbred rice cultivars and is one of the most significant applications of heterosis in crops (Liu *et al*., 2020) and is produced by crossing the male parent (restorer lines) and female parental lines (cytoplasmic male sterile lines (CMS)). The discovery of CMS lines enabled the researchers to develop more seeds for hybrid rice production, which is key to successful hybrid rice breeding. Hybrid seed production has been utilized using three-line or two-line systems [Chang *et al*., 2016]. The three-line method has a CMS line, a maintainer line (B), and a restorer line (R) (Xie and Zhang, 2018). Three-line hybrid rice played a significant role in developing rice production. Male sterility presence in CMS lines is governed by a single nuclear recessive gene or a pair of nuclear recessive genes sensitive to cytoplasm, including photoperiod or temperature, or their combination (Wongpastsa *et al*., 2014).

Generally, the parents with a more distant genetic relationship result in stronger heterosis in the hybrid. However, strong heterosis does not guarantee high yield performance in hybrids. Genetic richness in any germplasm is vital for any crop improvement effort since it is the key to integrating favourable alleles and bringing about desired modifications (Sharma *et al*., 2021). Breeding and agricultural development require a thorough understanding of current genetic diversity (Verma *et al*., 2021). Inborn deviation among traits is central to bringing and selecting anticipated types (Khan *et al*., 2021). For increasing grain output via breeding, it is important to recognize the species' variability, the nature of character associations, and the involvement of various traits.

Single plant yield is a complex trait, governed by multiple genetic factors. It is influenced not only by the number and type of genes involved, but also by how those genes are arranged, how they interact with one another, the genetic background in which they exist, and the environmental conditions surrounding them. In addition, single plant yield is directly or indirectly interrelated with other agronomic traits such as plant stature, growth spell, panicle length, tiller per plant, loaded grains per panicle, and primary and secondary branches per panicle [Asante *et al*., 2019]. The primary aim of the plant breeders is to pick desirable features in the blend, to get economic gain based on their selection preferences.

For this the knowledge of the association of the yield and its dependent variables is essential to discover plant selection guidelines. Apart, from this association analysis, these traits may also be partitioned into direct and indirect impacts to find which characteristics are most responsible for increasing seed yield. Therefore, it is crucial to link component qualities to yield and to each other. So based on this, the current study was undertaken to see the stable performance of these 129 promising entries with different genetic makeup to be used as potential restorers in hybrid rice breeding.

Materials and Methods

The current study of analysing 129 promising lines (including two checks AR-9-18, PS 344) in irrigated ecology was conducted during *Kharif,*2024 and *Rabi,* 2024-2025 at experimental rice fields of ICAR-Indian Institute of Rice Research. The experiment was conducted in Augmented Design with a spacing of 20 × 15 cm. All proper precautionary measures were taken and package of practices were followed to raise a normal crop. Data was taken for the following traits such as days to heading, days to 50% flowering, plant height (cm), panicle length (cm), number of productive tillers, total grains per panicle, spikelet fertility (%), test weight (g), panicle weight (g), per day productivity (g), and single plant yield (g). For the trait days to heading, days to 50% flowering it was taken on a plot basis, while for the other traits data was taken on six random plants. Correlation coefficients were calculated at the genotypic and phenotypic levels using the formulae suggested by Falconer (1981) The direct and indirect effects both at genotypic and phenotypic levels were estimated by taking seed yield as dependent variable, using path coefficient analysis suggested by Wright (1921) and Dewey and Lu (1959). The following analysis was done using variability package in R studio.

Results and Discussions

By showing the relationship between various traits and yield, correlation analysis helps focus breeding efforts on specific traits The trait single plant yield showed positive significant relationship with panicle length (0.1422), number of productive tillers (0.1418), test weight (0.2588), per day productivity (0.9999). The trait days to 50% flowering showed positive significant relationship with plant height (0.1789), panicle length (0.127), and total number of grains per panicle (0.1397). Similar reports were reported by Bhadru *et al.* (2012), Ravinder Babu *et al.* (2012), in case of the plant height. Sathish *et al.* (2009), Srijan *et al.* (2016), in case of panicle length, Eswara reddy *et al.* (2013) and Rao *et al.* (2014) in case of total number of grains per panicle. The trait plant height showed positive significant relationship with panicle length (0.3948), test weight (0.1914), panicle weight (0.1359), days to heading (0.1834), days to 50% flowering (0.1798). similar results were reported by Ravinder Babu *et al.* (2012), Eswara reddy *et al.* (2013), in case of panicle length, soni *et al.* (2013), Mishra *et al.* (2014), in case of test weight, Anis *et al.* (2016), Rajendra prasad *et al.* (2017) in case of panicle weight. The trait panicle length showed positive significant relation with test weight (0.1794), per day productivity (0.1422), single plant yield (0.1422). Days to heading (0.1258), days to 50% flowering (0.127), plant height (0.3948), similar results were reported by Nandan *et al.* (2010), in case of test weight.

The trait number of productive tillers showed positive significant relation with per day productivity (0.1418), single plant yield (0.1418).The trait total grains per panicle showed positive significant association with spikelet fertility (0.1388), panicle weight (0.1502), days to heading (0.1343), days to 50% flowering (0.1397), similar results were reported by Mishra *et al.* (2014) and Naseer *et al.* (2015), in

case of spikelet fertility. The trait test weight showed positive significant relation with panicle weight (0.2445), per day productivity (0.2588), single plant yield (0.2588), plant height (0.1914), panicle length (0.1794). The trait panicle weight showed positive significant relation with plant height (0.1359), total grains per panicle (0.1502), similar results were reported by Nandeshwar *et al.* (2010), Ranwake and Amarasighe (2014), in case of total grains per panicle. The trait per day productivity showed positive significant relationship with panicle length (0.1422), number of productive tillers (0.1418), test weight (0.2588), single plant yield (0.9999),

Path analysis

Path analysis is a powerful statistical tool that goes beyond simple correlation by dissecting the direct and indirect effects of individual traits on a target variable in this case, single plant yield. In rice breeding, where multiple traits interact in complex ways, path analysis helps clarify which traits exert genuine influence and which act through intermediaries. This distinction is crucial for breeders aiming to optimize selection strategies, as it allows them to focus on traits that have a true causal impact on yield rather than those that merely correlate due to shared pathways. By quantifying these relationships, path analysis supports more informed decision-making and accelerates genetic improvement.

The trait days to heading showed a negative direct effect (-0.1530) on single plant yield, and negative indirect effects through plant height (-0.0019), total grains per panicle(-0.0002), spikelet fertility(-0.0002), Test weight(-0.0011), and per day productivity(-0.0030), while it showed a low positive indirect effects through days to 50% flowering (0.1753), panicle length (0.0008), Number of productive tillers (0.0002), panicle weight (0.0012).

The trait days to 50% flowering showed a positive direct effect (0.1755) on single plant yield, and negative indirect effects through days to heading (-0.1528), plant height (-0.0019), total grains per panicle (-0.0002), spikelet fertility (-0.0001), test weight (-0.0010), while it showed a low positive indirect effect through panicle length (0.0008), number of productive tillers (0.0001), panicle weight (0.0012), per day productivity (0.0078). similar results were showed by Golam *et al.* (2015) and Rajendra prasad *et al.* (2017) in case of panicle length, Srijan *et al.* (2016) and Rajendra prasad *et al.* (2017), in case of productive tillers, Srijan *et al.* (2016) in case of panicle weight.

The trait plant height showed a negative direct effect (-0.0095) on single plant yield, and negative indirect effects through plant height (-0.0306), spikelet fertility (-0.0029), panicle weight (-0.0020), per day productivity (-0.0047), while it showed a high positive indirect effect through days to 50% flowering (0.0347), panicle length (0.0021), number of productive tillers (0.0021), test weight (0.0000) and test weight (0.0015). similar results were showed by kiranmayee *et al.* (2018) and satturu *et al.* (2023), in case of days to 50% flowering, Pandey *et al.* (2012) and Ratna *et al.* (2015) in case of panicle length, Aris *et al.* (2010) and Rajendra prasad *et al.* (2017) in case of number of productive tillers, Kumar and Verma *et al* .(2015) in case of total grains per panicle, Dilruba *et al.* (2014) and Rahman *et al.* (2014) in case of test weight.

The trait panicle length showed a positive direct effect (0.0043) on single plant yield, and negative indirect effects through days to heading (-0.0266), plant height (-0.0047), spikelet fertility (-0.0028), while it showed a high positive indirect effect through days to 50% flowering (0.0313), number of productive tillers (0.0003), total grains per panicle (0.0000), test weight (0.0021), panicle weigh (0.0002), per day productivity (0.2059). similar results were showed by Ravi *et al.* (2014) and Srijan *et al.* (2016) in case of days to 50% flowering, Reddy *et al.* (2013) and Rahman *et al.* (2014), in case of number of productive tillers, Patel *et al.* (2014) and Srijan *et al.* (2016) in case of test weight, Srijan *et al.* (2016), in case of panicle weight.

The trait number of productive tillers showed a negative direct effect (-0.0069) on single plant yield and negative indirect effects through days to 50% flowering (-0.0025), panicle length (-0.0002), spikelet fertility (-0.0005), test weight (-0.0014), while it showed a high positive indirect effect through days to heading (0.0036), plant height (0.0029), total grains per panicle (0.0003), panicle weight (0.0046), per day productivity (0.0449). similar results were showed by Rahman *et al.* (2014) and Ratna *et al.* (2015), in case of plant height, Patel *et al.* (2014), in case of total grains per panicle, Rajendra prasad *et al.* (2017), in case of panicle weight.

The trait total grains per panicle showed a negative direct effect (-0.0010) on single plant yield and negative indirect effects through days to heading (-0.0233), panicle length (-0.0001), test weight (-0.0013), panicle weight (-0.0019), while it showed a high positive indirect effect through days to 50% flowering (0.0277), plant height (0.0000), number of productive tillers (0.0021), spikelet fertility (0.0077), per day productivity (0.1122), similar results were showed by Patel *et al.* (2014) in case of days to 50% flowering, Ganapati *et al.* (2014), in case of plant height,

Rajamadhan *et al.* (2011), in case of number of productive tillers.

The trait spikelet fertility showed a positive direct effect (0.0205) on single plant yield and negative indirect effects through days to 50% flowering (-0.0008), panicle length (-0.0006), total grains per panicle (-0.0004), panicle weight (-0.0001), while it showed a high positive indirect effect through days to heading (0.0015), plant height (0.0013), number of productive tillers (0.0002), test weight (0.0005), per day productivity (0.1496).

The trait test weight showed a positive direct effect (0.0070) on single plant yield and negative indirect effects through days to 50% flowering (-0.0256), plant height (-0.0021), panicle weight (-0.0040), while it showed a high positive indirect effect through days to heading (0.0233), panicle length (0.0013), number of productive tillers (0.0014), total grains per panicle (0.0002), spikelet fertility (0.0014), per day productivity (0.3621). similar results were showed by Rajamadhan *et al.* (2011) in case of panicle length, Ratna *et al.* (2015) in case number of productive tillers, Naseer *et al.* (2015) in case total grains per panicle.

The trait panicle weight showed a negative direct effect (-0.0075) on the single plant yield and negative indirect effect through days to 50% flowering (-0.0284), plant height (-0.0026), panicle length (-0.0001), total grains per panicle (-0.0003), while it showed a high positive indirect effect through days to heading (0.0238), number of productive tillers (0.0042), spikelet fertility (0.0002), test weight (0.0038), per day productivity (0.0497). similar results were showed by Rajamadhan *et al.* (2011), in case of number of productive tillers, Naseer *et al.* (2015) in case of test weight.

The trait per day productivity showed a positive direct effect (0.9939) on the single plant yield and negative indirect effect through number of productive tillers (-0.0003), total grains per panicle (-0.0001), panicle weight (-0.0004), while it showed a high positive indirect effect through days to heading (0.0005), days to 50% flowering (0.0014), plant height (0.0000), panicle length (0.0009), spikelet fertility (0.0031), test weight (0.0026).

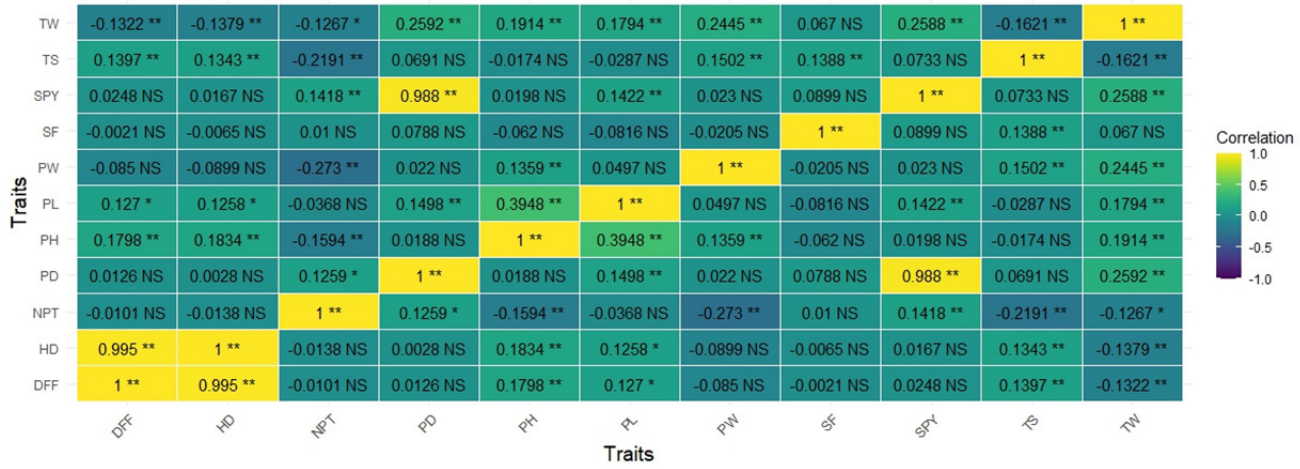
Conclusion

Correlation analysis plays a pivotal role in crop improvement research by revealing the interrelationships among agronomic traits and yield components. It shows how traits influence one another, and it enables the breeders to prioritize the selection targets that are most likely to influence productivity. In this study, the strong positive correlations between single plant yield and traits such as panicle length, number of productive tillers, test weight, and per day productivity show the importance of these traits in yield enhancement strategies.

Moreover, traits like days to 50% flowering, plant height, and panicle length showed significant positive associations with grain number and panicle weight, suggesting that phenological and morphological traits are intricately linked to reproductive success. These findings are consistent with earlier reports by Bhadru *et al.* (2012), Ravinder Babu *et al.* (2012), reinforcing the reliability of these associations across diverse genetic backgrounds and environments. Such consistency strengthens the case for integrating correlation analysis into multi-trait selection frameworks, especially when aiming to balance yield with plant architecture (*height, panicle length and grain number*) and maturity.

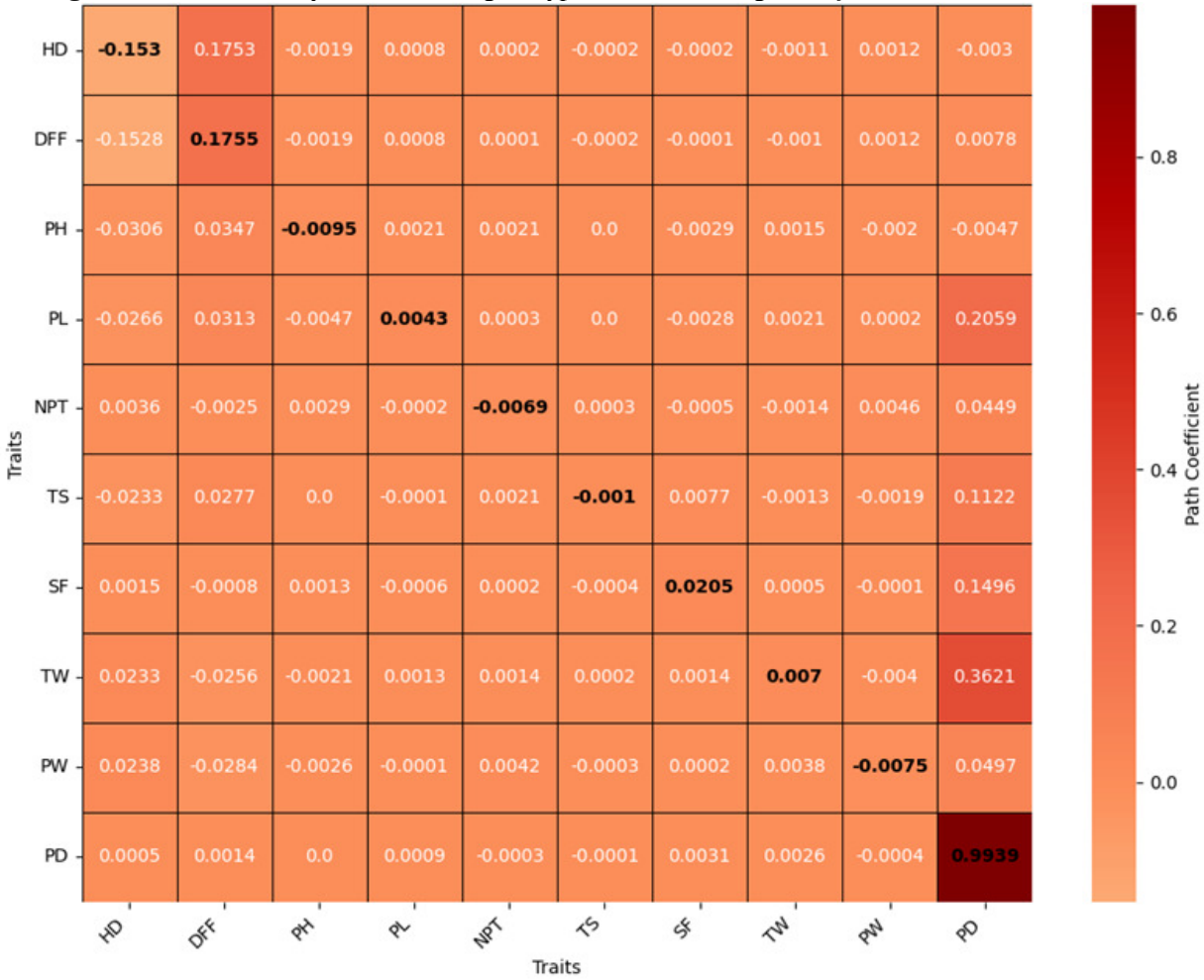
Based on the observed results, it can be concluded that traits such as panicle length, test weight, and number of productive tillers are not only positively correlated with yield but also with each other, forming a synergistic trait complex that can be exploited in breeding. These associations show that optimizing plant stature could indirectly improve grain yield and biomass allocation. These interdependencies provide a roadmap for designing ideotypes that combine favorable trait combinations.

In the present study, path analysis revealed that per day productivity had the strongest positive direct effect (0.9939) on single plant yield, making it a key driver of performance. Traits like days to 50% flowering (0.1755) and spikelet fertility (0.0205) also contributed positively through direct effects, while others such as days to heading (–0.1530), plant height (–0.0095), and panicle weight (–0.0075) showed negative direct effects. Interestingly, several traits compensated for their weak or negative direct effects through strong positive indirect pathways, especially via per day productivity, days to 50% flowering, and test weight. For example, panicle length, though having a modest direct effect (0.0043), contributed significantly through indirect effects via per day productivity (0.2059) and days to 50% flowering (0.0313). Traits like test weight, panicle length, and spikelet fertility also emerged as valuable contributors through their indirect pathways.



HD-days to heading, DFF-days to 50% flowering, PH-plant height (cm), PL-panicle length (cm), NPT- number of productive tillers, TS- total grains per panicle, SF-spikelet fertility (%),TW- test weight (g), PW-panicle weight (g), PD-per day productivity (g), SPY-single plant yield (g)

Fig. 1: Correlation analysis of the 129 genotypes studied during *Kharif*, 2024 and *Rabi*, 2024-2025



HD-days to heading, DFF-days to 50% flowering, PH-plant height (cm), PL-panicle length (cm), NPT- number of productive tillers, TS- total grains per panicle, SF-spikelet fertility (%),TW- test weight (g), PW-panicle weight (g), PD-per day productivity (g), SPY-single plant yield (g)

Fig. 2: Path coefficient analysis of the 129 genotypes studied during *Kharif*, 2024 and *Rabi*, 2024-2025

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