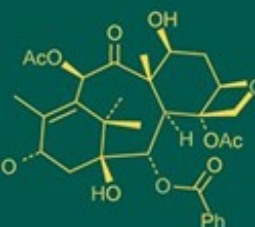
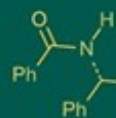


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Genetic association and path analysis of yield and yield-contributing traits in parental lines of hybrid rice (*Oryza sativa* L.)

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ABSTRACT

Rice (*Oryza sativa* L.) is an important staple crop, and improving grain yield remains a major objective for rice breeding. The present study was conducted to assess the association among yield and yield-contributing traits in parental lines of hybrid rice. A total of 105 genotypes were evaluated during the Kharif, 2025 at the Indian Institute of Rice Research farm, Rajendranagar, Hyderabad, in an Augmented Design. Correlation and path coefficient analysis were employed to determine the direct and indirect contributions of different traits on single plant yield. Single plant yield showed positive and significant association with number of productive tillers (0.2667), test weight (0.2152), and panicle weight (0.4619). Path analysis revealed that panicle weight exerted the positive direct effect on single plant yield (0.43066), followed by number of productive tillers (0.25381), plant height (0.06739), test weight (0.06259), and spikelet fertility (0.04863). Conversely, days to 50% flowering and panicle length showed negative direct effects on single plant yield. The results indicated that panicle weight and number of productive tillers are important yield-contributing traits and may serve as effective selection criteria for improving single plant yield in hybrid rice.

Keywords: Correlation, Path analysis, Hybrid rice, Yield

Introduction

Rice (*Oryza sativa* L.) plays a key role in global food security as a major food source for more than half of the world's population. As the world population is expected to reach over 9.7 billion by 2050 and climate change uncertainties continue to increase, there is an urgent need to develop high yielding rice cultivars with enhanced nutritional values that can withstand with wide range of challenging environmental conditions. (Chauhan *et al.*, 2017) [1], (Shi *et al.*, 2023) [2].

Although several Asian countries have significantly improved food production over the past recent decades, future food security continues to be a major concern due to population growth and diminishing resources. Inspired by the success of hybrid rice in China, the International Rice Research Institute and national programs initiated exploring hybrid rice technology in the 1980s. Many scientists have suggested the potential of heterosis exploitation

in this self-pollinated crop to increase yield (Saravanan *et al.*, 2026) [3], (Cheng *et al.*, 2007) [4], (Virmani, 1996) [5], (Toriyama *et al.*, 2016) [6].

Cytoplasmic Male Sterility (CMS) is considered as the most effective and practical approach for producing male-sterile lines, particularly in the commercial production of hybrid crops. (Chase, 2006; Sharma *et al.*, 2026; Liu *et al.*, 2026) [7, 8, 9]. In India, most commercially released hybrid rice is mainly based on the wild abortive (WA) cytoplasmic male sterility (CMS), because of its stability, easy hybrid seed production and availability of a diverse range of restorer lines (R lines) (Priyadarshi *et al.*, 2026) [10], (Mishra *et al.*, 2025) [11].

CMS is controlled by the mitochondrial genome, while its expression can be reversed by specific nuclear-encoded genes known as restorer-of-fertility (*Rf*) genes. The CMS system has been extensively utilized for the commercial production of hybrid seeds in various crops and also serves as an important model for investigating mitochondrial-nuclear interactions and coevolution in plants (Jiang *et al.*, 2022; Awad-Allah *et al.*, 2022) [13, 12].

Many rice-producing countries extensively employ the three-line breeding system for the development and commercial production of hybrid rice, which relies on cytoplasmic genetic male-sterile (CGMS) lines as the female parent (Virmani *et al.*, 1997) [14]. In this system, the availability of effective fertility-restorer lines is essential for the successful development of high-performing hybrids in rice breeding programmes (Krishnan *et al.*, 2012) [15].

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Correlation analysis between grain yield and its component traits provides valuable insight into the extent and nature of their associations (Jayasudha *et al.*, 2010) [16]. Since yield is a complex quantitative trait influenced by several component characters, evaluating the relationships between yield and its contributing traits is important for effective selection. Several studies have employed correlation and path analysis to elucidate the phenotypic and genetic relationships between grain yield and its component traits (Sahoo *et al.*, 2026; Jeke *et al.*, 2021; Thuy *et al.*, 2023) [18, 17, 19]. Correlation analysis, together with path coefficient analysis, is a useful approach for determining the strength of associations and distinguishing the direct and indirect effects of individual traits on yield (Jangala *et al.*, 2022; Kumar *et al.*, 2025) [20, 21].

Materials and methods

The current study was conducted during the *Kharif*, 2025 at the Indian Institute of Rice Research farm, Rajendranagar, Hyderabad. The experimental materials consisted of 105 genotypes including checks (AR-9-18), (IR79156B). The genotypes were evaluated in Augmented design with a spacing of 20×15 cm. Check varieties were replicated across blocks to control for environmental variation, while test genotypes were unreplicated. This quantitative data was recorded for nine parameters from five randomly selected plants per each entry viz. Days to 50% flowering, Plant height, Number of productive tillers per plant, Spikelet fertility, 1000 grain weight, Panicle weight, Single plant yield. All statistical analyses were performed in R statistical software (Posit Team, 2025) utilizing packages such as 'metan' (Olivoto *et al.*, 2020) [22] for analysis of variance, correlation, and path coefficient calculations.

Results and discussions

Correlation

Correlation analysis is a valuable statistical tool that helps determine the strength and direction of these relationships among different traits. Hence, correlation studies play a crucial role in crop improvement programmes. In the present study, Single plant yield exhibited a positive and statistically significant correlation with the number of productive tillers (0.2667 **), test weight (0.2152 **), and panicle weight (0.4619 **), suggesting that improvements in these traits can contribute to increased yield.

Days to 50% flowering exhibited a positive and significant correlation with plant height (0.3485 **), panicle length (0.1612 **) indicating that genotypes with a longer time to flowering generally produced taller plants and longer panicles. Similar results were reported by Srikanth *et al.*, (2017) [23], Srijan *et al.*, (2016) [24], Saketh *et al.*, (2023) [25], Belete *et al.*, (2022) [26]. Plant height exhibited a positive and significant correlation with panicle length (0.3816 **) suggests that increased plant stature may contribute to improved panicle growth, which is an important morphological trait influencing yield potential. Similar findings were reported by Saketh *et al.*, (2023) [25]. Panicle length exhibited a positive and statistically significant correlation with test weight (0.1697 **) and panicle weight (0.1467 **), indicating that genotypes with longer panicles generally tended to produce heavier grains and higher panicle weight. Similar findings were reported by Soni *et al.*, (2013) [27], Guru *et al.*, (2016) [28]. The number of productive tillers demonstrated a positive and statistically significant correlation with single plant yield (0.2667 **).

This suggests that genotypes with a greater number of productive tillers generally produced higher grain yield per plant. The results are in accordance with Saran *et al.*, (2023) [29], Saketh *et al.*, (2023) [25]. This finding suggests that the number of productive tillers is an important yield-contributing trait and can serve as a useful selection criterion in rice improvement programmes. Spikelet fertility showed a positive but statistically non-significant correlation with test weight (0.0996), panicle weight (0.0292), and single plant yield (0.0292). Although the relationships were positive, the lack of statistical significance indicates that variation in spikelet fertility had only a limited influence on these yield-related traits under the conditions of the present study.

Test weight exhibited a positive and statistically significant correlation with panicle weight (0.352**), and with single plant yield (0.2152**) indicating that genotypes with heavier grains generally tended to produce greater panicle weight and higher grain yield per plant. Satturu *et al.*, (2023) [30], Bhavana *et al.*, (2021) [31] also revealed similar results for test weight. Panicle weight revealed a positive and statistically significant correlation with single plant yield (0.4619**), indicating that genotypes with higher panicle weight generally produced greater grain yield per plant as reported by Reddy *et al.*, (2024) [32].

Table 1. Correlation coefficient analysis among traits of hybrid rice

TRAITS	DFF	PH	PL	NPT	SF	TW	PW	SPY
DFF	1 **	0.3485 **	0.1612 **	0.089 NS	-0.3617 **	-0.1031 NS	-0.0106 NS	-0.1239 *
PH		1 **	0.3816 **	0.0667 NS	-0.2254 **	-0.0605 NS	0.0128 NS	0.0032 NS
PL			1 **	0.0355 NS	-0.0834 NS	0.1697 **	0.1467 **	0.014 NS
NPT				1 **	-0.0809 NS	-0.0048 NS	0.0618 NS	0.2667 **
SF					1 **	0.0996 NS	0.0292 NS	0.0846 NS
TW						1 **	0.352 **	0.2152 **
PW							1 **	0.4619 **
SPY								1 **

DFF -Days to 50% flowering; PH -Plant height; PL - Panicle length; NPT -Number of productive tillers per plant; SF - Spikelet fertility; TW - Test weight; PW -Panicle weight; SPY - Single plant yield. ** - Significant at 1% probability level; * -Significant at 5% probability level; NS - Non-significant.

Path analysis

To assess the direct and indirect contributions of yield-related traits to grain yield, phenotypic correlation analysis was carried out. This analysis helps in understanding the extent to which individual traits

influence grain yield, either directly or indirectly through their association with other characters. The study of phenotypic correlations provides valuable information on the interrelationships among traits and aids in identifying important characteristics for effective selection in rice breeding programmes.

Days to 50% flowering exerted a negative direct influence on single plant yield (-0.13023), indicating that delayed flowering was generally detrimental to productivity. Although positive indirect contributions were observed through the number of productive tillers (0.02259) and plant height (0.02349). Conversely, several traits mediated negative indirect effects, including spikelet fertility (-0.01759),

test weight (-0.00645), panicle weight (-0.00452), and panicle length (-0.01118). Similar results were reported by Chavan *et al.*, (2022) [33], Lakshmi *et al.*, (2021) [34], Golam *et al.*, (2015) [35], Ratna *et al.*, (2015) [36].

Plant height exerted a positive direct effect on single plant yield (0.06739), underscoring its role as a favourable determinant of productivity. Positive indirect contributions were also evident through the number of productive tillers (0.01693) and panicle weight (0.00547). In contrast, negative indirect effects, including days to 50% flowering (-0.04538), panicle length (-0.02646), spikelet fertility (-0.01096), and test weight (-0.00379). These results are comparable with the findings of Naseer *et al.*, (2015) [37], Golam *et al.*, (2015) [35], Lakshmi *et al.*, (2021) [34], Chavan *et al.*, (2022) [33], Saran *et al.*, (2023) [29], Patel *et al.*, (2014) [38], Ratna *et al.*, (2015) [36], Binod *et al.*, (2016) [39].

Panicle length exhibited a Negative direct effect on single plant yield (-0.06934) indicating that its direct contribution to grain yield was unfavorable. Moreover, positive indirect effects were observed through plant height (0.02572), number of productive tillers (0.00901), test weight (0.01062), and panicle weight (0.06305). Negative indirect effects were observed through days to 50% flowering (-0.02101) and spikelet fertility (-0.00406). These results are in line with the earlier reports of Nikhil *et al.*, (2014) [40], Binod *et al.*, (2016) [39], Rahman *et al.*, (2014) [41], Srijan *et al.*, (2016) [24], Ratna *et al.*, (2015) [36], Lakshmi *et al.*, (2021) [34], Chavan *et al.*, (2022) [33].

The number of productive tillers demonstrated a positive direct effect on single plant yield (0.25381) indicating its substantial contribution to grain yield. Furthermore, positive indirect effects were observed through plant height (0.0045) and panicle weight (0.02668). Conversely negative indirect effects were showed through days to

50% flowering (-0.01159), panicle length (-0.00246), spikelet fertility (-0.00393) and test weight (-0.00379). These results are in agreement with the earlier reports of Ratna *et al.*, (2015) [36], Rajamadhan *et al.*, (2011) [42], Lakshmi *et al.*, (2021) [34], Chavan *et al.*, (2022) [33].

Spikelet fertility showed a positive direct effect on single plant yield (0.04863) indicating its favorable contribution to grain yield. Additionally, positive indirect effects were observed through days to 50% flowering (0.04712), panicle length (0.00578), test weight (0.00623), and panicle weight (0.01257). Conversely, negative indirect effects were showed through plant height (-0.01519) and the number of productive tillers (-0.02054). Similar results were reported by Chavan *et al.*, (2022) [33].

Test weight revealed a positive direct effect on single plant yield (0.06259) indicating its favorable contribution to grain yield. In addition, positive indirect effects were observed through days to 50% flowering (0.01343), spikelet fertility (0.00484), and panicle weight (0.1514). Conversely, negative indirect effects were showed through plant height (-0.00408), panicle length (-0.01177), and the number of productive tillers (-0.00122). Similar results were reported by Mahalakshmi *et al.*, (2024) [43], Naseer *et al.*, (2015) [37], Golam *et al.*, (2015) [35], Srijan *et al.*, (2016) [24], Chavan *et al.*, (2022) [33].

Panicle weight observed a positive direct effect on single plant yield (0.43066) indicating that it is one of the major contributors to grain yield. In addition, positive indirect effects were observed through days to 50% flowering (0.00137), plant height (0.00086), number of productive tillers (0.01574), spikelet fertility (0.00142), and test weight (0.02202). Conversely, negative indirect effects were showed through panicle length (-0.01016). The results are in accordance with Srijan *et al.*, (2016) [24], Awaneet *et al.*, (2013) [44], Bhadru *et al.*, (2011) [45], Rajamadhan *et al.*, (2011) [42], Satturu *et al.*, (2023) [30].

Table 2. Path analysis on grain yield per plant in genotypes of hybrid rice

TRAITS	DFF	PH	PL	NPT	SF	TW	PW	SPY
DFF	-0.13023	0.02349	-0.01118	0.02259	-0.01759	-0.00645	-0.00452	-0.1239
PH	-0.04538	0.06739	-0.02646	0.01693	-0.01096	-0.00379	0.00547	0.0032
PL	-0.02101	0.02572	-0.06934	0.00901	-0.00406	0.01062	0.06305	0.014
NPT	-0.01159	0.0045	-0.00246	0.25381	-0.00393	-0.0003	0.02668	0.2667
SF	0.04712	-0.01519	0.00578	-0.02054	0.04863	0.00623	0.01257	0.0846
TW	0.01343	-0.00408	-0.01177	-0.00122	0.00484	0.06259	0.1514	0.2152
PW	0.00137	0.00086	-0.01016	0.01574	0.00142	0.02202	0.43066	0.4619

DFF -Days to 50% flowering; PH -Plant height; PL - Panicle length; NPT -Number of productive tillers per plant; SF - Spikelet fertility; TW - Test weight; PW -Panicle weight.

Conclusion

The present study revealed considerable variation among the rice genotypes for yield and yield-contributing traits, offering good prospects for their utilization in rice breeding programmes. Correlation analysis revealed that single plant yield was positively and significantly associated with panicle weight (0.4619**), number of productive tillers (0.2667**) and test weight (0.2152**), identifying these as the most important yield-contributing traits. Significant positive associations were also observed among several yield-related characters, including days to 50% flowering with plant height and panicle length, plant height with panicle length, panicle length with test weight and panicle weight, and test weight with panicle weight. Spikelet fertility showed only weak and non-significant associations with the major yield traits. These results indicate that selection for higher panicle weight, more productive tillers and greater test weight would be effective for improving grain yield in hybrid rice.

Path coefficient analysis further revealed that panicle weight exerted the highest positive direct effect on single plant yield, followed by number of productive tillers, test weight, plant height and spikelet fer-

tility. In contrast, days to 50% flowering and panicle length exhibited negative direct effects on yield. The consistency between correlation and path analysis underscores that panicle weight and number of productive tillers are particularly important traits for direct selection aimed at improving yield. Therefore, greater emphasis on these traits, along with test weight and other positively contributing characters, could enhance the efficiency of selection and facilitate the development of high-yielding rice genotypes. Overall, the identified yield-associated traits may serve as reliable selection criteria for future rice breeding programmes.

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