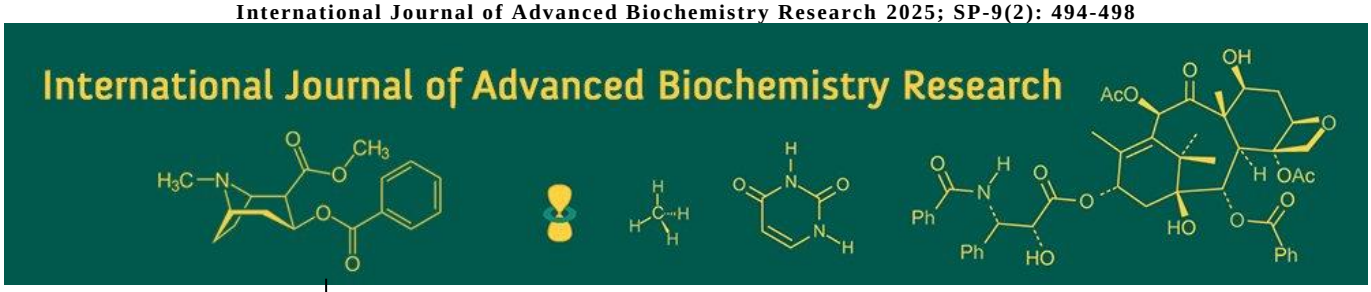

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Manoj Kumar SC
(1) Acharya N.G. Ranga Agricultural University, Lam, Guntur, Andhra Pradesh, India
(2) ICAR-Indian Institute of Rice Research, Hyderabad, Telangana, India

RM Sundaram
ICAR-Indian Institute of Rice Research, Hyderabad, Telangana, India

A Vishnuvardhan Reddy
Acharya N.G. Ranga Agricultural University, Lam, Guntur, Andhra Pradesh, India

C Gireesh
ICAR-Indian Institute of Seed Science, Bengaluru, Karnataka, India

R Mahender Kumar
ICAR-Indian Institute of Rice Research, Hyderabad, Telangana, India

SL Krishnamurthy
ICAR-Indian Institute of Rice Research, Hyderabad, Telangana, India

MS Anantha
ICAR-Indian Institute of Rice Research, Hyderabad, Telangana, India

M Reddi Sekhar
Acharya N.G. Ranga Agricultural University, Lam, Guntur, Andhra Pradesh, India

Corresponding Author:
C Gireesh
ICAR-Indian Institute of Seed Science, Bengaluru, Karnataka, India

Selection of traits for yield improvement in rice through interactions of yield-related traits in F_2 population

Manoj Kumar SC, RM Sundaram, A Vishnuvardhan Reddy, C Gireesh, R Mahender Kumar, SL Krishnamurthy, MS Anantha and M Reddi Sekhar

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Abstract
The present study aimed to analyse the correlation and path coefficients among 240 F_2 segregants derived from the cross MTU 1121 × Pusa 44 NIL to establish selection criteria for developing high-yielding genotypes. These 240 individual plants were assessed for 10 distinct yield related traits. Phenotypic correlation studies showed that single plant yield was significantly and positively associated with number of productive tillers (0.67***), total grains per panicle (0.37***), number of filled grains per panicle (0.39***), spikelet fertility (0.24***) and test weight (0.19**). Path analysis indicated that solitarily number of productive tillers had strong direct effect on single plant yield and spikelet fertility exerted medium direct effect, which are utmost importance for direct selection for yield improvement whereas other traits with significant correlations showed weak direct effects, suggesting their secondary role in yield improvement.

Keywords: Path coefficient, correlation analysis, selection, rice

Introduction
Rice is a vital staple crop across Asia, Africa, and Latin America, serving as a primary source of carbohydrates and energy for nearly half of the global population (Fukagawa & Ziska, 2019) [8]. The official world's rice production is 799.9 million tonnes, with an estimated area and productivity of 168.36 million hectares and 4.75 tonnes per hectare (FAOSTAT 2023) [5]. As the world's second largest producer, India is accountable for over 25% of the world's rice growing area, playing an integral role in global food security (Rathna Priya *et al.*, 2019) [18]. However, rice production faces challenges such as yield plateaus due to biotic and abiotic factors, highlighting the need for higher-yielding and resilient varieties (Kumar *et al.*, 2024) [15].

In a breeding program, the selection of superior genotypes is mostly focused on improving yield, which is crucial for enhancing productivity and overall crop production (Kozak *et al.*, 2008). The ideal generation for selection is one that displays significant segregation and recombination (Thirugnanakumar *et al.*, 2011) [28]. Yield and its associated traits are complex, often interdependent. Its improvement necessitates the understanding of relationships between yield and its components, as well as their direct and indirect effects on yield. Correlation and path coefficient analysis studies assist in deciphering the direct and indirect effects of characters on yield, providing promising information for efficient selection (Priya and Joel, 2009) [18].

Correlation studies can help breeder to identify various traits and trait combination to act upon by selection for the yield (Singh *et al.*, 2020) [24]. The path coefficient studies provide information on inter-relation among the mentioned characteristics. It is a standardized partial regression coefficient that measures the direct effect of one trait upon another and permits in distinguishing the correlation coefficient into components of direct and indirect effects (Board *et al.*, 1997) [3]. With this background, the present study was planned to determine the inter relationships and its effects on yield and yield related characters by using F_2 generations of a cross between elite lines in rice.

Materials and Methods

The present study was conducted at the Indian Institute of Rice Research (ICAR-IIRR), Rajendranagar, Hyderabad. The cross between MTU 1121 and Pusa 44 NIL was made during Kharif 2022 in the IIRR crossing block. A total of 240 F_2 segregants from the cross MTU 1121 × Pusa 44 NIL were raised during Kharif 2023. Thirty-day-old seedlings were transplanted in the main field with a spacing of 20 x 15 cm, and recommended agronomic practices were followed throughout the crop growth period. Data were collected from all segregants for the following traits: days to 50% flowering, plant height (cm), number of productive tillers per plant, panicle length (cm), total number of grains per panicle, number of filled grains per panicle, number of chaffy grains per panicle, spikelet fertility (%), test weight (g) and single plant yield (g).

Correlation coefficients were calculated using the formula proposed by Singh and Choudhary (1977) [32]. Path coefficient analysis, as described by Dewey and Lu (1959) [33], was used to estimate the direct and indirect effects of different components on grain yield. The strength of these effects was classified according to Lenka and Mishra (1973) [34] as follows: very strong (greater than 1), strong (0.3-0.9), medium (0.2-0.29), weak (0.1-0.19) and negligible (less than 0.1). All statistical analyses and the association plot were generated using R software version 4.4.1.

Results and Discussion

Selection of best recombinant by considering traits that affect yield is important to understand the link between yield and its constituent parts. The results on inter-character associations for yield component traits are presented in Fig. 1. Correlation study results revealed a significant and positive association ($p \leq 0.01$) of grain yield with the yield component traits *viz.*, number of productive tillers (0.67***), total number of grains per panicle (0.37***), the number of filled grains per panicle (0.39***), spikelet fertility (0.24***) and test weight (0.19**) indicating scope for their simultaneous improvement with grain yield per plant. These results were in accordance with the findings of Muthuvijayaragavan *et al.* (2020) [17] for number of productive tillers, total number of grains, the number of filled grains and spikelet fertility, while the reports of Prashant *et al.* (2024) [16] and Fathima *et al.* (2021) [6] were in agreement with significant relation of test weight on yield. Selection of traits which are strongly associated helps in enhancing the yield (Sujitha *et al.*, 2020; Basavaraj *et al.*, 2020) [26, 22].

Days to flowering showed a significant positive correlation with plant height (0.14*) and the number of productive tillers per plant (0.15*). These results are consistent with previous studies that identify plant height as a critical trait associated with yield (Kumar *et al.*, 2024; Saketh *et al.*, 2023) [15, 27] and highlight the relationship between days to flowering and productive tiller production (Singh *et al.*, 2020) [24]. Panicle length exhibited significant positive correlations with the total number of grains per panicle (0.54***), the number of filled grains per panicle (0.53***) and spikelet fertility (0.18**). These findings align with research highlighting the influence of panicle architecture on grain number in F_2 populations (Sowmya. *et al.*, 2023) [23]. The strong positive correlation between panicle length and filled grains underscores its importance in determining yield, while the positive association of spikelet fertility with yield components emphasizes its role in enhancing grain production (Banjare *et al.*, 2024) [2].

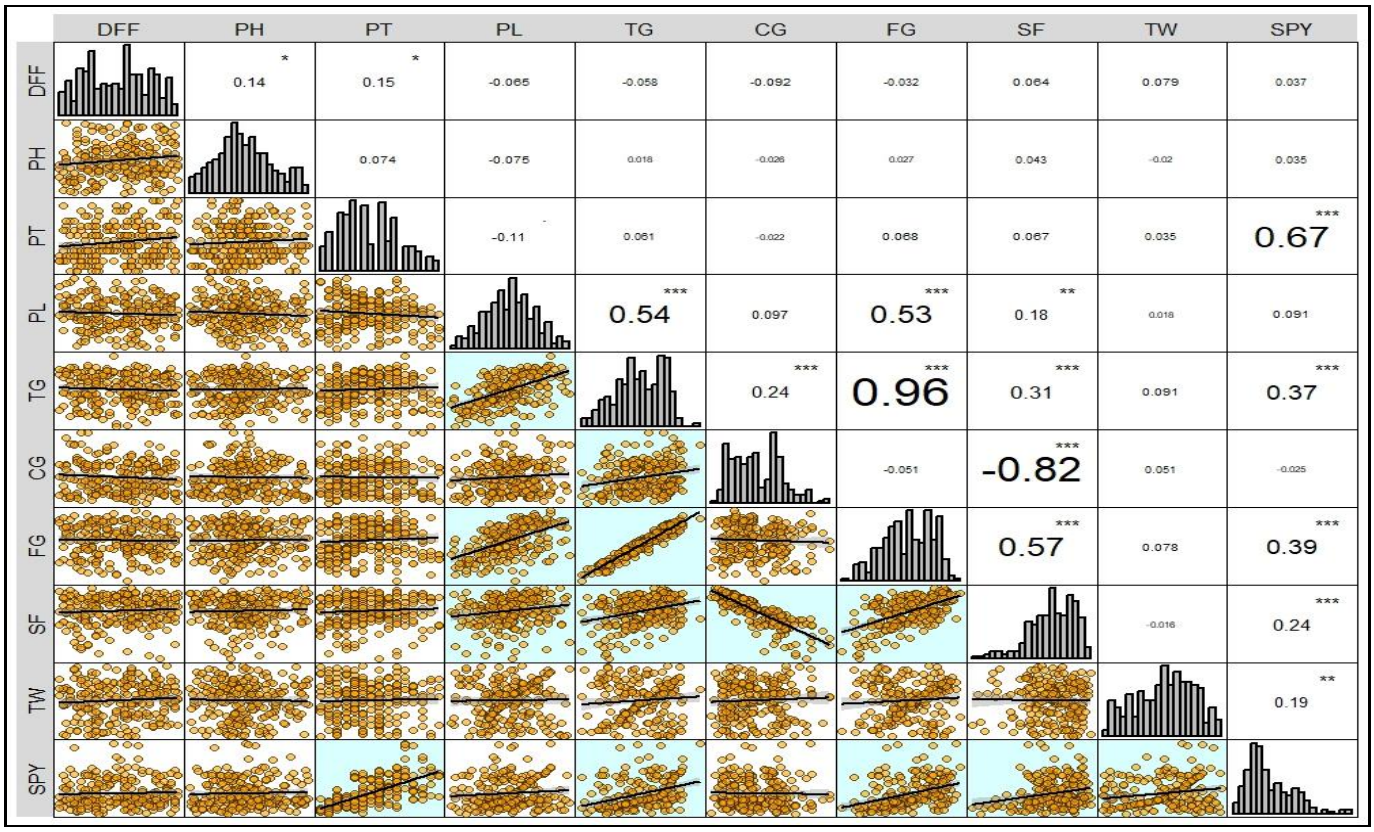
The total number of grains per panicle showed significant positive correlations with the number of filled grains per panicle (0.96***), spikelet fertility (0.31***) and the number of chaffy grains per panicle (0.24 ***). Similar findings were reported by Prashanth *et al.*, 2024 [16] for total number of grains and filled grains per panicle. Spikelet fertility, a key determinant of yield potential, further emphasizes its critical role in enhancing grain production (Sowmya. *et al.*, 2023) [23]. The influence of genetic factors on filled grains highlights their importance in overall yield improvement and their significance in breeding programs (Lu *et al.*, 2022) [30]. Spikelet fertility exhibited a significant negative correlation with the number of chaffy grains per panicle (-0.82***) and a significant positive correlation with the number of filled grains (0.57***). These findings suggest that an increase in chaffy grains reduces spikelet fertility, leading to lower seed set, often due to poor grain filling in dense panicle cultivars prone to sterility (Yuxiang *et al.*, 2020; Sekhar *et al.*, 2021) [31, 25]. Conversely, higher filled grain counts positively influence spikelet fertility, highlighting its role in enhancing overall yield (Sekhar *et al.*, 2021) [25]. The significant association between days to flowering, productive tillers, and plant height in rice indicates that prolonged flowering enhances tiller production, increasing single plant yield. Studies support positive correlations among these traits, with productive tillers having a strong direct effect on grain yield (Kiran *et al.*, 2014; Reshma *et al.*, 2023) [12, 20].

Correlation studies identify associations among traits, they often fail to reveal the relative importance of each trait in contributing to yield. To address this limitation, path coefficient analysis was conducted using single plant yield as the dependent variable and nine other traits as independent variables, enabling the partitioning of correlation coefficients into their direct and indirect components (Table 1). This method is invaluable for identifying the key traits that should be prioritized for yield improvement and for understanding the interrelationships between yield-associated characteristics.

Among all the characters, the number of productive tillers per plant (0.6433) exerted the strong positive direct effect on grain yield, followed by the medium positive effect of spikelets per panicle (0.2306). Similar findings were reported by Kumar *et al.* (2024) [15], highlighting the importance of productive tillers and spikelet fertility as primary traits for selection in breeding programs. Traits such as total grains per panicle (0.1555), thousand grain weight (0.148), and number of chaffy grains per panicle (0.1375) showed weak positive effects, indicating their secondary importance in yield improvement. Banjare *et al.* (2023) [2] and Dalei *et al.*, (2019) [4] also identified productive tillers per plant, thousand grain weight, and total grains per panicle as significant contributors to yield. Perween *et al.* (2020) [21] found similar weak positive effects of number of chaffy grains on yield, while Begum (2023) [10] emphasized the weaker positive impact of total grains per panicle, thousand grain weight, and number of chaffy grains per panicle. These traits except number of chaffy grains for panicle had also recorded positive and significant association with grain yield per plant, indicating the effectiveness of direct phenotypic selection for the traits in improvement of grain yield per plant. Days to fifty percent

flowering (-0.0588), panicle length (-0.0223) and plant height (0.0059), exhibited negligible negative direct effects on grain yield. These traits negative direct effects on grain yield were consistent with findings by Reetisana *et al.* (2020) [19], Kar *et al.* (2016) [13] and Gour *et al.* (2017) [9].

The indirect effect of days to fifty percent flowering on grain yield via studied traits was all negligible, negative highest and lowest via total number of grains per panicle (-0.0093) and plant height (-0.0008) respectively, while positive highest via number of productive tillers (0.0965) and lowest via panicle length (0.0013). The indirect effect of plant height on grain yield via studied traits was all negligible, positive highest via highest via number of productive tillers (0.045) and lowest via test weight (0.0001), while negative highest and lowest via, plant height (-0.0059) and total number of grains per panicle (-0.0093). Days to 50% flowering and plant height showed non-significant positive correlation with grain yield which was majorly due to indirect effect of number of productive tillers for on these traits. These results are in agreement with the results of Herawati *et al.*, (2019) [11] and Prashanth *et al.* (2024) [16] for plant height.



*Significant at 5%, ** Significant at 1%, *** Significant at 0.1% level

DFF-Days to 50% flowering, PH-Plant height (cm), PT-Number of productive tillers per plant, PL-Panicle length (cm), TG-Total number of grains per panicle, FG-Number of filled grains per panicle, CG-Number of chaffy grains per panicle, SF-Spikelet fertility (%), TW-Test weight (g) and SPY-Single plant yield (g).

Fig 1: Estimates of correlation coefficients between yield and it's component traits in F_2 population of cross MTU 1121 × Pusa 44 NIL.

Table 1: Phenotypic path coefficient analysis representing direct and indirect effects on single plant yield by its contributing traits in F_2 population of MTU 1121 x Pusa 44 NIL.

Trait	DFF	PH	PT	PL	TG	FG	CG	SF	TW	SPY
DFF	-0.0588	-0.0008	0.0965	0.0013	-0.0093	-0.0021	-0.0124	0.0138	0.0118	0.04
PH	-0.0082	-0.0059	0.0450	0.0018	0.0031	0.0021	-0.0041	0.0092	-0.0029	0.04
PT	-0.0088	-0.0004	0.6433	0.0025	0.0093	0.0049	-0.0027	0.0161	0.0059	0.67***
PL	0.0035	0.0005	-0.0708	-0.0223	0.0840	0.0369	0.0137	0.0415	0.0029	0.09
TG	0.0035	-0.0001	0.0386	-0.0120	0.1555	0.0668	0.0330	0.0715	0.0133	0.37***
FG	0.0018	-0.0002	0.0450	-0.0118	0.1493	0.0696	-0.0069	0.1314	0.0118	0.39***
CG	0.0053	0.0002	-0.0129	-0.0022	0.0373	-0.0035	0.1375	-0.1891	0.0074	-0.02
SF	-0.0035	-0.0002	0.0450	-0.0040	0.0482	0.0397	-0.1127	0.2306	-0.0029	0.24**
TW	-0.0047	0.0001	0.0257	-0.0004	0.0140	0.0056	0.0069	-0.0046	0.1475	0.19**

Residual effect - 0.4083, The values in the diagonal box (bold) are direct effects

DFF-Days to 50% flowering, PH-Plant height (cm), PT-Number of productive tillers per plant, PL-Panicle length (cm), TG-Total number of grains per panicle, FG-Number of filled grains per panicle, CG-Number of chaffy grains per panicle, SF-Spikelet fertility (%), TW-Test weight (g) and SPY-Single plant yield (g).

The indirect effect of the number of productive tillers on grain yield through the studied traits was mostly negligible. Among the negative effects, the highest was observed via days to fifty percent flowering (-0.0088) and the lowest via plant height (-0.0004). Conversely, among the positive effects, the highest was through spikelet fertility (0.0161)

and the lowest through panicle length (0.0025). These finding are in accordance with the findings of Prashanth *et al.*, 2024 [16] for panicle length and test weight. The indirect effect of panicle length on grain yield through the studied traits was negligible and positive for all traits except the number of productive tillers. The highest positive effect was observed via the total number of grains (0.0840), while the lowest was via plant height (0.0005). In contrast, the number of productive tillers exhibited a negligible negative effect of-0.0708. Converse results were reported for number of panicles by Saleh *et al.* (2020) [22].

The indirect effect of total number of grains on grain yield via studied traits was all negligible, positive for most traits except panicle length (-0.0120) and plant height (-0.0001). Among positive effects, spikelet fertility (0.0715) exhibited highest while days to fifty percent flowering showed lowest effect (0.0035). The indirect effect of filled grains per panicle on grain yield via studied traits was weak and positive for total number of grains (0.1493) and spikelet fertility (0.1314). Negligible and positive via number of productive tillers (0.0450), test weight (0.0118) and days to fifty percent flowering (0.0018). Negligible and negative effects via panicle length (-0.0118), number of chaffy grains (0.0069) and plant height (-0.0002).

The indirect effect of chaffy grains per panicle on grain yield via studied traits was weak and negative for spikelet fertility (-0.1891). Negligible, negative effects via number of productive tillers (-0.0129), number of filled grains per panicle (-0.0035) and panicle length (-0.0022). Positive, negligible effects via total number of grains per panicle (0.0373), test weight (0.0074), days to 50% flowering (0.0053) and plant height (0.0002). The indirect effect of spikelet fertility on grain yield via studied traits was weak and negative for number of chaffy grains per panicle (-0.1891). Positive, negligible effects via total number of grains per panicle (0.0482), number of productive tillers (0.0450) and number of filled grains per panicle (0.0397). Negligible, negative effects via., panicle length (-0.0040), days to 50% flowering (-0.0035), test weight (-0.0029) and plant height (-0.0002). Similar results were reported for indirect effects of these traits on yield by Prashant *et al.*, (2024) [16], Saleh *et al.*, (2020) [22] and Thuy *et al.*, (2023) [29].

The indirect effect of the test weight on grain yield through the studied traits was all negligible. Among the negative effects, the highest was observed via days to fifty percent flowering (-0.0047), and the lowest via panicle length (-0.0004). Conversely, among the positive effects, the highest was through productive tillers (0.0257), and the lowest through plant height (0.0001). Similar findings were reported by Prashant *et al.*, (2024) [16] and Reetisana *et al.* (2022) [19]. The residual effect in the present study was 0.4083 at phenotypic level indicating other attributes besides the characters studied are also contributing for single plant yield (Fentie *et al.*, 2021) [7].

Conclusion

The present study showed single plant yield was significantly and positively correlated with the number of productive tillers, total number of grains per panicle, number of filled grains per panicle, spikelet fertility and test weight, suggesting that these traits can be considered for selection process. Number of productive tillers per plant followed by spikelet fertility showed high and medium positive direct effects coupled with significant and positive correlation with grain yield per plant. Hence, these two traits are identified as effective selection criterion for effecting grain yield improvement. The relationship between the effect and a causal factor was similar to its direct effect, so the true relationship was explained and plant breeder could select directly through these traits. Based on residual effect there is a moderate amount of unexplained variance in the yield traits and therefore, other attributes besides the characters studied are also contributing for yield improvement.

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Conflict of interest disclosure

The authors declare that there is no conflict of interest.

References

1. Basavaraj PS, Gireesh C, Bharamappanavara M, Manoj CA, Ishwaryalakshmi LV, Senguttuvel P, *et al*. Genetic analysis of introgression lines of *Oryza rufipogon* for improvement of low phosphorous tolerance in *indica* rice. Indian J Genet Plant Breed. 2022;82(2):135-142.
2. Banjare B, Katiyar P, Thakur N, Magar AS. Evaluating panicle architecture and yield characteristics in medium-duration rice genotypes through correlation and principal component analysis. J Exp Agric Int. 2024;46(9):154-163. doi: 10.9734/jeai/2024/v46i92814.
3. Board JE, Kang MS, Hartville BG. Path analyses identify indirect selection criteria for yield of late-planted soybean. Crop Sci. 1997;37:879-884.
4. Dalei DR. The path coefficient analysis of different component traits on yield in short-grain aromatic rice (*Oryza sativa* L.) of Odisha. Int J Chem Stud. 2019;7(3):2215-2218.
5. FAOSTAT. 2023. Available online.
6. Fathima MA, Geetha S, Amudha K, Uma D. Genetic variability, frequency distribution, and association analysis in ADT (R) 48 × Kavuni derived F2 population of rice (*Oryza sativa* L.). Electron J Plant Breed. 2021;12(3):659-666.
7. Fentie DB, Abera BB, Ali HM. Association of agronomic traits with grain yield of lowland rice (*Oryza sativa* L.) genotypes. Int J Agric Sci. 2021;8(3):2348-3997.
8. Fukagawa NK, Ziska LH. Rice: Importance for global nutrition. J Nutr Sci Vitaminol (Tokyo). 2019;65:S2-S3.
9. Gour L, Koutu GK, Singh SK, Patel DD, Shrivastava A, Singh Y. Genetic variability, correlation, and path analysis for selection in elite breeding materials of rice (*Oryza sativa* L.) genotypes in Madhya Pradesh. Pharma Innov J. 2017;6(11):693-696.
10. Begum H. Analyzing genetic variability and heritability in rice breeding: A focus on yield improvement. Int J Sci Res. 2023. doi: 10.21275/sr231213092606.

11. Herawati R. Genetic analysis of grain yield of F4 populations for developing a new type of upland rice. SABRAO J Breed Genet. 2019;51(1).
12. Kiran K, Rao MR, Rajanna MP, Rao A, Mahadevu P, Siddegowda DK. Correlation and path analysis in F2 populations of two crosses of rice (*Oryza sativa* L.). Trends Biosci. 2014;7(10):896-899.
13. Kar RK, Mishra TP, Pandey RK, Das SR. Assessment of genetic variability in lowland SUB1 introgressed rice genotypes showing tolerance to submergence and stagnant flooding. IOSR J Agric Vet Sci. 2016;9(6):42-46.
14. Kozak M, Bocianowski J, Rybinski W. Selection of promising genotypes based on path and cluster analyses. J Agric Sci. 2008;146:85-92.
15. Kumar MB, Vidhyadhar B, Fiyaz RA, Anuradha C, Chary DS. Correlation and path coefficient analysis in F2 segregating population of RNR-15048 × Dokra-dokri in rice (*Oryza sativa* L.). J Adv Biol Biotechnol. 2024;27(11):232-240. doi: 10.9734/jabb/2024/v27i111608.
16. Prashanth M, Gireesh C, Lakshmi GS, Laha GS, Kumari LP, Anantha MS, *et al*. Study of genetic variability in F2 population for yield-enhancing traits under direct seed condition in rice (*Oryza sativa* L.). J Sci Res Rep. 2024;30(8):803-816. doi: 10.9734/jsrr/2024/v30i82300.
17. Muthuvijayaragavan R, Murugan E. Association analysis of F2 generation in rice (*Oryza sativa* L.) under salinity condition. Electron J Plant Breed. 2020;11(1):283-289.
18. Priya TS, Nelson ARLE, Ravichandran K, Antony U. Nutritional and functional properties of coloured rice varieties of South India: A review. J Ethn Foods. 2019;6:1-11.
19. Reetisana N, Sastry EVD, Renuka T, Julia T, Pyngrope AH. Correlation and path coefficient analysis in screening of submergence tolerance in rice (*Oryza sativa* L.) genotypes of Manipur. Biol Forum Int J. 2022;14(2):1130-1135.
20. Reshma O, Shivaprasad KM, Surendra P, Reddy B. Path and correlation analysis of elite rice (*Oryza sativa* L.) genotypes under diverse situations. Biol Forum Int J. 2023;15(5):1443-1448.
21. Perween S, Kumar A, Adan F, Danish M. The inter-relationship among yield and yield attributing traits of rice (*Oryza sativa* L.) under irrigated condition through correlation coefficient studies and path analysis. Int J Chem Stud. 2020;8(2):1409-1414. doi: 10.22271/CHEMI.2020.V8.I2V.8960.
22. Saleh MM, Salem KF, Elabd AB. Definition of selection criterion using correlation and path coefficient analysis in rice (*Oryza sativa* L.) genotypes. Bull Natl Res Cent. 2020;44(1):1-6.
23. Sowmya B, Jyothi B, Eswari KB, Raghuveer RP. Panicle architecture in enhancing grain yield in rice (*Oryza sativa* L.). Int J Environ Clim Change. 2023. doi: 10.9734/ijecc/2023/v13i113607.
24. Singh S, Mishra DK, Saha S. Study of genetic variability using correlation and heritability in F2 populations of rice. Int J Chem Stud. 2020;8(6):1829-1831. doi: 10.22271/CHEMI.2020.V8.I6Z.11035.
25. Sekhar SS, Kumar J, Mohanty S, Mohanty N, Panda RS, Das S, *et al*. Identification of novel QTLs for grain fertility and associated traits to decipher poor grain filling of basal spikelets in dense panicle rice. Sci Rep. 2021;11(1):13617. doi: 10.1038/S41598-021-93134-7.
26. Sujitha R, Pillai MA, Kannan R, Shoba D. Genetic diversity and association studies in rice (*Oryza sativa* L.). J Pharmacogn Phytochem. 2020;9(6):487-492.
27. Saketh T, Shankar GV, Srinivas B, Hari Y. Correlation and path coefficient studies for grain yield and yield components in rice (*Oryza sativa* L.). Int J Plant Soil Sci. 2023;35(19):1549-1558. doi: 10.9734/ijpss/2023/v35i193700.
28. Thirugnanakumar S, Narasimman R, Anandan A, Senthil Kumar N. Studies of genetics of yield and yield component characters in F2 and F3 generations of rice (*Oryza sativa* L.). Afr J Biotechnol. 2011;10(41):8797-8800.
29. Thuy NP, Trai NN, Khoa BD, Thao NHX, Thi QVC, Phong VT. Correlation and path analysis of association among yield, micronutrients, and protein content in rice accessions grown under aerobic condition from Karnataka, India.
30. Lu Y, Chuan MT, Wang H, Chen R, Tao T, Zhou Y, *et al*. Genetic and molecular factors in determining grain number per panicle of rice. Front Plant Sci. 2022;13. doi: 10.3389/fpls.2022.964246.
31. Yuxiang Z, Yuan C, Zhijuan J, Yan L, Changdeng Y. A novel digenic epistatic interaction at two loci regulating spikelet fertility in rice. Plant Growth Regul. 2020;90(2):347-357. doi: 10.1007/S10725-019-00557-4.
32. Chaudhary BD, Kakar SN, Singh RK. Estimation of genetic parameters in barley (*Hordeum vulgare* L.) II. Partial diallel analysis. Theoretical and Applied Genetics. 1977 Jul;49:153-156.
33. Dewey DR, Lu K. A correlation and path-coefficient analysis of components of crested wheatgrass seed production 1. Agronomy journal. 1959 Sep;51(9):515-518.
34. Lenka D, Misra B. Path-coefficient analysis of yield in rice varieties; 1973.