*Plant Archives* Vol. 26, No. 2, 2026 pp. 2757-2766 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.2.378

# VARIABILITY AND TRAIT ASSOCIATION FOR ASSIMILATE PARTITIONING, FLAG LEAF TRAITS AND GRAIN YIELD IN RICE GENOTYPES

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(Date of Receiving-04-08-2026; Date of Revision-13-10-2026; Date of Acceptance-19-10-2026)

**ABSTRACT**

Rice productivity improvement requires the effective exploitation of genetic variability and a clear understanding of the traits that contribute to grain yield. The present study was conducted to evaluate genetic variability, trait relationships, and the direct and indirect effects of assimilate partitioning and flag leaf traits on grain yield in 24 rice genotypes. The experiment was carried out at the Instructional Farm, Odisha University of Agriculture and Technology, Bhubaneswar, in a randomized complete block design with three replications. Significant differences among genotypes were observed for all 15 traits, indicating the presence of considerable genetic variability. Flag leaf and assimilate partitioning traits exhibited high genotypic and phenotypic coefficients of variation. Broad-sense heritability ranged from 72.36% for flag leaf angle to 99.58% for days to 50% flowering. Number of fertile grains per panicle, 100-grain weight, harvest index, flag leaf area, pre-flowering photosynthetic contribution to grain yield, grain yield per plant, and plot yield exhibited high GCV, high broad-sense heritability, and high GAM suggesting good potential for effective selection. Grain yield per plant showed a strong positive genotypic association with harvest index (0.729), whereas days to 50% flowering (-0.435) and plant height (-0.410) were negatively associated with yield. Path coefficient analysis further revealed that post-flowering photosynthetic contribution to grain yield had the highest positive direct effect, followed by pre-flowering photosynthetic contribution, harvest index and flag leaf area. Overall, the findings emphasize the importance of efficient assimilate partitioning, harvest index, and flag leaf traits in improving grain yield and suggest that these traits can serve as useful selection criteria for identifying superior rice genotypes.

***Key words :*** Variability, Rice, flag leaf, Assimilate Partitioning.

## Introduction

Rice is the predominant dietary energy source for billions of people worldwide and holds immense economical, social and cultural importance for consumers in eighteen Asian countries. In India, rice is a major staple food, consumed by nearly three-fourths of the population, and contributes substantially to the livelihoods and agricultural income of millions of farm households (Babu *et al.*, 2015 and Kumar *et al.*, 2024). With increasing population and rising demand for food, the requirement for rice is expected to increase substantially in the coming decades. At the current level of per capita availability, rice production in India needs to increase by approximately 40% by 2030 and 70% by 2050, from about 105 million tonnes to 145 and 190 million tonnes of milled rice, respectively (Siddiq, 2013; Rice Almanac, 2013; Suman *et al.*, 2026). It is therefore, a challenging task to achieve this production targets in the next few decades as increase in productivity has to come from the declining and degrading resource base in terms of land, water and other

inputs and demand for environmentally sound rice production practices (Siddiq, 2013).

The most effective and economical strategy to enhance rice productivity and food security is through genetic improvements. The success of any breeding programme depends largely on the availability of genetic variability (Paramanik *et al*., 2023). Understanding the extent of genetic variability as well as important parameters such as heritability and genetic advance is a critical prerequisite for developing effective breeding programs and superior crop varieties. Such information will assist in evaluating and selecting desirable promising genotypes to provide food for the increased populations and to meet consumer and market preferences (Kumar *et al*., 2026). However, grain yield is a complex trait governed by several component traits and is strongly influenced by environmental conditions, making direct selection for yield alone relatively less efficient.

Among the physiological and morpho-agronomical traits, contributing to yield, assimilate partitioning and flag leaf traits plays a pivotal role as they influence photosynthetic efficiency, source-sink relationships, and the translocation of photosynthates to developing grains. Efficient partitioning of assimilates and favourable flag leaf characteristics contribute significantly to grain filling and final grain yield (Vishwakarma *et al*., 2023 and Li *et al*., 2026). Understanding the variability present in these traits and their relationship with grain yield is consequently important for identifying useful selection criteria in rice breeding.

Since grain yield is a complex trait influenced by multiple component characters, selection based solely on yield may not always provide consistent genetic gain. Therefore, in order to successfully select for superior yield, a full understanding of the nature and extent of association between various yield and contributing characters must be understood. Correlation analysis provides valuable information about the nature and magnitude of associations between grain yield, assimilate partitioning traits and flag leaf characteristics, thereby providing an initial basis for indirect selection. However, correlation coefficients alone do not distinguish between direct and indirect contributions of individual traits. Path coefficient analysis overcomes this limitation by partitioning correlation coefficients into direct and indirect effects, enabling the identification of traits that exert the greatest influence on grain yield (Rahangdale, 2019; Babu and Thouseem, 2024).

Therefore, genetic variability assessment together with correlation and path coefficient analyses of assimilate partitioning, flag leaf traits and grain yield can provide a better understanding of the genetic relationships among these characters. Such information can help identify traits with greater potential as selection criteria and facilitate the efficient selection of rice genotypes with desirable combinations of physiological and yield-related attributes. The present study was therefore undertaken to assess the extent of variability and to elucidate the associations and direct and indirect effects of assimilate partitioning and flag leaf traits on grain yield among rice genotypes, with the aim of identifying useful traits for yield improvement in rice breeding programmes.

## Materials and Methods

The experimental trial was conducted during the *kharif* season of 2021 under normal field conditions at the Instructional Farm, Orissa University of Agriculture and Technology, Bhubaneswar. A randomized complete block design (RCBD) with three replications was laid out. The experimental materials consisted of 24 genotypes along with four checks varieties, Lalat, Jaya, Swarna and NDR 359 (Table 1). The seed sowing was done on 25$^{th}$ July 2021 and seedlings were transplanted on 20$^{th}$ August, 2021. Each genotype was accommodated in a four-row plot of 3.75 m², maintaining a spacing of 20 cm between rows and 15 cm between plants. A fertilizer dose of 100kg N, 50kg $P_2O_5$ and 50kg $K_2O$ per hectare was applied as per the scheduled management practices. The recommended crop management practices were followed including need-based plant protection measures to raise a normal crop.

### Data recording and Statistical analysis

Observations were recorded for 15 metric traits from five competitive plants selected randomly from the middle rows of each plot to minimize border effects. The characters like plot yield and days to 50% flowering were recorded on plot basis. The data recorded for various traits were subjected to statistical analysis based on the mean values of the observations.

The Analysis of Variance (ANOVA) was carried out separately for each trait following the procedures outlined by Panse and Shukhatme (1954) for randomized block design. The significance of differences among genotypes was tested using the appropriate error variance from the ANOVA. Descriptive and genetic variability parameters, including mean, range, standard error of mean ($SE_m$), standard error of difference ($SE_d$), critical difference (CD), phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability ($h^2_{bs}$) and genetic advance (GA) were estimated. The estimation of Variability parameters was

**Table 1 :** List of genotypes, parentage and origin.

| S. no. | Designation | Parentage | Origin |
|---|---|---|---|
| 1 | CR 3561-3-2-1-1-1-1 | Surendra/Annapurna | NRRI |
| 2 | CB 12132 | CO 50/CB 05501 | TNAU |
| 3 | RP 5952-41-20-8-2-1-1 | LP2/JV 42//NDR 359 | IIRR |
| 4 | R 1500-HR-NPT-1 | IR 71677-402-3-3-2/Mahamaya | IGKV |
| 5 | CR 3856-44-22-2-1-11-1 | IR 73963-86-1-5-2-2/CR 2324-1 | NRRI |
| 6 | NPT 14-10 | NPT 29/R 296 | IGKV |
| 7 | NDR 359 (C) | BG 90-2-4/OB 677 | NDAUT |
| 8 | RP 5953-43-9-1-1-1-1 | LP 3/JV 40//RP 5125-12-4-1-1-1 | IIRR |
| 9 | CR 3816-1-2-1-1-1 | Gayatri/AC 38700 | NRRI |
| 10 | RTN 1109-39-1-5 | RTN 95-2-1-1-1/RTN 50-1-1-1 | KKV |
| 11 | Swarna (C) | Vasistha/Mahsuri | ANGRAU |
| 12 | CR 3936-11-1-1-1-1-1 | IR 72967-12-2-3/MTU 1001 | NRRI |
| 13 | GNV 13-01 | RS 17-1/IET 19228 | UAS |
| 14 | RP 5953-118-11-4-3-2-1-B | LP 3/JV 40//RP 5125-12-4-1-1-1 | IIRR |
| 15 | PA 6444 | - | Bayer Bio-Sci. |
| 16 | CR 2683-7-1-2-2-2 | CRLC 899/AC 38700 | NRRI |
| 17 | R 1501-HR-NPT-1 | IR 71677-402-3-3-2/IR 64 | IGKV |
| 18 | RP 5954-18-6-4-1-1-1 | Secormandi/NDR 359//IR 78878-53-2-2-2 | IIRR |
| 19 | CR 2682-1-2-5-1-3 | CRLC 899/AC 38606 | NRRI |
| 20 | Hiranmayee | OR 1530-8/IR 68181-B-49 | OUAT |
| 21 | Jaya (C) | TN 1/T 141 | IIRR |
| 22 | Pratikshya | Swarna/IR64 | OUAT |
| 23 | Lalat (C) | OBS 677/IR 2071//Vikram/ W1263 | OUAT |
| 24 | Mahanadi | IR 19661-131-1-3-1/Savitri | OUAT |

carried out according to the method suggested by the formula suggested by Burton (1952) and Johnson *et al.* (1955).

Using the various covariance components, the genotypic, phenotypic and environmental correlations between different character pairs were computed according to Robinson *et al*. (1951), Johnson *et al.* (1955) and Al-Jibouri *et al*. (1958). Path coefficient analysis was performed by solving simultaneous equations following the method proposed by Wright (1921), Dewey and Lu (1959). Grain yield per plant/plot was considered the dependent variable, while the remaining yield-related and assimilate partitioning and flag leaf traits were considered causal variables in the path analysis.

## Results and Discussion

### ANOVA, mean performance and Range

The analysis of variance in respect to various traits were carried out and presented in Table 2. The mean square due to genotypes were significant for all the traits studied, implying presence of significant variability among the genotypes. Significant genotypic variation provides an opportunity for the identification and selection of superior genotypes for the improvement of grain yield and associated traits.

Considerable variation was observed among the genotypes for phenological and plant architectural traits. Days to 50% flowering ranged from 88 days in Lalat to 110 days in CR 2682-1-2-5-1-3 and CR 2683-7-1-2-2-2 with an overall mean of 98 days, indicating the tested genotypes to be placed into mid-early to late in maturity duration groups. Plant height ranged from 89.21 cm in RTN 1109-39-1-5 to 148.99 cm in CR 2683-7-1-2-2-2, with a mean of 113.87 cm. Panicle length varied from 21.71 cm in RTN 1109-39-1-5 to 29.32 cm in NDR 359. The number of panicles per plant ranged from 6.00 in CR 2683-7-1-2-2-2 to 10.67 in Swarna, Hiranmayee and Pratikshya, with a mean of 7.99. The number of fertile grains per panicle ranged from 112.33 in Lalat to 273.33 in RTN 1109-39-1-5, with a mean of 191.51. Fertility percentage varied from 66.09% in NDR 359 to 90.78% in R 1501-HR-NPT-1, with an overall mean of 77.78%. The 100-grain weight ranged from 1.59 g in CB 12132 to 3.28 g in CR 3936-11-1-1-1-1-1, with a mean of 2.35 g. Harvest index ranged from 0.26 in CR 2682-1-2-5-1-3 to 0.56 in R 1500-HR-NPT-1, with an overall mean of 0.42.

**Table 2 :** Analysis of variance for various characters (Mean sum of squares).

| S. no. | Characters | Source of variation (df) | | |
|---|---|---|---|---|
| | | Replication (2) | Genotype (23) | Error (46) |
| 1. | Days to 50% flowering | 2.63* | 130.41** | 0.55 |
| 2. | Plant height (cm) | 24.77 | 709.57** | 19.86 |
| 3. | Panicle length (cm) | 0.73 | 12.17** | 1.56 |
| 4. | Panicle number | 3.09 | 6.22** | 1.65 |
| 5. | No. of fertile grains/panicle | 7373.00** | 5435.94** | 1150.12 |
| 6. | Fertility percentage | 87.66* | 139.21** | 18.15 |
| 7. | 100-grain weight (g) | 0.001 | 0.564** | 0.006 |
| 8. | Harvest index | 0.00002 | 0.018** | 0.0003 |
| 9 | Flag leaf angle ($0^0$) | 4.16 | 25.54** | 7.06 |
| 10. | Flag leaf length (cm) | 13.62 | 85.61** | 14.85 |
| 11. | Flag leaf area ($cm^2$) | 13.95 | 442.20** | 35.94 |
| 12. | Pre-flowering photosynthetic translocation to grain yield(%) | 5.13 | 480.29** | 17.84 |
| 13. | Post-flowering photosynthetic contribution to grain yield (%) | 5.11 | 480.07** | 17.85 |
| 14. | Grain yield / plant (g) | 44.29** | 26.07** | 4.41 |
| 15. | Plot yield (q/ha) | 5.49 | 156.58** | 9.52 |

Flag leaf angle varied from $10.03^0$ in Hiranmayee to $18.98^0$ in R 1500-HR-NPT-1 with over all mean of $13.75^0$. Flag leaf length and flag leaf area ranged from 24.32 to 46.67 cm and 21.30 to 75.66 $cm^2$, respectively. The contribution of pre-flowering photosynthates to grain yield varied from 10.30 to 63.43%, with a mean of 26.64%, whereas the post-flowering contribution ranged from 36.57 to 89.70%, with a mean of 73.36%. Grain yield per plant ranged from 5.47 g in CR 2682-1-2-5-1-3 to 18.76 g in Pratikshya, with a mean of 13.28 g. Plot yield varied considerably among the genotypes, with PA 6444 recording the highest performance and an overall mean of 37.29 q $ha^{-1}$. Overall, the wide range of variability observed for yield and associated traits suggested good scope for effective selection in the experimental material.

A significant amount of variability was observed among the genotypes for days to 50% flowering, plant height, length of panicle, number of panicles/plant, number of productive grains per panicle, fertility percentage, 100-seed weight, harvest index, angle of flag leaf, length of flag leaf, area of flag leaf, pre-flowering photosynthetic contribution to grain yield, post-flowering photosynthetic contribution to grain yield, grain yield per plant, and plot yield. These wide ranges of variability for each character implies that there exists great genetic diversity among the genotypes evaluated, which will provide greater opportunity for successful selection and improvement of crops through breeding programs. The presence of considerable variability for yield and related traits in rice has also been reported by Jha *et al.* (2014), Kumar *et al.* (2014), Srujana *et al.* (2017), Choudhary *et al.* (2018), Rahangdale *et al.* (2019), Akshay *et al.* (2022), Mahesh *et al.* (2022), and Kumar *et al.* (2026).

## Coefficient of variation, genotypic and phenotypic coefficients of variation

The overall mean, range, CV, genotypic and phenotypic coefficient of variation for yield and its component traits along with physiological characters are presented in Table 3. The coefficient of variations (CV) for studied traits ranged from 0.76% for days to 50% flowering to 19.32% for flag leaf angle. The CV recorded was below 18% for majority of the quantitative and physiological traits. Among the characters studied the GCV ranged from 6.69% for days to 50% flowering to 46.60% for pre-flowering photosynthetic translocation to grain yield and similarly for PCV it varied from 6.70% for days to 50% flowering to 47.49% for pre-flowering photosynthetic translocation to grain yield. Majority of the traits showed smaller difference between PCV and GCV. For all the traits, PCV was slightly higher than GCV, indicating the lower contribution of environmental variation to the observed phenotypic variability. High GCV and PCV (more than 15%) were observed for traits like panicle number, number of fertile grains per panicle, 100-grain weight, harvest index, flag leaf angle, flag leaf area, pre-flowering photosynthetic translocation to grain yield, post-flowering photosynthetic contribution to grain yield, grain yield per plant and plot yield suggesting that these traits are under the influence of genetic control. Similar observations of high GCV and PCV for these traits have been reported by Kushwah *et al.* (2021), Singh *et al.* (2021), Paramanik *et al.* (2023) and Kumar *et al.* (2026).

## Heritability and genetic advance

The estimates of broad sense heritability and genetic advance as percentage of mean (GAM) for all the traits are presented in Table 3 and Fig. 1. The heritability values varied from 72.36% for flag leaf angle to 99.58% for days to 50% flowering. Moderate to high degree of heritability estimates were observed for majority of the traits under study. High heritability (>80%) were observed

**Table 3 :** Mean, Range, Coefficient of variation, Genotypic and phenotypic coefficient of variation, Heritability and Genetic advance estimates of various characters

| S. no. | Characters | Mean | Range | CV (%) | GCV (%) | PCV (%) | $h^2$ (%) | GA | GA as percent of mean |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Days to 50% flowering | 98.33 | 88.33-110.00 | 0.76 | 6.69 | 6.70 | 99.58 | 11.56 | 11.75 |
| 2. | Plant height (cm) | 113.87 | 89.21-148.99 | 3.91 | 13.32 | 13.51 | 97.20 | 26.31 | 23.11 |
| 3. | Panicle length (cm) | 25.51 | 21.71-29.32 | 4.90 | 7.37 | 7.90 | 87.18 | 3.09 | 12.12 |
| 4. | Panicle number | 7.99 | 6.00-10.67 | 16.07 | 15.45 | 18.03 | 73.49 | 1.86 | 23.32 |
| 5. | No. of fertile grains/ panicle | 191.51 | 112.33-273.33 | 17.71 | 19.74 | 22.23 | 78.84 | 59.07 | 30.84 |
| 6. | Fertility percentage | 77.78 | 66.09-90.78 | 5.53 | 8.16 | 8.76 | 86.71 | 10.40 | 13.37 |
| 7. | 100-grain weight (g) | 2.35 | 1.59-3.28 | 3.35 | 18.37 | 18.47 | 98.90 | 0.76 | 32.14 |
| 8. | Harvest index | 0.42 | 0.26-0.56 | 4.09 | 17.92 | 18.08 | 98.29 | 0.13 | 31.27 |
| 9 | Flag leaf angle ($0^0$) | 13.75 | 10.03-18.98 | 19.32 | 18.05 | 21.22 | 72.36 | 3.72 | 27.02 |
| 10. | Flag leaf length (cm) | 32.68 | 24.32-46.67 | 11.79 | 14.86 | 16.34 | 82.66 | 7.77 | 23.78 |
| 11. | Flag leaf area ($cm^2$) | 38.40 | 21.30-75.66 | 15.61 | 30.30 | 31.62 | 91.87 | 19.63 | 51.12 |
| 12. | Pre-flowering photosynthetic translocation to grain yield (%) | 26.64 | 10.30-63.43 | 15.85 | 46.60 | 47.49 | 96.29 | 21.44 | 80.48 |
| 13. | Post-flowering photosynthetic contribution to grain yield (%) | 73.36 | 36.57-89.70 | 5.76 | 16.92 | 17.24 | 96.28 | 21.44 | 29.22 |
| 14. | Grain yield / plant (g) | 13.28 | 5.47-18.76 | 15.83 | 20.24 | 22.21 | 83.07 | 4.31 | 32.46 |
| 15. | Plot yield (q/ha) | 37.29 | 25.89-53.11 | 8.27 | 18.78 | 19.38 | 93.92 | 11.94 | 32.03 |

for days to 50% flowering, plant height, panicle length, fertility percentage, 100-grain weight, harvest index, flag leaf length, flag leaf area, pre-flowering photosynthetic translocation to grain yield, post-flowering photosynthetic contribution to grain yield, grain yield per plant and plot yield. However, the traits like panicle number, number of fertile grains per panicle and flag leaf angle showed moderate heritability values extending from 60-80 per cent. Similar reports of high heritability for plant height, days to 50% flowering, days to maturity and spikelet fertility percentage were reported by Dinesh *et al*. (2023) and Kumar *et al*. (2026).

Genetic advance as percentage of mean varied from 11.75% for days to flowering to 80.48% for pre-flowering photosynthetic translocation to grain yield. Traits like number of fertile grains per panicle, 100-grain weight, harvest index, flag leaf area, pre-flowering photosynthetic translocation to grain yield, grain yield per plant and plot yield exhibited higher values of genetic advance ranging from 30.84 to 80.48%. Moderate levels of genetic

**Table 4 :** Estimates of genotypic correlation coefficients among studied characters in rice.

| Traits | DF | PH | PL | PN | GN | F% | HGW | HI | FLA | FLL | FLAr | PPTG | PPCG | GYPP (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DF | **1** | 0.663** | -0.213 | -0.178 | 0.134 | -0.192 | 0.233 | -0.855** | 0.069 | -0.13 | 0.081 | 0.668** | -0.668** | -0.435* |
| PH | | **1** | 0.041 | -0.501* | 0.336 | 0.073 | 0.307 | -0.672** | 0.196 | 0.142 | 0.279 | 0.33 | -0.33 | -0.410* |
| PL | | | **1** | -0.013 | 0.137 | -0.347 | -0.134 | 0.249 | 0.092 | 0.213 | 0.179 | -0.172 | 0.172 | 0.123 |
| PN | | | | **1** | -0.409* | 0.091 | -0.429* | 0.343 | -0.535** | -0.473* | -0.554** | -0.308 | 0.308 | 0.322 |
| GN | | | | | **1** | 0.068 | -0.343 | -0.049 | 0.562** | 0.525** | 0.647** | 0.256 | -0.256 | 0.198 |
| F% | | | | | | **1** | -0.19 | 0.21 | -0.189 | -0.294 | -0.293 | -0.450* | 0.450* | 0.148 |
| HGW | | | | | | | **1** | -0.202 | 0.157 | -0.026 | 0.106 | 0.137 | -0.137 | -0.153 |
| HI | | | | | | | | **1** | 0.031 | 0.045 | -0.049 | -0.567** | 0.567** | 0.729** |
| FLA | | | | | | | | | **1** | 0.581** | 0.640** | 0.283 | -0.283 | 0.286 |
| FLL | | | | | | | | | | **1** | 0.888** | 0.069 | -0.069 | 0.033 |
| FLAr | | | | | | | | | | | **1** | 0.175 | -0.175 | 0.12 |
| PPTG | | | | | | | | | | | | **1** | -1.000** | -0.352 |
| PPCG | | | | | | | | | | | | | **1** | 0.352 |
| GYPP (g) | | | | | | | | | | | | | | 1 |

Days to 50% flowering (DF), plant height (PH), panicle length (PL), panicle number (PN), grain number per panicle (GN), fertility percentage (F%), 100-grain weight (HGW), harvest index (HI), flag leaf angle (FLA), flag leaf length (FLL), flag leaf area (FLAr), pre-flowering photosynthetic translocation to grain yield (PPTG) and post-flowering photosynthetic contribution to grain yield (PPCG), grain yield per plant (GYPP).

advance ranging from 23.11 to 29.22% were recorded for plant height, panicle number, flag leaf angle, flag leaf length and post-flowering photosynthetic contribution to grain yield. Lower values of genetic advance ranging from 11.75 to 13.37 percent were recorded for days to 50% flowering, panicle length and fertility percentage.

Overall, number of fertile grains per panicle, 100-grain weight, harvest index, flag leaf area, pre-flowering photosynthetic contribution to grain yield, grain yield per plant, and plot yield exhibited high GCV, high broad-sense heritability, and high GAM. This indicates the preponderance of additive gene and hence selection based on phenotypic performance for these traits would be effective. Similar reports for these traits were also reported by Pandey *et al.* (2012), Sandhya *et al.* (2014), Savitha and Usha Kumari (2015), Mishu *et al.* (2016), Singh *et al.* (2021) and Kumar *et al.* (2026).

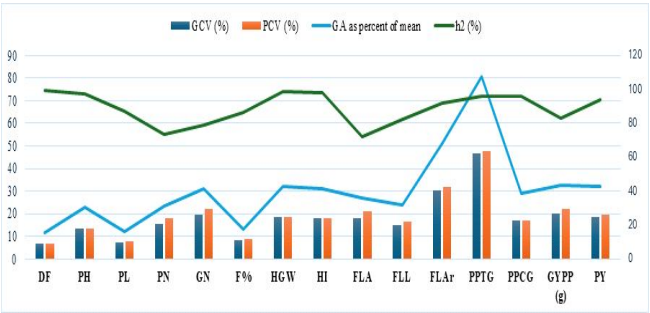



**Fig. 1 :** Combined graphical representation of GCV, PCV, heritability and genetic advance as percent of mean for different traits.

**Nature of character association**

The results of the nature and magnitude of association of characters are presented below trait wise at genotypic level (Table 4). Grain yield per plant (GYPP) exhibited positive associations with number of panicles per plant, number of grains per panicle, flag leaf area, flag leaf length, flag leaf area retention and harvest index. Among these, the association between harvest index and grain yield was positive and highly significant (0.729**), indicating that efficient partitioning of assimilates towards reproductive sinks was an important contributor to higher grain yield. The positive association of grain yield with PN (0.322) and GN (0.198), although non-significant, further indicated the contribution of yield-component traits towards productivity.

Days to flowering exhibited a significant and positive association with plant height (0.663**) and flag leaf area retention (0.668**), whereas it was significantly and negatively correlated with harvest grain weight (-0.855**). DF also exhibited a significant negative association with grain yield per plant (-0.435*), suggesting that relatively earlier flowering genotypes tended to perform better for grain yield under the experimental conditions. Plant height showed significant negative

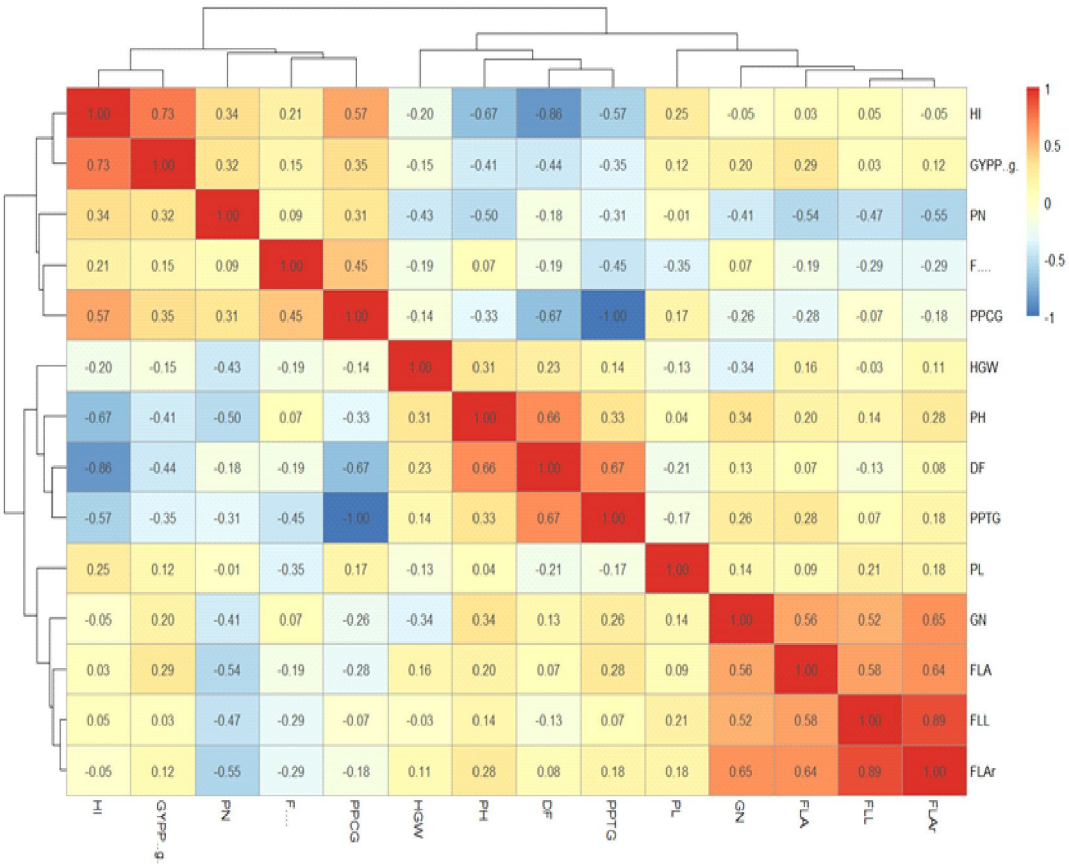



**Fig. 2 :** Clustered correlation heatmap depicting interrelationships among yield and associated traits.

associations with PN (-0.501*) and HI (-0.672**), and its association with grain yield was also negative and significant (-0.410*). This indicated that excessive vegetative growth may be associated with reduced reproductive efficiency and lower grain productivity.

Number of panicles per plant showed significant negative associations with GN (-0.409*), HGW (-0.429*), HI (-0.535**) and FLA (-0.473*). Conversely, GN showed significant positive associations with FLA (0.525**), FLL (0.647**) and FLAr (0.256), suggesting that longer retained flag leaves may support grain development through enhanced assimilate production during the reproductive stage. The flag-leaf traits also showed strong interrelationships. Flag leaf area was significantly and positively correlated with FLL (0.581**) and FLAr (0.640**), indicating that larger flag leaves tended to have greater area retention during grain filling. The positive association of FLA with grain yield (0.286) and FLAr with grain yield (0.120) further suggests that maintenance of photosynthetically active leaf area during the reproductive stage may contribute to yield formation. Harvest index also showed a significant positive association with FLAr (0.729**), reinforcing the importance of maintaining functional photosynthetic tissue during grain filling for efficient biomass partitioning.

Overall, the correlation pattern indicated that harvest index, panicle number, flowering time, and flag-leaf attributes were important traits associated with grain yield. The significant positive relationship between harvest index and grain yield, together with the negative association of plant height and days to flowering with grain yield, suggests that these traits may be useful as indirect selection criteria for improving productivity in the studied rice genotypes. However, number of fertile grains per panicle, flag leaf angle and flag leaf area differed slightly in their association pattern between the two yield traits. The association trends for both grain yield per plant and plot yield were more or less similar and also the association between these two traits revealed that selection on the basis of characters contributing grain yield per plant also bears relevance to plot yield. These results are in agreement with Babu *et al*. (2012), Singh *et al*. (2013), Lingaiah *et al*. (2014), Kumar *et al*. (2015), Pradhan *et al*. (2015) and Mishu *et al*. (2016).

**Path coefficient analysis**

The path analysis presented in Table 5 revealed that harvest index exhibited the strongest positive direct effect (0.939) and, importantly, also showed a strong positive correlation with grain yield (0.729**), identifying it as the most reliable selection criterion among the traits evaluated.

**Table 5 :** Path co-efficient analysis of direct (diagonal) and indirect effects of various traits on grain yield per plant.

| Characters | DF | PH | PL | PN | GN | F% | 100-GW | HI | FLA | FLL | FLAr | PPTG | PPCG | Correlation with yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Days to 50% flowering | **0.363** | 0.038 | 0.033 | -0.050 | 0.014 | 0.023 | -0.010 | -0.812 | 0.018 | 0.066 | 0.036 | 24.96 | -25.13 | -0.435 |
| Plant height | 0.242 | **0.057** | -0.007 | -0.139 | 0.037 | -0.008 | -0.014 | -0.634 | 0.070 | -0.069 | 0.136 | 12.33 | -12.41 | -0.410 |
| Panicle length | -0.074 | 0.002 | **-0.159** | -0.004 | 0.015 | 0.041 | 0.008 | 0.234 | 0.033 | -0.103 | 0.087 | -6.43 | 6.47 | 0.123 |
| Panicle number | -0.066 | -0.029 | 0.002 | **0.278** | -0.045 | -0.011 | 0.022 | 0.327 | -0.193 | 0.229 | -0.269 | -11.51 | 11.59 | 0.322 |
| Grain number | 0.045 | 0.019 | -0.022 | -0.114 | **0.111** | -0.008 | 0.019 | -0.051 | 0.202 | -0.254 | 0.314 | 9.57 | -9.63 | 0.198 |
| Fertility percentage | -0.070 | 0.004 | 0.055 | 0.025 | 0.008 | **-0.118** | 0.007 | 0.193 | -0.068 | 0.142 | -0.142 | -16.81 | 16.93 | 0.148 |
| 100-grain weight | 0.071 | 0.015 | 0.025 | -0.119 | -0.040 | 0.016 | **-0.051** | -0.157 | 0.042 | 0.027 | 0.033 | 4.04 | -4.06 | -0.153 |
| Harvest index | -0.314 | -0.039 | -0.040 | 0.097 | -0.006 | -0.024 | 0.009 | **0.939** | 0.008 | -0.022 | -0.025 | -21.41 | 21.55 | 0.729 |
| Flag leaf angle | 0.019 | 0.011 | -0.015 | -0.149 | 0.062 | 0.022 | -0.006 | 0.022 | **0.360** | -0.282 | 0.311 | 10.57 | -10.64 | 0.286 |
| Flag leaf length | -0.049 | 0.008 | -0.034 | -0.131 | 0.058 | 0.035 | 0.003 | 0.042 | 0.209 | **-0.485** | 0.432 | 2.58 | -2.63 | 0.033 |
| Flag leaf area | 0.027 | 0.016 | -0.028 | -0.154 | 0.072 | 0.035 | -0.003 | -0.049 | 0.230 | -0.430 | **0.486** | 6.54 | -6.62 | 0.12 |
| Pre-flowering photo-synthetic translocation to grain yield | 0.242 | 0.019 | 0.027 | -0.086 | 0.028 | 0.053 | -0.006 | -0.538 | 0.102 | -0.033 | 0.085 | **37.37** | -37.61 | -0.352 |
| Post-flowering photo-synthetic contribution to grain yield | -0.242 | -0.019 | -0.027 | 0.086 | -0.028 | -0.053 | 0.006 | 0.538 | -0.102 | 0.034 | -0.086 | -37.37 | **37.61** | 0.352 |

Positive direct effects were also observed for flag leaf area retention (0.486), days to 50% flowering (0.363), flag leaf angle (0.360), panicle number (0.278), number of grains per panicle (0.111) and plant height (0.057), whereas flag leaf length (-0.485), panicle length (-0.159), fertility percentage (-0.118) and 100-grain weight (-0.051) exhibited negative direct effects. The negative correlations of days to 50% flowering and plant height with grain yield, despite their positive direct effects, indicated that their overall relationships with yield were largely determined by indirect effects, particularly through harvest index. Similarly, the positive correlations of panicle length and fertility percentage with yield despite their negative direct effects resulted from compensatory positive indirect effects. The residual effect was estimated to be 0.189 thus the traits studied explained for approximately 96.4% of the variation in grain yield. Similar findings were reported by Singh *et al*. (2023), who identified harvest index, flag leaf area, biological yield per plant, spikelet fertility and number of spikelets per panicle as important selection criteria for improving grain yield in rice genotypes. These findings are consistent with previous studies of Hasan-Ud-Daula and Sarker (2020), Takele *et al*. (2022), Gayathridevi *et al*. (2023) and Babu and Thouseem (2024). Overall, harvest index emerged as the most dependable trait for indirect selection for increased grain yield, while panicle number, flag leaf traits, flowering time, and other physiological traits may provide additional selection information through their direct and indirect effects.

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