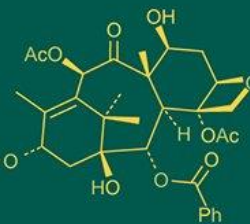
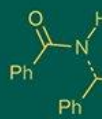
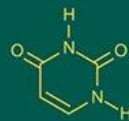
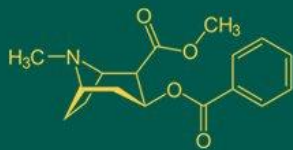


## International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693  
ISSN Online: 2617-4707  
NAAS Rating (2025): 5.29  
IJABR 2025; SP-9(11): 946-951  
[www.biochemjournal.com](http://www.biochemjournal.com)  
Received: 04-10-2025  
Accepted: 07-11-2025

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## Association analysis correlation and path among various crosses of Mungbean (*Vigna radiata* L.)

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DOI: <https://www.doi.org/10.33545/26174693.2025.v9.i11SI.6376>

### Abstract

The investigation employed correlation and path coefficient analyses to dissect the complex inter-relationships among various yield-attributing traits and their direct and indirect effects on Seed Yield per Plant (g), the ultimate breeding objective. The correlation analysis established that seed yield exhibits very strong positive associations (0.78) with its primary components: Harvest Index (%), Biological Yield per Plant (g), Number of Pods/Capsules per Plant, Number of Seeds per Pod/Capsule, and 100-Seed Weight (g). These robust correlations confirm the high efficacy of direct selection for any of these traits. Notably, several key traits also showed strong inter-correlations, such as the highest association of harvest index (%) with Number of Pods/Capsules per Plant (0.891). An unexpected finding was the significant negative correlation between Primary Branches per Plant and most yield components, including seed yield per plant (-0.261), suggesting a trade-off mechanism that needs further study. The path coefficient analysis provided a more granular view, revealing the direct causal influences on Seed Yield per Plant. Harvest Index exhibited the highest positive direct effect (+2.5006), immediately followed by biological yield per plant (+2.4963). This confirms their status as the most critical traits for yield improvement. Other components showing substantial positive direct effects were Number of Pods per Cluster (+0.7945) and Number of Clusters per Plant (+0.3085). The influence of traits with negligible direct effects, like Number of Pods per Plant, was mainly channeled through strong indirect effects, particularly via HI and BYPP. In contrast, Days to 50% Flowering showed a strong negative direct effect (-2.4215). The findings unequivocally emphasize the paramount importance of Harvest Index (%) and Biological Yield per Plant (g) as the primary selection indices, with secondary attention to Number of Pods per Cluster and Number of Clusters per Plant, in any breeding program aimed at maximizing Seed Yield per Plant.

**Keywords:** Correlation, path coefficient, mungbean, yield trait

### Introduction

Mungbean (*Vigna radiata* (L.) Wilczek), popularly known as green gram, is a prominent self-pollinated legume believed to have originated in the Indian subcontinent or the Indo-Burmese region, where its cultivation dates back to at least 1500-1000 BC. Green gram belongs to the family Leguminosae (*Fabaceae*), subfamily Papilionaceae, and has a diploid chromosome number of  $2n = 22$ . experimental material consisted of 67 genotypes received from the Research farm, Genetics and Plant Breeding, AKS University Satna (M.P). These genotypes were planted in a randomised complete block design with three replications. This short-duration grain legume exhibits wide adaptability and is now an economically important crop extensively cultivated throughout South Asia (India, Pakistan, Bangladesh), Southeast Asia (Thailand, Vietnam, Myanmar, Indonesia), and East Asia (China). Its historical origin is supported by the works of pioneers in crop origin, including Decandole, Vavilov, and Zukoveskij. Green gram is considered one of the most important pulse crops in India, ranking third in production after Bengal gram (*Cicer arietinum*) and red gram (*Cajanus cajan*). It is versatile, being mainly utilized in making dhal, curries, soup, sweets, and snacks. The food value of mungbean lies in its high and easily digestible protein. The seeds typically contain approximately 22-28% protein, 1.0-1.5% oil (lipid), 3.5-4.5% crude fiber, 4.5-5.5% ash, and 62-65% carbohydrates on a dry weight basis (Dahiya *et al.*, 2015). Recent research also highlights the presence of bioactive compounds, including polyphenols (like vitexin and isovitexin), which confer health benefits such as antioxidant, anti-inflammatory, and antihypertensive properties. Character association provides information about the

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characters that are correlated in a desirable direction with each other and also with the seed yield in improving the yield. These correlations can be partitioned by path analysis into direct and indirect effects will be an added advantage and helps in selection to a greater extent for improvement of yield.

### Materials and Methods

The field experiment was carried out at Research farm, Genetics and Plant Breeding, AKS University Satna (M.P) In terms of geography and fertility, the experimental region was relatively uniform. The experimental material consisted of 67 genotypes received from the Research farm, Genetics and Plant Breeding, AKS University Satna (M.P). These genotypes were planted in a randomised complete block design with three replications. Table 3.1 includes information about these genotypes. The experimental material consisted of 67 genotypes received from the Research farm, Genetics and Plant Breeding, AKS University Satna (M.P). These genotypes were planted in a randomised complete block design with three replications. Table 3.1 includes information about these genotypes. The comprehensive two-season Mungbean research program begins in *Kharif* 2024-25. This stage concludes with a field experiment employing the Line  $\times$  Tester mating design involving 12 Purelines selected as lines and 5 Testers along with 50 crosses (Table1).

**Table 1:** List of 50 F1 hybrids Crosses

| S.No | Crosses        | S.No | Crosses                    |
|------|----------------|------|----------------------------|
| 1    | IC121301 X M1  | 26   | PPU-911 X M5               |
| 2    | IC121301 X M5  | 27   | PPU-911 X M4               |
| 3    | IC121301 X M4  | 28   | PPU-911 X M3               |
| 4    | IC121301 X M3  | 29   | WGG-42 X M1                |
| 5    | IC121301 X M2  | 30   | WGG-42 X M3                |
| 6    | IC-314694 X M3 | 31   | WGG-42 X M4                |
| 7    | IC-314694 X M2 | 32   | WGG-42 X M5                |
| 8    | IC-314694 X M1 | 33   | IPM409-4 X M2              |
| 9    | IC-314694 X M5 | 34   | IPM409-4 X M1              |
| 10   | IC-314523 X M3 | 35   | IPM409-4 X M3              |
| 11   | IC-314523 X M1 | 36   | PS-16 X M5                 |
| 12   | IC-314523 X M2 | 37   | PS-16 X M4                 |
| 13   | IC-314523 X M5 | 38   | PS-16 X M1                 |
| 14   | IC-314523 X M4 | 39   | PS-16 X M3                 |
| 15   | PM-6 X M2      | 40   | IPM410-3 X M1              |
| 16   | PM-6 X M5      | 41   | IPM410-3 X M3              |
| 17   | PM-6 X M3      | 42   | IPM410-3 X M5              |
| 18   | PM-6 X M1      | 43   | PDM-139 X M5               |
| 19   | BWCD-10 X M4   | 44   | PDM-139 X M4               |
| 20   | BWCD-10 X M2   | 45   | PDM-139 X M3               |
| 21   | BWCD-10 X M1   | 46   | PDM-139 X M1 (IN LINE-19)  |
| 22   | BWCD-10 X M3   | 47   | IPM512-1 X M5 (IN LINE-20) |
| 23   | BWCD-10 X M5   | 48   | IPM512-1 X M1 (IN LINE-21) |
| 24   | PPU-911 X M1   | 49   | IPM512-1 X M3 (IN LINE-22) |
| 25   | PPU-911 X M2   | 50   | IPM512-1 X M2 (IN LINE-24) |

Data on following traits will be recorded on five randomly selected competitive plants from each plot. Observations of flowering and maturity will be recorded on plot basis as per the Mungbean descriptors developed by IBPGR and ICRISAT (1993). Standard package of practices will be

adopted to raise the good crop. List of quantitative characters Days to 50% Flowering, Number of Primary Branches per Plant, Number of Secondary Branches per Plant, Days to Maturity, Plant Height (cm), Number of Clusters per Plant, Number of Pods per Cluster, Number of Pods per Plant, Number of Seeds per Pod, Pod Length (cm), 100 Seed Weight, Biological Yield per Plant (g), Harvest Index (%) and Seed Yield per plant. Miller *et al.* provided the method for calculating correlation coefficients for all quantitative character combinations at the phenotypic, genotypic, and environmental levels. The computation of genotypic, phenotypic, and environmental correlations involved substituting the relevant variance and covariance values into the aforementioned formula. The estimation of covariance between two traits followed the same method used for the corresponding variance components.

$$r_{xixj} = \frac{Cov\ Xi\ Xj}{\sqrt{(Var\ Xi)} \cdot \sqrt{(Var\ Xj)}}$$

Where,

$r\ X_i\ X_j$  = Coefficient of correlation between  $X_i^{th}$  and  $X_j^{th}$  traits

$Cov\ X_i\ X_j$  = Covariance between  $X_i^{th}$  and  $X_j^{th}$  traits

$Var\ X_i$  = Variance of  $X_i^{th}$  trait

$Var\ X_j$  = Variance of  $X_j^{th}$  trait

### Path coefficient analysis

The direct and indirect contribution of various characters to yield were calculated through path coefficient analysis as suggested by Wright and elaborated by Dewey and Lu. The following set of simultaneous equations were formed and solved for estimating direct and indirect effects.

$$\begin{array}{l} r_1Y = P_1Y + r_{12}P_2Y + r_{13}P_3Y + \dots + r_{1k}P_kY \\ r_2Y = r_{21}P_1Y + P_2Y + r_{23}P_3Y + \dots + r_{2k}P_kY \\ \vdots \\ r_kY = r_{k1}P_1Y + r_{k2}P_2Y + r_{k3}P_3Y + \dots + P_kY \end{array}$$

Where,

$r_1Y$  to  $r_kY$  = Coefficients of correlation between causal factors 1 to 'k' and independent character Y

$P_1Y$  to  $P_kY$  = Direct effects of characters 1 to 'k' on character Y

$r_{12}$  to  $r_{(k-1),1}$  = Coefficient of correlation among causal factors

The above equations were written in a matrix form as under

$$\begin{array}{c} \text{A} \\ \left[ \begin{array}{c} r_1Y \\ r_2Y \\ \vdots \\ r_kY \end{array} \right] \end{array} = \begin{array}{c} \text{C} \\ \left[ \begin{array}{cccccc} 1 & r_{12} & r_{13} & \dots & r_{1k} \\ r_{21} & 1 & r_{23} & \dots & r_{2k} \\ \vdots & \vdots & \vdots & & \vdots \\ r_{k1} & r_{k2} & r_{k3} & \dots & 1 \end{array} \right] \end{array} \begin{array}{c} \text{B} \\ \left[ \begin{array}{c} P_1Y \\ P_2Y \\ \vdots \\ P_kY \end{array} \right] \end{array}$$

Then,  $B=[C]^{-1} \cdot A$

Where,

$$[C]^{-1} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & \cdots & C_{1k} \\ C_{21} & C_{22} & C_{23} & \cdots & C_{2k} \\ \vdots & \vdots & \vdots & & \vdots \\ C_{k1} & C_{k2} & C_{k3} & \cdots & C_{kk} \end{bmatrix}$$

Then direct effects were calculated as follows

$$P_1 Y = \sum_{i=1}^K C_{1i} r_{ik} Y$$

$$P_k Y = \sum_{i=1}^K C_{ki} r_{ik} Y$$

$$P_2 Y = \sum_{i=1}^K C_{2i} r_{ik} Y$$

Residual effect was obtained as per for formula given below

$$R = \sqrt{1 - \sum d_i r_{ij}}$$

Where,

$d_j$  = Direct effect of the  $i^{\text{th}}$  character

$r_{ij}$  = correlation coefficient of the  $i^{\text{th}}$  character with  $j^{\text{th}}$  character

Later the path coefficients were rated based on the scales given below (Lenka and Mishra, 1973).

- $>1.00$  = Very high  $0.3-0.99$  = High
- $0.2-0.29$  = Moderate  $0.1-0.19$  = Low
- $0.0-0.09$  = Negligible

## Results

### Correlation Coefficient Analysis

The correlation analysis highlighted the inter-relationships among various traits and their influence on Seed Yield per plant (g). Seed Yield per plant (g) exhibited very strong positive correlations ( $\geq 0.78$ ) with its primary components: Number of Seeds per Pod/Capsule (0.78), Number of Pods/Capsules per plant (0.78), Biological Yield per Plant (g) (0.78), Harvest Index (%) (0.78), and 100-Seed Weight (g) (0.78). This suggests that direct selection for any of these traits would be highly effective in improving Seed Yield per plant (g). Furthermore, Seed Yield per plant (g) also showed a strong positive association with Pod/Capsule Length (cm) (0.684) and Plant Height (cm) (0.643). Several

yield-attributing traits also demonstrated robust correlations with each other. Harvest Index (%) exhibited the highest association with Number of Pods/Capsules per plant (0.891), closely followed by Biological Yield per Plant (g) (0.888) and Number of Seeds per Pod/Capsule (0.879). Similarly, Number of Pods/Capsules per plant showed very strong positive associations with Number of Seeds per Pod/Capsule (0.893), Harvest Index (%) (0.891), Biological Yield per Plant (g) (0.871), Seed Yield per plant (g) (0.78), and 100-Seed Weight (g) (0.809), underscoring its role as a primary determinant of yield. Plant Height (cm) also exhibited very strong positive associations with almost all major yield components, including Harvest Index (%) (0.679), Seed Yield per plant (g) (0.643), Biological Yield per Plant (g) (0.599), and 100-Seed Weight (g) (0.630), indicating that taller plants are generally higher yielding. Days to Maturity showed a strong positive association with Days to 50% flowering (0.829), suggesting that later-flowering accessions tend to mature later. Results were supported by studies of Sandhiya *et al.*, (2018) [5], Prasanna *et al.*, (2013) [6], Hemavathy *et al.*, (2015) [7] and Kour *et al.*, (2018) [8]. (Table 1)

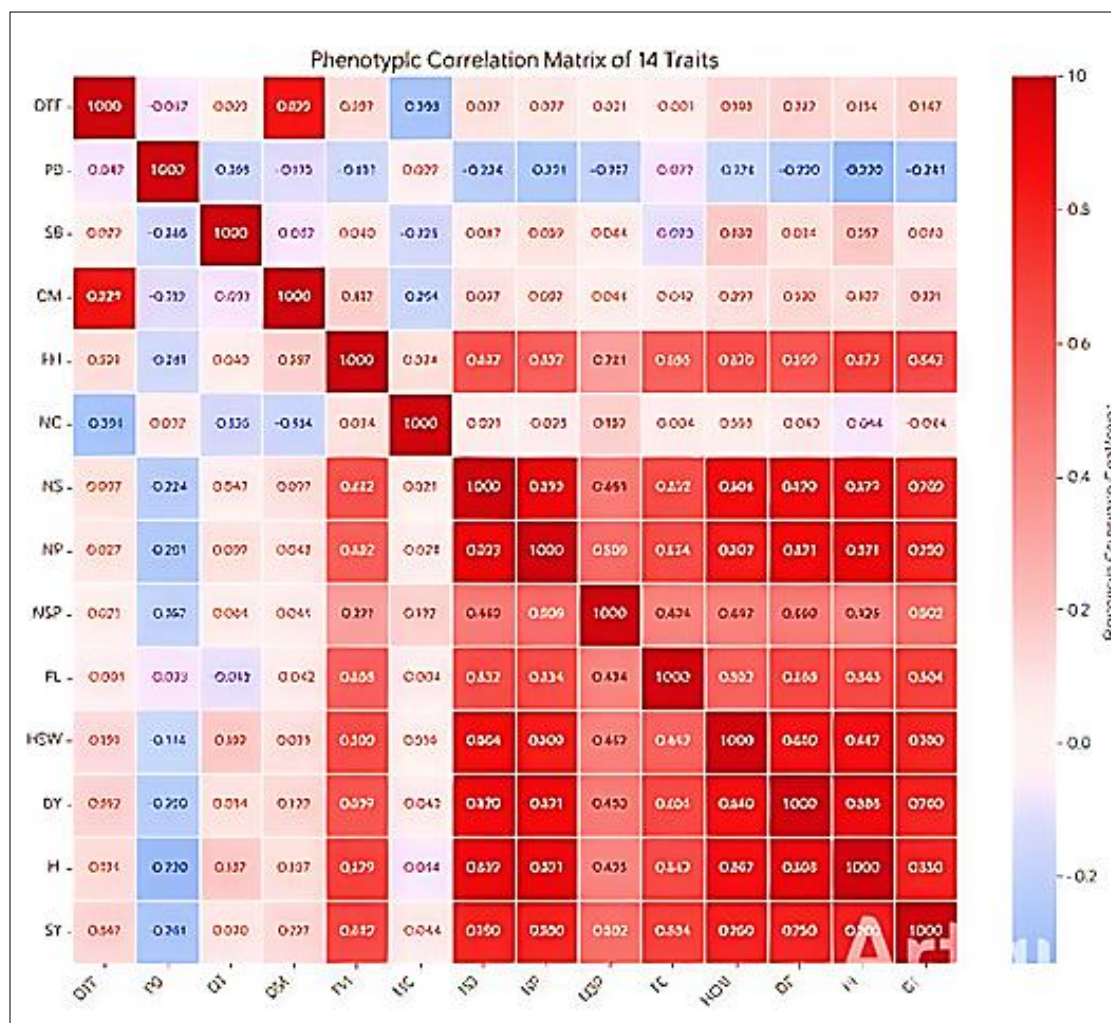
Primary Branches per plant showed an unexpected and significant negative association with most yield components, particularly Harvest Index (%) (-0.330), Seed Yield per plant (g) (-0.261), Number of Pods/Capsules per plant (-0.251), and Number of Seeds per Pod/Capsule (-0.224). This negative relationship is contrary to expectation and suggests a potential trade-off or limiting factor within the studied germplasm. Additionally, Days to 50% Flowering exhibited a positive association with Days to Maturity (0.829) and Seed Yield per plant (g) (0.147), suggesting that earlier flowering is generally associated with lower yields, though it showed a negative correlation with Number of Capsules/Capitula per plant (-0.285). Number of Capsules/Capitula per plant itself showed negative associations with Days to 50% Flowering (-0.285), Days to Maturity (-0.166), Harvest Index (%) (-0.066) and Seed Yield per plant (g) (-0.044). In summary, selection should prioritize traits with strong positive correlations to Seed Yield per plant (g), such as Harvest Index (%), Biological Yield per Plant (g), Number of Pods/Capsules per plant, Number of Seeds per Pod/Capsule, and 100-Seed Weight (g), while considering the negative impact of Primary Branches per plant. Salman *et al.*, (2021) [3] Srivastava *et al.*, (2012) [4] also reported similar results for Days to 50% Flowering, Harvest Index (%) and Biological Yield per Plant (g). (Fig.1)

**Table 2:** Phenotypic correlation among 14 yield attributing traits

|     | DTF | PB     | SB     | DM     | PH     | NC     | NS     | NP     | NSP    | PL     | HSW    | BY     | HI     | SY     |
|-----|-----|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| DTF | 1   | -0.067 | 0.023  | 0.829  | 0.109  | -0.285 | 0.087  | 0.077  | 0.021  | -0.001 | 0.118  | 0.142  | 0.114  | 0.147  |
| PB  |     | 1      | -0.148 | -0.115 | -0.141 | 0.002  | -0.224 | -0.251 | -0.187 | -0.073 | -0.176 | -0.23  | -0.33  | -0.261 |
| SB  |     |        | 1      | -0.069 | 0.04   | -0.125 | 0.049  | 0.089  | 0.044  | -0.093 | 0.183  | 0.094  | 0.187  | 0.07   |
| DM  |     |        |        | 1      | 0.157  | -0.166 | 0.097  | 0.069  | 0.046  | -0.042 | 0.099  | 0.13   | 0.107  | 0.121  |
| PH  |     |        |        |        | 1      | 0.094  | 0.612  | 0.567  | 0.321  | 0.555  | 0.63   | 0.599  | 0.679  | 0.643  |
| NC  |     |        |        |        |        | 1      | 0.021  | -0.025 | 0.152  | -0.004 | 0.018  | -0.043 | -0.066 | -0.044 |
| NS  |     |        |        |        |        |        | 1      | 0.893  | 0.468  | 0.632  | 0.856  | 0.87   | 0.879  | 0.78   |
| NP  |     |        |        |        |        |        |        | 1      | 0.508  | 0.634  | 0.809  | 0.871  | 0.891  | 0.78   |
| NSP |     |        |        |        |        |        |        |        | 1      | 0.434  | 0.442  | 0.46   | 0.425  | 0.502  |
| PL  |     |        |        |        |        |        |        |        |        | 1      | 0.552  | 0.655  | 0.643  | 0.684  |
| HSW |     |        |        |        |        |        |        |        |        |        | 1      | 0.84   | 0.847  | 0.78   |
| BY  |     |        |        |        |        |        |        |        |        |        |        | 1      | 0.888  | 0.78   |
| HI  |     |        |        |        |        |        |        |        |        |        |        |        | 1      | 0.78   |
| SY  |     |        |        |        |        |        |        |        |        |        |        |        |        | 1      |

**Note:** Days to 50% Flowering (DF), Number of Primary Branches per Plant (NPBPP), Number of Secondary Branches per Plant (NSBPP), Days to Maturity (DM), Plant Height (cm), Number of Clusters per Plant (NCPP), Number

of Pods per Cluster (NPPC), Number of Pods per Plant (NPP), Number of Seeds per Pod (NSP), Pod Length (cm), 100 Seed Weight, Biological Yield per Plant (g) (BYPP), Harvest Index (%) (HI) and Seed Yield per plant (SY)



**Fig 1:** Visual representation of phenotypic correlation among various traits

### Path Analysis

The path coefficient analysis revealed the direct and indirect effects of various traits on Seed Yield per Plant (g). Biological Yield per Plant (g) exhibited the second-highest positive direct effect (+2.4963), while Harvest Index (%) showed the highest positive direct effect (+2.5006). This indicates these two traits are the most crucial factors for increasing SYPP. The effects of HI were further amplified by positive indirect impacts through Plant Height (cm) (+0.0001), Number of Primary Branches per Plant (+0.0000), and Number of Secondary Branches per Plant (+0.0000), though a negative indirect effect was noted via, Days to 50% Flowering (-0.0094). Several other traits also exhibited substantial positive direct effects. Number of Pods per Cluster displayed a strong positive direct effect (+0.7945) and an extremely high positive indirect impact through Harvest Index (%) (+0.4802) and Number of Pods per Plant (+0.3844). (Fig. 2) Similarly, Number of Clusters per Plant showed a moderate positive direct effect (+0.3085) and a very strong positive indirect effect through Harvest Index (%) (+0.3577). Number of Seeds per Pod also registered a moderate positive direct effect (+0.1173). In contrast, Days to 50% Flowering displayed a strong

negative direct effect (-2.4215), suggesting that early flowering is beneficial for yield, despite showing positive indirect impacts via, Harvest Index (%) (+0.2633) and 100 Seed Weight (+0.0473). Pod Length (cm) also exhibited a moderate negative direct effect (-0.3250), though this was compensated by strong positive indirect effects through Number of Pods per Plant (+0.1236) and Number of Pods per Cluster (+0.1086). The remaining traits—Number of Primary Branches per Plant (-0.0012), Number of Secondary Branches per Plant (-0.0006), Days to Maturity (-0.0001)—demonstrated negligible negative direct effects. Plant Height (cm) (+0.0003), Number of Pods per Plant (+0.0006), and 100 Seed Weight (+0.0000) showed negligible positive direct effects, with their influence primarily channeled through strong indirect effects, notably through Harvest Index (%) and Biological Yield per Plant (g). Overall, the analysis underscores the paramount importance of Harvest Index (%) and Biological Yield per Plant (g) as primary selection criteria, followed by Number of Pods per Cluster and Number of Clusters per Plant, for enhancing Seed Yield per Plant (g). Similar results were observed by Vadivel *et al.*, (2020) [1] Sineka *et al.*, (2021) [2]. (Table 2)

**Table 3:** Path coefficient analysis for various yield and yield attributing traits

| Traits                 | DTF     | PB      | SB      | DM      | PH      | NC      | NS      |
|------------------------|---------|---------|---------|---------|---------|---------|---------|
| DTF                    | -0.0018 | 0.0004  | 0.0006  | -0.0006 | -0.0012 | 0.0005  | 0.0004  |
| PB                     | 0.0608  | -0.2557 | -0.1663 | -0.0853 | -0.3391 | -0.0076 | 0.0499  |
| SB                     | 0.0164  | -0.0304 | -0.0467 | 0.0028  | 0.0127  | -0.0119 | 0.0126  |
| DM                     | -0.0038 | -0.0036 | 0.0006  | -0.0107 | -0.0095 | 0.0019  | 0.0013  |
| PH                     | 0.0037  | 0.0072  | -0.0015 | 0.0048  | 0.0054  | -0.0017 | -0.0016 |
| NC                     | -0.0232 | 0.0024  | 0.0207  | -0.0146 | -0.0253 | 0.0813  | -0.0102 |
| NS                     | -0.0613 | -0.0485 | -0.067  | -0.0312 | -0.075  | -0.0312 | 0.2482  |
| NP                     | -0.126  | 0.0201  | 0.0438  | 0.0175  | 0.0411  | 0.1892  | 0.1751  |
| NSP                    | 0.0054  | -0.0253 | -0.0306 | 0.0061  | 0.0156  | 0.0024  | -0.003  |
| PL                     | 0.0519  | 0.2385  | 0.1323  | 0.0861  | 0.2599  | -0.0783 | -0.0353 |
| HSW                    | 0.0376  | 0.0473  | 0.0725  | 0.0387  | -0.1249 | -0.0054 | -0.1218 |
| BY                     | 0.1262  | -0.1057 | 0.0601  | 0.1458  | -0.5747 | -0.3355 | -0.3932 |
| HI%                    | -0.0151 | 0.0076  | -0.2491 | -0.0239 | 0.3577  | 0.4802  | 0.3862  |
| SY                     | 0.071   | -0.1456 | -0.2303 | 0.1356  | -0.4573 | 0.2841  | 0.3085  |
| Partial R <sup>2</sup> | -0.0001 | 0.0372  | 0.0108  | -0.0014 | -0.0025 | 0.0231  | 0.0766  |

R Square = 0.9690 Residual Effect = 0.1761

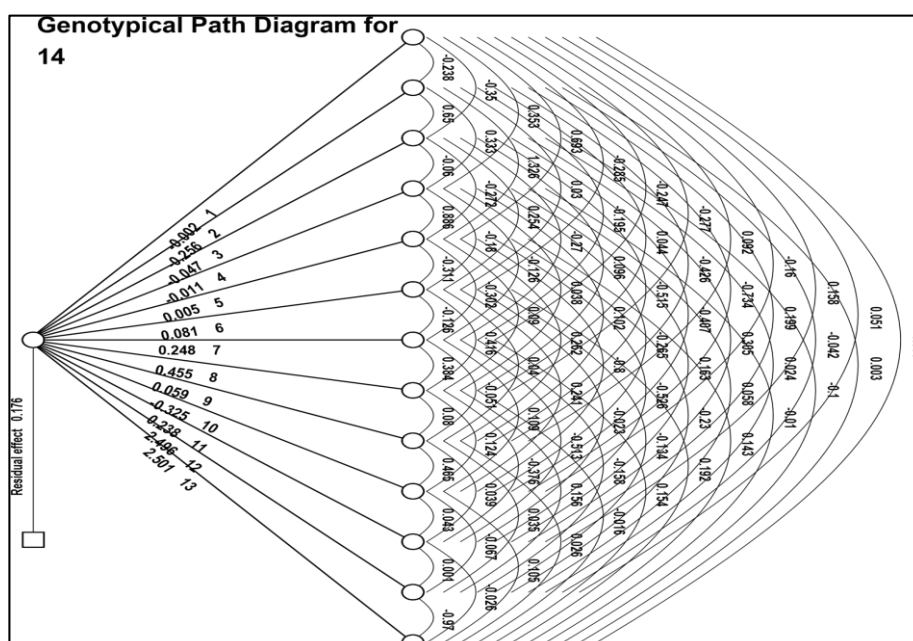
**Table 4:** Path coefficient analysis for various yield and yield attributing traits

| Traits                 | NP      | NSP     | PL      | HSW     | BY      | HI%     |
|------------------------|---------|---------|---------|---------|---------|---------|
| DTF                    | 0.0005  | -0.0002 | 0.0003  | -0.0003 | -0.0001 | 0       |
| PB                     | -0.0113 | 0.1089  | 0.1877  | -0.0509 | 0.0108  | -0.0008 |
| SB                     | -0.0045 | 0.024   | 0.019   | -0.0143 | -0.0011 | 0.0047  |
| DM                     | -0.0004 | -0.0011 | 0.0028  | -0.0017 | -0.0006 | 0.0001  |
| PH                     | 0.0005  | 0.0014  | -0.0043 | -0.0028 | -0.0012 | 0.0008  |
| NC                     | 0.0338  | 0.0032  | 0.0196  | -0.0018 | -0.0109 | 0.0156  |
| NS                     | 0.0954  | -0.0126 | 0.027   | -0.1272 | -0.0391 | 0.0383  |
| NP                     | 0.4553  | 0.0366  | 0.0563  | -0.1712 | 0.0712  | -0.0074 |
| NSP                    | 0.0048  | 0.0595  | 0.0277  | 0.0023  | 0.0021  | 0.0015  |
| PL                     | -0.0402 | -0.1513 | -0.325  | -0.0141 | 0.0218  | -0.0342 |
| HSW                    | -0.0893 | 0.0094  | 0.0103  | 0.2376  | 0.0003  | -0.0063 |
| BY                     | 0.3904  | 0.0881  | -0.1673 | 0.0027  | 2.4963  | -2.4215 |
| HI%                    | -0.0405 | 0.064   | 0.2633  | -0.0659 | -2.4257 | 2.5006  |
| SY                     | 0.7945  | 0.2299  | 0.1173  | -0.2076 | 0.1237  | 0.0914  |
| Partial R <sup>2</sup> | 0.3618  | 0.0137  | -0.0381 | -0.0493 | 0.3088  | 0.2286  |

R Square = 0.9690 Residual Effect = 0.1761

**Note:** Days to 50% Flowering (DF), Number of Primary Branches per Plant (NPBPP), Number of Secondary Branches per Plant (NSBPP), Days to Maturity (DM), Plant Height (cm), Number of Clusters per Plant (NCP), Number

of Pods per Cluster (NPPC), Number of Pods per Plant (NPP), Number of Seeds per Pod (NSP), Pod Length (cm), 100 Seed Weight, Biological Yield per Plant (g) (BYPP), Harvest Index (%) (HI) and Seed Yield per plant (SY)

**Fig 2:** Clustering among various crosses

## Conclusion

The correlation analysis revealed that seed yield per plant has very strong positive associations (0.78) with its key components: Harvest Index (%), Biological Yield per Plant (g), Number of Pods/Capsules per Plant, Number of Seeds per Pod/Capsule, and 100-Seed Weight (g). This suggests that simple, direct selection for any of these traits would be highly effective in boosting yield. Conversely, Primary Branches per Plant showed an unexpected but significant negative correlation with most yield components, indicating a potential physiological trade-off that should be considered. The subsequent path coefficient analysis separated the direct and indirect influences, confirming the paramount importance of HI (highest positive direct effect: +2.5006) and BYPP (second-highest positive direct effect: +2.4963) as the primary determinants of seed yield. These traits should be the main focus of selection. Other traits with substantial positive direct effects include Number of Pods per Cluster (+0.7945) and Number of Clusters per Plant (+0.3085), which also demonstrated strong positive indirect effects, often channeled through HI. Conversely, Days to 50% Flowering showed a strong negative direct effect (-2.4215), implying that earlier flowering accessions may be advantageous for yield. The most effective breeding strategy for improving seed yield should prioritize Harvest Index (%) and Biological Yield per Plant (g), followed by Number of Pods per Cluster and Number of Clusters per Plant, while also considering the negative implications of selecting for Primary Branches per Plant.

## Acknowledgment

I wish to express my deepest gratitude to all who contributed to the successful completion of this research. Special thanks go to my research guide for their invaluable expertise and guidance. I am also sincerely grateful to AKS University, Satna, for providing the essential resources and facilities.

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