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## Study on character association and path coefficient analysis in bread wheat (*Triticum aestivum* L.)

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### Abstract

**Background:** Bread wheat (*Triticum aestivum* L.) is among the most extensively cultivated cereal crops and serves as a cornerstone of global food and nutritional security. Grain yield in wheat is a complex quantitative trait that is influenced by the combined effects of several agronomic and physiological characteristics. A comprehensive understanding of the relationships among these traits, through correlation and path coefficient analyses, provides valuable insights into their contribution to grain yield and facilitates the identification of reliable selection criteria. Accordingly, the present investigation was conducted to evaluate the mean performance of genotypes, examine the associations among yield-related traits, and determine their direct and indirect effects on grain yield in bread wheat.

**Methods:** The experimental material consisted of ten genetically diverse bread wheat parental lines and forty-five F<sub>1</sub> hybrids generated using a half-diallel mating scheme without reciprocals. Field evaluation was carried out during the Rabi season of 2023-24 at the Crop Research Centre, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India. The trial was laid out in a Randomized Block Design (RBD) with three replications. Data were collected on eleven important agronomic and yield-related traits, including days to flowering, days to maturity, plant height, productive tillers per plant, spike length, spikelets per spike, grains per spike, biological yield per plant, 1000-kernel weight, harvest index, and grain yield per plant. Statistical analyses comprised estimation of mean performance, genotypic and phenotypic correlation coefficients, and path coefficient analysis to elucidate the relationships among traits and quantify their direct and indirect contributions to grain yield.

**Results:** The evaluated genotypes displayed substantial variability across all the traits studied, reflecting the existence of ample genetic diversity for the improvement of grain yield in bread wheat. Correlation analysis revealed that grain yield per plant was positively and significantly associated with the number of grains per spike, harvest index, biological yield per plant, and 1000-kernel weight at both the genotypic and phenotypic levels. In contrast, days to maturity showed a significant negative correlation with grain yield. Path coefficient analysis further demonstrated that harvest index contributed the greatest positive direct effect on grain yield, followed by the number of grains per spike, biological yield per plant, spikelets per spike, and 1000-kernel weight at both levels of analysis. The relatively low residual values suggested that these traits collectively explained a major proportion of the variability observed in grain yield. Overall, the results highlight harvest index, grains per spike, biological yield per plant, and 1000-kernel weight as key yield-contributing traits, indicating their potential as dependable selection criteria for the development of high-yielding bread wheat cultivars in future breeding programmes.

**Keywords:** Bread wheat, Correlation coefficient, Grain yield, Path coefficient analysis, *Triticum aestivum* L

### Introduction

Bread wheat (*Triticum aestivum* L.) is one of the most extensively cultivated cereal crops and constitutes a major component of the human diet across the world. Owing to its broad adaptability, high yield potential, and superior nutritional value, it plays a fundamental role in sustaining global food and nutritional security. Wheat grains provide an important source of carbohydrates, proteins, vitamins, and essential minerals, supplying a significant share of the daily energy requirements of millions of people. In India, wheat ranks second only to rice among food crops and is grown under both irrigated and rainfed production systems. The crop occupies approximately 31.23 million hectares, producing 112.92 million tonnes of grain with an average productivity of 3,615 kg ha<sup>-1</sup>, which places India as the world's second-largest wheat-producing

nation (Progress Report, 2023-24). The continuous increase in global population, together with the adverse impacts of climate change, evolving pathogen populations, and shrinking natural resources, has intensified the need to develop wheat cultivars with higher yield potential and improved resilience. Achieving sustainable genetic improvement requires the availability of broad genetic variability and a thorough understanding of the inheritance of economically important traits. Estimates of genetic parameters, particularly heritability and genetic advance, provide valuable insights into the magnitude of genetic variation, the nature of gene action, and the expected efficiency of selection, thereby assisting breeders in designing effective improvement programmes.

Grain yield is a highly complex quantitative trait resulting from the combined expression of numerous morphological, physiological, and developmental characters. Consequently, simultaneous evaluation of these component traits is essential for improving selection efficiency in wheat breeding. Correlation analysis is widely employed to assess the magnitude and direction of relationships among yield and its associated traits, whereas path coefficient analysis further partitions these relationships into direct and indirect effects, enabling the identification of traits with the greatest contribution to grain yield. Such information provides a sound scientific basis for formulating effective selection strategies and accelerating the development of high-yielding bread wheat cultivars.

### Materials and Methods

The present investigation was undertaken to evaluate the mean performance, characterize the relationships among yield-related traits, and quantify their direct and indirect contributions to grain yield in bread wheat (*Triticum aestivum* L.). The field experiment was conducted during the Rabi season of 2023-24 at the Crop Research Centre, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India.

The experimental material consisted of ten genetically diverse parental lines and forty-five  $F_1$  hybrids developed through a half-diallel mating design, excluding reciprocal crosses. The parental lines and their hybrids were evaluated using a Randomized Block Design (RBD) with three replications. Each genotype was sown in a single row of 3 m length, maintaining a spacing of 20 cm between rows and 10 cm between plants. All recommended agronomic and crop management practices were followed throughout the crop growth period to ensure uniform crop establishment and development.

Data were collected on eleven agronomic and yield-attributing traits, namely days to flowering, days to maturity, plant height, productive tillers per plant, spike length, spikelets per spike, grains per spike, biological yield per plant, 1000-kernel weight, harvest index, and grain yield per plant. Observations for all characters were recorded from five randomly selected competitive plants in each replication, whereas days to flowering and days to maturity were recorded on a plot basis.

The average performance of the parental lines and  $F_1$  hybrids was estimated for each trait. Genotypic and phenotypic correlation coefficients were computed to assess the strength and direction of associations among grain yield and its component traits following the procedure described by Croxton and Cowden (1964) [4]. To further clarify the contribution of individual traits to grain yield, path coefficient analysis was carried out according to the method proposed by Dewey and Lu (1959) [6]. This analysis partitioned the observed correlation coefficients into their direct and indirect

effects, thereby identifying the most influential yield-determining characters that could serve as effective selection criteria in bread wheat breeding programmes.

**Table 1:** List of parents and hybrid used in this study

| S. No | Parents         | S. No. | $F_1$ Hybrid    | S. No | $F_1$ Hybrid    |
|-------|-----------------|--------|-----------------|-------|-----------------|
| 1     | HD2967          | 18     | HD2967 X DBW173 | 37    | HD3226 X PBW550 |
| 2     | HD3059          | 19     | HD2967 X DBW187 | 38    | HD3226 X WH1105 |
| 3     | HD3086          | 20     | HD3059 X HD3086 | 39    | HD3226 X DBW173 |
| 4     | HD3226          | 21     | HD3059 X HD3226 | 40    | HD3226 X DBW187 |
| 5     | PBW343          | 22     | HD3059 X PBW343 | 41    | PBW343 X PBW373 |
| 6     | PBW373          | 23     | HD3059 X PBW373 | 42    | PBW343 X PBW550 |
| 7     | PBW550          | 24     | HD3059 X PBW550 | 43    | PBW343 X WH1105 |
| 8     | WH1105          | 25     | HD3059 X WH1105 | 44    | PBW343 X DBW173 |
| 9     | DBW173          | 26     | HD3059 X DBW173 | 45    | PBW343 X DBW187 |
| 10    | DBW187          | 27     | HD3059 X DBW187 | 46    | PBW373 X PBW550 |
|       |                 | 28     | HD3086 X HD3226 | 47    | PBW373 X WH1105 |
|       | $F_1$ Hybrid    | 29     | HD3086 X PBW343 | 48    | PBW373 X DBW173 |
| 11    | HD2967 X HD3059 | 30     | HD3086 X PBW373 | 49    | PBW373 X DBW187 |
| 12    | HD2967 X HD3086 | 31     | HD3086 X PBW550 | 50    | PBW550 X WH1105 |
| 13    | HD2967 X HD3226 | 32     | HD3086 X WH1105 | 51    | PBW550 X DBW173 |
| 14    | HD2967 X PBW343 | 33     | HD3086 X DBW173 | 52    | PBW550 X DBW187 |
| 15    | HD2967 X PBW373 | 34     | HD3086 X DBW187 | 53    | WH1105 X DBW173 |
| 16    | HD2967 X PBW550 | 35     | HD3226 X PBW343 | 54    | WH1105 X DBW187 |
| 17    | HD2967 X WH1105 | 36     | HD3226 X PBW373 | 55    | DBW173 X DBW187 |

### Results and discussion

#### Distribution of mean performance

The mean performance of the fifty-five bread wheat genotypes, comprising ten parental lines and forty-five  $F_1$  hybrids, for eleven agronomic and yield-related traits is summarized in Table 2. The overall mean values recorded for days to flowering, days to maturity, plant height, productive tillers per plant, spike length, spikelets per spike, grains per spike, biological yield per plant, 1000-kernel weight, harvest index, and grain yield per plant were 80.96 days, 127.35 days, 102.36 cm, 10.09, 10.31 cm, 20.26, 55.80, 57.97 g, 39.73 g, 48.25%, and 27.90 g, respectively. Noticeable differences in mean performance were observed among the evaluated genotypes for all the characters, indicating the existence of substantial genetic variability. The magnitude of this variation suggests considerable scope for genetic improvement and provides opportunities for the effective selection of superior genotypes aimed at enhancing grain yield and its associated traits in bread wheat.

**Table 2:** Mean values of different agronomic and yield-related traits in wheat (*Triticum aestivum* L.)

| Trait                          | Mean value |
|--------------------------------|------------|
| Days to flowering (days)       | 80.96      |
| Days to maturity (days)        | 127.35     |
| Plant height (cm)              | 102.36     |
| Number of productive tillers   | 10.09      |
| Spike length (cm)              | 10.31      |
| Spikelets per spike            | 20.26      |
| Number of grains per spike     | 55.80      |
| Biological yield per plant (g) | 57.97      |
| 1000-kernel weight (g)         | 39.73      |
| Harvest index (%)              | 48.25      |
| Grain yield per plant (g)      | 27.90      |

### Correlation coefficient analysis

The relationships between grain yield per plant and its associated agronomic traits were examined by estimating genotypic and phenotypic correlation coefficients, and the results are presented in Tables 3 and 4. In general, both genotypic and phenotypic correlations exhibited similar trends with respect to the direction of association. However, the magnitude of the genotypic correlation coefficients was consistently greater than that of the corresponding phenotypic coefficients, indicating that the observed associations were primarily controlled by genetic factors, whereas environmental effects tended to reduce their phenotypic expression. Comparable findings have also been documented by Ayer *et al.* (2017), Sharma *et al.* (2018), Saini *et al.* (2020), and Chauhan *et al.* (2022) [1, 3, 13, 15].

At the phenotypic level, grain yield per plant showed a highly significant and positive association with the number of grains per spike (0.615), followed by harvest index (0.468), biological yield per plant (0.424), and 1000-kernel weight (0.283). Positive but relatively weaker correlations were also observed with plant height, productive tillers per plant, and spikelets per spike. Conversely, days to maturity (-0.324) and spike length (-0.139) were negatively correlated with grain yield, suggesting that delayed maturity and longer spikes were not advantageous for improving grain production under the present experimental conditions. These results emphasize the importance of grains per spike, harvest index, biological yield, and kernel weight as major

yield-enhancing traits and indicate their usefulness as selection criteria in wheat breeding. Similar trends have been reported by Verma *et al.* (2019), Maurya *et al.* (2020), Nageshwar *et al.* (2021), Kumar *et al.* (2022), and Saini *et al.* (2024) [8, 9, 10, 14, 16].

A comparable pattern was observed at the genotypic level, where grain yield per plant exhibited the strongest positive association with the number of grains per spike (0.757), followed by harvest index (0.664), biological yield per plant (0.486), and 1000-kernel weight (0.302). In addition, plant height, productive tillers per plant, and spikelets per spike were positively associated with grain yield, whereas days to maturity (-0.464) and spike length (-0.250) showed significant negative relationships. The comparatively higher genotypic correlation coefficients further indicate that these associations are largely under genetic control and are less influenced by environmental variation.

The correlation matrix also revealed several favourable interrelationships among important yield-contributing characters. Plant height exhibited positive associations with grains per spike, biological yield per plant, spike length, and 1000-kernel weight, while productive tillers per plant were positively correlated with spikelets per spike and grains per spike. Likewise, biological yield per plant maintained positive relationships with both grain number and 1000-kernel weight. These favourable associations suggest that simultaneous improvement of these component traits could indirectly enhance grain yield and thereby improve the efficiency of selection in bread wheat breeding programmes.

**Table 3:** Estimates of genotypic (G) correlation coefficients for different traits in wheat (*Triticum aestivum* L.)

| Parent/Hybrids                 | Days to Flowering (days) | Days to Maturity (days) | Plant Height (cm) | Number of Productive Tillers | Spike Length (cm) | Spikelets Per Spike | Number of Grain Per Spike | Biological Yield Per Plant (g) | 1000 kernel weight (g) | Harvest Index (%) | Grain Yield Per Plant (g) |
|--------------------------------|--------------------------|-------------------------|-------------------|------------------------------|-------------------|---------------------|---------------------------|--------------------------------|------------------------|-------------------|---------------------------|
| Days to Flowering (days)       | 1.000                    | 0.313**                 | 0.185*            | -0.152                       | -0.037            | -0.164*             | 0.265**                   | 0.146                          | -0.003                 | 0.029             | 0.189*                    |
| Days to Maturity (days)        | -                        | -                       | 0.404**           | -0.300**                     | -0.135            | -0.193*             | -0.321**                  | -0.365**                       | 0.479**                | -0.144            | -0.464**                  |
| Plant Height (cm)              | -                        | -                       | -                 | 0.416**                      | 0.714**           | 0.307**             | 0.832**                   | 0.687**                        | 0.799**                | -0.353**          | 0.299**                   |
| Number of Productive Tillers   | -                        | -                       | -                 | -                            | 0.321**           | 0.866**             | 0.506**                   | 0.381**                        | 0.144                  | -0.166*           | 0.206**                   |
| Spike Length (cm)              | -                        | -                       | -                 | -                            | -                 | 0.410**             | 0.000                     | 0.253**                        | 0.283**                | -0.474**          | -0.250**                  |
| Spikelets Per Spike            | -                        | -                       | -                 | -                            | -                 | -                   | 0.259**                   | 0.755**                        | 0.473**                | -0.437**          | 0.185*                    |
| Number of Grain Per Spike      | -                        | -                       | -                 | -                            | -                 | -                   | -                         | 0.520**                        | 0.327**                | 0.287**           | 0.757**                   |
| Biological Yield Per Plant (g) | -                        | -                       | -                 | -                            | -                 | -                   | -                         | -                              | 0.728**                | -0.475**          | 0.486**                   |
| 1000 kernel weight (g)         | -                        | -                       | -                 | -                            | -                 | -                   | -                         | -                              | -                      | -0.315**          | 0.302**                   |
| Harvest Index (%)              | -                        | -                       | -                 | -                            | -                 | -                   | -                         | -                              | -                      | -                 | 0.664**                   |
| Grain Yield Per Plant (g)      | -                        | -                       | -                 | -                            | -                 | -                   | -                         | -                              | -                      | -                 | 1.000                     |

\*, \*\* significant at 5% and 1% level, respectively

**Table 4:** Estimates of phenotypic (G) correlation coefficients for different traits in wheat (*Triticum aestivum* L.)

| Parent/Hybrids                 | Days to Flowering (days) | Days to Maturity (days) | Plant Height (cm) | Number of Productive Tillers | Spike Length (cm) | Spikelets Per Spike | Number of Grain Per Spike | Biological Yield Per Plant (g) | 1000 kernel weight (g) | Harvest Index (%) | Grain Yield Per Plant (g) |
|--------------------------------|--------------------------|-------------------------|-------------------|------------------------------|-------------------|---------------------|---------------------------|--------------------------------|------------------------|-------------------|---------------------------|
| Days to Flowering (days)       | 1.000                    | -0.041                  | 0.195*            | -0.064                       | -0.064            | -0.078              | 0.084                     | 0.054                          | -0.001                 | 0.023             | 0.057                     |
| Days to Maturity (days)        | -                        | -                       | -0.059            | -0.192*                      | -0.096            | -0.130              | -0.162*                   | -0.241**                       | 0.242**                | -0.111            | -0.324**                  |
| Plant Height (cm)              | -                        | -                       | -                 | 0.241**                      | 0.436**           | 0.096               | 0.245**                   | 0.379**                        | 0.519**                | -0.172*           | 0.143                     |
| Number of Productive Tillers   | -                        | -                       | -                 | -                            | 0.205**           | 0.493**             | 0.387**                   | 0.229**                        | 0.086                  | -0.057            | 0.119                     |
| Spike Length (cm)              | -                        | -                       | -                 | -                            | -                 | 0.187*              | 0.019                     | 0.258**                        | 0.182*                 | -0.385**          | -0.139                    |
| Spikelets Per Spike            | -                        | -                       | -                 | -                            | -                 | -                   | 0.171*                    | 0.393**                        | 0.364**                | -0.371**          | 0.093                     |
| Number of Grain Per Spike      | -                        | -                       | -                 | -                            | -                 | -                   | -                         | 0.407**                        | 0.113                  | 0.236**           | 0.615**                   |
| Biological Yield Per Plant (g) | -                        | -                       | -                 | -                            | -                 | -                   | -                         | -                              | 0.558**                | -0.395**          | 0.424**                   |
| 1000 kernel weight (g)         | --                       | -                       | -                 | -                            | -                 | -                   | -                         | -                              | -                      | -0.288**          | 0.283**                   |
| Harvest Index (%)              | -                        | -                       | -                 | -                            | -                 | -                   | -                         | -                              | -                      | -                 | 0.468**                   |
| Grain Yield Per Plant (g)      | -                        | -                       | -                 | -                            | -                 | -                   | -                         | -                              | -                      | -                 | 1.000                     |

\*, \*\* significant at 5% and 1% level, respectively

### Path coefficient analysis

Path coefficient analysis was employed to partition the correlation coefficients into their direct and indirect components in order to quantify the relative contribution of individual agronomic traits to grain yield per plant. The results obtained at the genotypic and phenotypic levels are presented in Tables 5 and 6. Although the pattern of direct and indirect effects remained largely consistent across both levels of analysis, the genotypic path coefficients were generally greater than the corresponding phenotypic estimates. This indicates that the expression of these traits was influenced predominantly by genetic factors, while environmental conditions moderated their phenotypic expression.

At the genotypic level, harvest index exerted the largest positive direct effect on grain yield per plant (0.7717), demonstrating its major contribution to yield improvement. Other traits showing substantial positive direct effects included number of grains per spike (0.5741), spikelets per spike (0.5120), biological yield per plant (0.2599), and 1000-kernel weight (0.2437). A similar trend was evident at the phenotypic level, where harvest index (0.5591) remained the most influential trait, followed by 1000-kernel weight (0.3641), number of grains per spike (0.3434), and biological yield per plant (0.3152). The consistently high positive direct effects observed for these characters indicate that they play a pivotal role in determining grain yield and, therefore, represent reliable targets for selection in bread wheat breeding programmes.

Comparable observations have also been reported by Kumar *et al.* (2017), Sharma *et al.* (2018), Rathod *et al.* (2019), Saini *et al.* (2020), Devesh *et al.* (2021), Kumar *et al.* (2022), Saini *et al.* (2024), and Aziz and Al-Zubaidy (2024) [2, 5, 7, 8, 12, 13, 14, 15].

Conversely, plant height, productive tillers per plant, and days to maturity recorded negative direct effects on grain yield at the genotypic level. At the phenotypic level, negative direct effects were observed for days to maturity, plant height, productive tillers per plant, and spike length. Despite these negative direct influences, several of these traits exerted favourable indirect effects on grain yield through harvest index, number of grains per spike, and biological yield per plant. This finding suggests that their contribution to yield improvement is largely mediated through their association with key yield-determining traits rather than through their independent effects. The residual effects were relatively low at both the genotypic (0.128) and phenotypic (0.237) levels, indicating that the set of characters included in the present investigation accounted for a substantial proportion of the total variability in grain yield. Collectively, the results identify harvest index, number of grains per spike, biological yield per plant, and 1000-kernel weight as the most important determinants of grain yield. These traits may therefore be considered dependable selection criteria for improving yield potential and should receive priority in hybridization and selection programmes aimed at developing superior bread wheat cultivars.

**Table 5:** Estimates of direct and indirect effect of different characters at genotypic level on grain yield per plant in wheat (*Triticum aestivum* L.)

| Parent/Hybrids                 | Days to Flowering (days) | Days to Maturity (days) | Plant Height (cm) | Number of Productive Tillers | Spike Length (cm) | Spikelets Per Spike | Number of Grain Per Spike | Biological Yield Per Plant (g) | 1000 kernel weight (g) | Harvest Index (%) | Grain Yield Per Plant (g) |
|--------------------------------|--------------------------|-------------------------|-------------------|------------------------------|-------------------|---------------------|---------------------------|--------------------------------|------------------------|-------------------|---------------------------|
| Days to Flowering (days)       | 0.0841                   | -0.0474                 | -0.0466           | 0.0747                       | -0.0034           | -0.0841             | 0.1520                    | 0.0380                         | -0.0008                | 0.0221            | 0.189*                    |
| Days to Maturity (days)        | 0.0263                   | -0.1513                 | -0.1015           | 0.1474                       | -0.0122           | -0.0988             | -0.1844                   | -0.0949                        | 0.1167                 | -0.1113           | -0.464**                  |
| Plant Height (cm)              | 0.0156                   | -0.0611                 | -0.2512           | -0.2042                      | 0.0645            | 0.1572              | 0.4776                    | 0.1785                         | 0.1947                 | -0.2722           | 0.299**                   |
| Number of Productive Tillers   | -0.0128                  | 0.0454                  | -0.1045           | -0.4907                      | 0.0290            | 0.4432              | 0.2904                    | 0.0989                         | 0.0350                 | -0.1277           | 0.206**                   |
| Spike Length (cm)              | -0.0031                  | 0.0204                  | -0.1794           | -0.1574                      | 0.0903            | 0.2097              | 0.0003                    | 0.0657                         | 0.0689                 | -0.3658           | -0.250**                  |
| Spikelets Per Spike            | -0.0138                  | 0.0292                  | -0.0771           | -0.4248                      | 0.0370            | 0.5120              | 0.1485                    | 0.1961                         | 0.1152                 | -0.3373           | 0.185*                    |
| Number of Grain Per Spike      | 0.0223                   | 0.0486                  | -0.2090           | -0.2482                      | 0.0000            | 0.1325              | 0.5741                    | 0.1350                         | 0.0797                 | 0.2216            | 0.757**                   |
| Biological Yield Per Plant (g) | 0.0123                   | 0.0553                  | -0.1726           | -0.1868                      | 0.0228            | 0.3864              | 0.2983                    | 0.2599                         | 0.1774                 | -0.3669           | 0.486**                   |
| 1000 kernel weight (g)         | -0.0003                  | -0.0725                 | -0.2007           | -0.0706                      | 0.0255            | 0.2422              | 0.1878                    | 0.1892                         | 0.2437                 | -0.2428           | 0.302**                   |
| Harvest Index (%)              | 0.0024                   | 0.0218                  | 0.0886            | 0.0812                       | -0.0428           | -0.2237             | 0.1648                    | -0.1236                        | -0.0766                | 0.7717            | 0.664**                   |

Residual value (G) 0.128 \*, \*\* significant at 5% and 1% level, respectively

**Table 6:** Estimates of direct and indirect effect of different characters at phenotypic level on grain yield per plant in wheat (*Triticum aestivum* L.)

| Parent/Hybrids                 | Days to Flowering (days) | Days to Maturity (days) | Plant Height (cm) | Number of Productive Tillers | Spike Length (cm) | Spikelets Per Spike | Number of Grain Per Spike | Biological Yield Per Plant (g) | 1000 kernel weight (g) | Harvest Index (%) | Grain Yield Per Plant (g) |
|--------------------------------|--------------------------|-------------------------|-------------------|------------------------------|-------------------|---------------------|---------------------------|--------------------------------|------------------------|-------------------|---------------------------|
| Days to Flowering (days)       | <b>0.0089</b>            | 0.0100                  | -0.0264           | 0.0068                       | 0.0016            | -0.0018             | 0.0288                    | 0.0170                         | -0.0005                | 0.0131            | 0.057                     |
| Days to Maturity (days)        | -0.0004                  | -0.2451                 | 0.0079            | 0.0202                       | 0.0024            | -0.0031             | -0.0557                   | -0.0759                        | 0.0881                 | -0.0622           | -0.324**                  |
| Plant Height (cm)              | 0.0017                   | 0.0144                  | -0.1352           | -0.0254                      | -0.0108           | 0.0023              | 0.0843                    | 0.1196                         | 0.1889                 | -0.0963           | 0.143                     |
| Number of Productive Tillers   | -0.0006                  | 0.0472                  | -0.0326           | -0.1052                      | -0.0051           | 0.0116              | 0.1327                    | 0.0720                         | 0.0315                 | -0.0321           | 0.119                     |
| Spike Length (cm)              | -0.0006                  | 0.0235                  | -0.0589           | -0.0216                      | -0.0248           | 0.0044              | 0.0064                    | 0.0814                         | 0.0662                 | -0.2152           | -0.139                    |
| Spikelets Per Spike            | -0.0007                  | 0.0319                  | -0.0130           | -0.0519                      | -0.0046           | 0.0236              | 0.0586                    | 0.1238                         | 0.1324                 | -0.2073           | 0.093                     |
| Number of Grain Per Spike      | 0.0007                   | 0.0397                  | -0.0332           | -0.0407                      | -0.0005           | 0.0040              | 0.3434                    | 0.1282                         | 0.0412                 | 0.1320            | 0.615**                   |
| Biological Yield Per Plant (g) | 0.0005                   | 0.0590                  | -0.0513           | -0.0240                      | -0.0064           | 0.0093              | 0.1396                    | 0.3152                         | 0.2030                 | -0.2211           | 0.424**                   |
| 1000 kernel weight (g)         | 0.0000                   | -0.0593                 | -0.0702           | -0.0091                      | -0.0045           | 0.0086              | 0.0389                    | 0.1757                         | 0.3641                 | -0.1613           | 0.283**                   |
| Harvest Index (%)              | 0.0002                   | 0.0273                  | 0.0233            | 0.0060                       | 0.0095            | -0.0088             | 0.0811                    | -0.1246                        | -0.1050                | 0.5591            | 0.468**                   |

Residual value -0.237\*, \*\* significant at 5% and 1% level, respectively

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### Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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