**Studies on direct and indirect effects for grain yield and its components in bread wheat (*Triticum aestivum* L.)**

**Abstract**

The present study investigates the genetic relationships between various quantitative traits affecting grain yield in wheat, employing a Line × Tester mating design with 22 genotypes to generate 72 F1s and F2s. Wheat is recognized for its rich nutritional profile, providing essential nutrients such as carbohydrates, proteins, vitamins, and minerals. Path coefficient analysis is a critical statistical tool in wheat breeding, enabling breeders to evaluate complex relationships between traits by measuring their direct and indirect effects on yield. Fourteen traits were evaluated, revealing significant phenotypic and genotypic correlations. The present study was undertaken to assess the direct and indirect effects of fourteen agronomic and physiological traits on grain yield in wheat through path coefficient analysis in both F1 and F2 generations. The analysis was conducted at genotypic and phenotypic levels to identify key yield-contributing traits for effective selection in breeding programs. In the F1 generation, biological weight exhibited the highest positive direct effect on grain yield followed by harvest index, number of tillers, grains per ear, and spike length. Similarly, in the F2 generation, biological weight and harvest index remained the most influential contributors to yield, alongside 1000 grain weight and spike length. Conversely, plant height, days to 50% heading, and days to maturity showed negative direct effects in both generations, indicating their potential as unfavorable traits for yield improvement. The path coefficient analysis across both F1 and F2 generations highlighted biological weight and harvest index as the most reliable traits with strong and consistent positive direct effects on grain yield. The emphasis should be placed on selecting genotypes with high biological weight and harvest index, while cautiously managing traits with negative effects, to develop high-yielding, well-adapted wheat cultivars suitable for future cropping systems.

**Keywords**: genetic relationships, *Triticum aestivum, protein requirements, genotypic and phenotypic levels*

**Introduction**

The studies of character associations provide us with a better understanding of character`s responsible for grain yield. Path coefficient analysis helps to differentiate the characters influence directly and indirectly to increase grain yield (Kumar et al., 2023). Wheat (*Triticum aestivum* L. Em. Thell., 2n=42) is a vital self-pollinated cereal crop from the Poaceae family, playing a crucial role in global food security. It is often hailed as the 'King of Cereals' due to its adaptability, high productivity, and significance in global trade (FAO, 2021). Wheat provides nearly 20% of the world’s dietary energy and protein requirements, making it a staple food for billions (Shiferaw *et al.*, 2013). The development of high-yielding wheat cultivars is a major objective in wheat breeding programs. Yield is a complex trait, is a function of several component traits and their interaction with the environment. In this regard path coefficient analysis helps in the partitioning of correlation coefficients into direct and indirect effects and in the assessment of the relative contribution of each component character to the yield (Khare, 2022; Sanadi et al., 2023).

Three major wheat species are cultivated globally: *Triticum aestivum* (bread wheat), *Triticum durum* (durum wheat), and *Triticum dicoccum* (emmer wheat). Bread wheat, the most widely grown species, contributes about 95% of the global wheat area and is a key ingredient in foods like bread, pasta, noodles, and biscuits (Shewry and Hey, 2015). Durum wheat, known for its firm texture and high gluten content, is primarily used for pasta and semolina. Emmer wheat, an ancient grain, is cultivated in limited regions due to its hardiness and unique nutritional qualities (Bonjean *et al.*, 2016).

Wheat is recognized for its rich nutritional profile, providing essential nutrients such as carbohydrates, proteins, vitamins, and minerals. It is a significant source of dietary fiber, B vitamins (thiamine, niacin, and folate), and minerals like iron, magnesium, and zinc (Shewry and Hey, 2015). The presence of gluten, a protein composite, makes wheat ideal for baking, contributing to the elasticity and structure of bread and other baked products (Sleper and Poehlman, 2006).

Globally, wheat production reached 779 million tonnes in 2021, covering an estimated 220 million hectares (FAO, 2022). The leading producers include China, India, Russia, and the United States, accounting for over half of the global output. However, with a projected population of nearly 10 billion by 2050, global wheat production must rise by 60% to meet food security demands (Ray *et al.*, 2013).

In India, wheat is a staple food crop grown predominantly in the northern and central states.). In 2021-22, India’s wheat production reached approximately 110 million tonnes from 31.45 million hectares, ranking second globally after China (Ministry of Agriculture and Farmers Welfare, 2022Uttar Pradesh is the leading wheat-producing state, contributing around 32% of the nation’s output, followed by Madhya Pradesh (18%), Punjab (15%), Haryana (11%), and Rajasthan (10%). These states benefit from favorable climatic conditions and irrigation facilities, making them the backbone of Indian wheat production.

Path coefficient analysis is a critical statistical tool in wheat breeding, enabling breeders to evaluate complex relationships between traits by measuring their direct and indirect effects on yield. This approach enhances the accuracy of selection by identifying traits with the highest impact, accelerating genetic advancements (Dewey and Lu, 1959).

Introduced by Kempthorne (1957), the line x-tester analysis remains a cornerstone of genetic evaluation, providing insights into the general and specific combining abilities of parents. This method helps breeders identify superior lines for hybridization, supporting the development of high-yielding, resilient varieties.

To achieve future production targets, the integration of advanced biometrical tools, including path coefficient analysis and line x tester methods, is crucial. By prioritizing traits with the greatest influence on yield, these tools drive the development of wheat varieties that can thrive in diverse environments and meet global food demands sustainably.

**Material and methods-**

Basic material for this investigation, consisted of twenty-two genotypes *viz.,* K2012, K 1910, K 607, HD 2967, K 2007, HI 1612, PBW 644, DBW 398, PBW 386, HD 3171, DBW 252, K 2101, K 2105, DBW 173, DBW 222, HD 3059, WB 02, DBW 187, HI 1563, K 9423, K 307 and DBW 107. These were collected from a section of Rabi cereals, C. S. Azad University of agriculture and technology, Kanpur. Out of these, 18 genotypes were used as lines and four (HI 1563, K 9423, K 307 and DBW 107) as testers.

These parental lines were crossed to develop 72 F1s and F2s using Line X Tester mating design. A total of 166 treatments (22 parents + 72 F1s + 72 F2s) were evaluated for the study of genetic analysis of fourteen quantitative characters in wheat.

Data was recorded for 14 characters *i.e.,* for days to 50% heading, days to maturity, plant height, number of productive tillers/plant, flag leaf area, number of leaves/main tiller, number of spikelets/ear, spike length, number of grains/ear, biological yield/plant, 1000 grain weight, harvest index, protein content and grain yield/plant. The data was analyzed statistically for path-coefficient analysis was suggested by Wright and as elaborated by Dewey and Lu (1959).

**Result and Discussion**

Path coefficient analysis was carried out among all the fourteen characters at genotypic and phenotypic levels. The phenotypic and genotypic path analysis of F1 and F2 computed among the fourteen characters under study has been presented in Table 1 and Table 2 respectively.

In the genotypic path coefficient table for the F1 generation, traits like biological weight, number of tillers, grains per ear, spike length, number of spikelets/spike, protein content and harvest index show the highest positive direct effects on grain yield. Biological weight has the highest positive direct effect (0.856), indicating its importance as a trait for improving yield.

Similar findings were reported by Siddiqui *et al.* (2015), who found that biological yield had the highest direct contribution to grain yield. Likewise, Sharma *et al.* (2016) and Khatkar *et al.* (2020) also highlighted the significant role of biological weight and harvest index in determining yield, suggesting their importance as selection criteria in wheat breeding programs.

Harvest index (0.413), spike length (0.027), number of spikelets/spike (0.011), protein content (0.059) and grains per ear (0.007) are also significant contributors to yield.

These results are consistent with the findings of Amin *et al.* (2017), who noted that harvest index and grains per ear had positive direct effects on yield. Singh *et al.* (2018) also reported that spike length and spikelets per spike were positively associated with grain yield, and advocated their inclusion in selection indices for yield improvement.

On the other hand, traits like plant height, number of leaves per tiller and 1000 grain weight showed negative direct effects. 1000 grain weight exhibited a significant negative direct effect (-0.028) on grain yield per plant.

This aligns with the observations of Ali *et al.* (2018), who documented negative direct effects of 1000 grain weight on yield in certain genotypes, possibly due to resource reallocation. Additionally, Khan *et al.* (2013) and Verma *et al.* (2019) reported that plant height often has a negative direct effect on yield in semi-dwarf and high-yielding wheat varieties, likely due to increased lodging risk or inefficient biomass partitioning.

The phenotypic path coefficient analysis for F1 also highlights similar trends but with some distinctions in the strength of the relationships. Biological weight (0.857) remains a strong positive contributor. Number of tillers (0.042) and harvest index (0.483) also show significant positive effects. Some negative effects are observed in 1000 grain weight (-0.020) and plant height (-0.039), aligning with the genotypic results, emphasizing that these traits may reduce yield in this generation.

In the F2 generation, the genotypic path coefficient analysis also highlights traits with high direct effects on grain yield. Biological weight again shows the strongest positive direct effect (0.750), followed by harvest index (0.569), spike length (0.059) and 1000 grain weight (0.030) reflecting the high impact on grain yield/plant.

Similar findings were reported by Khan and Dar (2010), who observed that biological weight and harvest index had substantial positive direct effects on grain yield in segregating wheat populations. Sharma *et al.* (2018) also emphasized the importance of spike length and 1000 grain weight as key taits contributing to yield in F2 and later generations. Likewise, Shukla *et al.* (2021) found that harvest index and biological yield were among the most reliable direct contributors to yield performance in wheat breeding trials.

However, plant height (-0.091), days to 50% heading, days to maturity and plant height have negative direct effects, indicating that these characters may be unfavorable for increasing yield in this generation.

These negative direct effects are supported by the work of Verma *et al.* (2017), who reported that plant height and maturity duration negatively influenced yield due to extended vegetative periods and lodging risk. Yadav *et al.* (2016) also documented a negative direct effect of plant height and days to heading in their analysis of segregating wheat populations. Findings by Baloch *et al.* (2014) further confirmed that prolonged heading and maturity stages reduce grain yield by shortening the grain-filling period, especially under terminal heat conditions.

In the phenotypic analysis for F2, Biological weight (0.772) and harvest index (0.595) were found critical positive contributors while characters like plant height, days to 50% heading, days to maturity and plant height exhibited negative direct effect on grain yield per plant.

This supports the phenotypic trends reported by Singh *et al.* (2019), who highlighted that biological weight and harvest index remained stable indicators of higher grain yield across generations, while traits related to plant height and phenology negatively influenced yield in phenotypic path analysis.

**Conclusion**

The path coefficient analysis across both F1 and F2 generations highlighted biological weight and harvest index as the most reliable traits with strong and consistent positive direct effects on grain yield. These traits not only influence yield independently but also serve as integrative indicators of source-sink efficiency and resource allocation, making them ideal candidates for direct selection in wheat breeding programs.

Other traits such as spike length, number of grains per ear, and 1000 grain weight demonstrated moderate but positive direct contributions to yield, especially in the F2 generation, suggesting their potential role in trait pyramiding strategies aimed at cumulative yield improvement. In contrast, traits like plant height, days to 50% heading, and days to maturity exhibited negative direct effects on grain yield in both generations. These findings imply that selection against excessive plant height and prolonged phenological phases could help develop semi-dwarf, early-maturing wheat genotypes with superior yield potential—an important breeding objective under high-density planting systems and climate variability.

From a plant breeding standpoint, these results offer clear direction for parental selection, generation advancement, and trait-based selection indices. The consistent performance of key traits across generations further strengthens their breeding value, allowing for effective early-generation selection and accelerated genetic gain in yield-focused wheat improvement programs. Therefore, emphasis should be placed on selecting genotypes with high biological weight and harvest index, while cautiously managing traits with negative effects, to develop high-yielding, well-adapted wheat cultivars suitable for future cropping systems.

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**Table 1. Genotypic direct and indirect effects of different characters on Grain yield per plant in F1 generation.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Parent/Hybrids | Days to 50% heading | Days to maturity | Plant height | Number of tillers/plant | Leaf area | Number of leaves/ main tiller | Number of spikelets/spike | Spike length | Number of grains/ear | Biological weight | 1000 grain weight | Harvest index | Protein content | Grain yield per plant |
| Days to 50% heading | **0.0258** | -0.0551 | 0.0075 | -0.0129 | -0.0010 | 0.0001 | -0.0025 | -0.0074 | -0.0013 | -0.1053 | 0.0020 | 0.0239 | 0.0102 | -0.116 |
| Days to maturity | 0.0175 | **-0.0816** | 0.0001 | -0.0047 | -0.0034 | 0.0000 | -0.0019 | -0.0076 | 0.0002 | -0.1010 | 0.0047 | 0.0339 | 0.0200 | -0.124\* |
| Plant height | -0.0050 | 0.0003 | **-0.0390** | 0.0088 | 0.0050 | 0.0000 | 0.0018 | 0.0044 | 0.0006 | -0.0078 | -0.0055 | -0.0380 | -0.0077 | -0.082 |
| Number of tillers/plant | -0.0074 | 0.0085 | -0.0076 | **0.0450** | 0.0066 | 0.0000 | 0.0025 | 0.0089 | 0.0004 | 0.1965 | -0.0007 | -0.0138 | -0.0176 | 0.221\*\* |
| Leaf area | -0.0009 | 0.0095 | -0.0067 | 0.0102 | **0.0293** | 0.0000 | -0.0012 | 0.0040 | 0.0002 | 0.1768 | 0.0005 | -0.0537 | -0.0111 | 0.157\*\* |
| Number of leaves/main tiller | -0.0041 | -0.0029 | 0.0002 | -0.0028 | -0.0033 | **-0.0003** | 0.0003 | -0.0046 | -0.0002 | -0.1796 | -0.0003 | 0.0541 | 0.0006 | -0.143\* |
| Number of spikelets/spike | -0.0055 | 0.0137 | -0.0059 | 0.0095 | -0.0030 | 0.0000 | **0.0116** | 0.0115 | 0.0028 | 0.1267 | -0.0026 | -0.0443 | -0.0119 | 0.103 |
| Spike length | -0.0071 | 0.0231 | -0.0063 | 0.0149 | 0.0043 | 0.0001 | 0.0050 | **0.0270** | 0.0019 | 0.2632 | -0.0053 | -0.1063 | -0.0147 | 0.200\*\* |
| Number of grains/ear | -0.0042 | -0.0018 | -0.0031 | 0.0023 | 0.0009 | 0.0000 | 0.0041 | 0.0064 | **0.0078** | 0.2543 | 0.0003 | -0.0259 | -0.0056 | 0.236\*\* |
| Biological weight | -0.0032 | 0.0096 | 0.0004 | 0.0103 | 0.0061 | 0.0001 | 0.0017 | 0.0083 | 0.0023 | **0.8566** | 0.0031 | 0.0071 | -0.0131 | 0.889\*\* |
| 1000 grain weight | -0.0018 | 0.0132 | -0.0075 | 0.0012 | -0.0005 | 0.0000 | 0.0010 | 0.0050 | -0.0001 | -0.0912 | **-0.0286** | -0.0240 | -0.0089 | -0.142\* |
| Harvest index | 0.0015 | -0.0067 | 0.0036 | -0.0015 | -0.0038 | 0.0000 | -0.0012 | -0.0069 | -0.0005 | 0.0146 | 0.0017 | **0.4136** | 0.0021 | 0.416\*\* |
| Protein content | 0.0044 | -0.0272 | 0.0050 | -0.0132 | -0.0055 | 0.0000 | -0.0023 | -0.0066 | -0.0007 | -0.1874 | 0.0043 | 0.0146 | **0.0599** | -0.155\*\* |

Resi- 0.0379

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

**Table 2. Phenotypic direct and indirect effects of different characters on Grain yield per plant in F1 generation.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Parent/Hybrids | Days to 50% heading | Days to maturity | Plant height | Number of tillers/plant | Leaf area | Number of leaves/ main tiller | Number of spikelets/spike | Spike length | Number of grains/ear | Biological weight | 1000 grain weight | Harvest index | Protein content | Grain yield per plant |
| Days to 50% heading | **0.0167** | -0.0408 | 0.0073 | -0.0111 | -0.0008 | 0.0009 | -0.0024 | -0.0048 | -0.0006 | -0.0909 | 0.0011 | 0.0284 | 0.0085 | -0.089 |
| Days to maturity | 0.0101 | **-0.0674** | 0.0001 | -0.0041 | -0.0026 | -0.0002 | -0.0019 | -0.0047 | 0.0001 | -0.0972 | 0.0029 | 0.0349 | 0.0172 | -0.113 |
| Plant height | -0.0030 | 0.0002 | **-0.0399** | 0.0082 | 0.0037 | 0.0000 | 0.0017 | 0.0030 | 0.0003 | -0.0203 | -0.0041 | -0.0208 | -0.0065 | -0.078 |
| Number of tillers/plant | -0.0044 | 0.0066 | -0.0077 | **0.0424** | 0.0050 | 0.0005 | 0.0025 | 0.0059 | 0.0002 | 0.1843 | -0.0005 | -0.0043 | -0.0155 | 0.215\*\* |
| Leaf area | -0.0005 | 0.0070 | -0.0060 | 0.0086 | **0.0246** | 0.0009 | -0.0014 | 0.0024 | 0.0001 | 0.1741 | 0.0003 | -0.0577 | -0.0091 | 0.143\* |
| Number of leaves/main tiller | -0.0021 | -0.0016 | -0.0001 | -0.0026 | -0.0030 | **-0.0073** | 0.0002 | -0.0022 | -0.0001 | -0.1307 | 0.0000 | 0.0500 | 0.0006 | -0.099 |
| Number of spikelets/spike | -0.0030 | 0.0099 | -0.0051 | 0.0080 | -0.0026 | -0.0001 | **0.0133** | 0.0072 | 0.0013 | 0.1094 | -0.0015 | -0.0414 | -0.0097 | 0.086 |
| Spike length | -0.0041 | 0.0165 | -0.0061 | 0.0130 | 0.0030 | 0.0009 | 0.0050 | **0.0192** | 0.0008 | 0.2220 | -0.0033 | -0.0751 | -0.0122 | 0.180\*\* |
| Number of grains/ear | -0.0025 | -0.0013 | -0.0029 | 0.0022 | 0.0004 | 0.0002 | 0.0044 | 0.0042 | **0.0039** | 0.2349 | 0.0003 | -0.0208 | -0.0050 | 0.218\*\* |
| Biological weight | -0.0018 | 0.0076 | 0.0009 | 0.0091 | 0.0050 | 0.0011 | 0.0017 | 0.0050 | 0.0011 | **0.8578** | 0.0021 | -0.0293 | -0.0113 | 0.849\*\* |
| 1000 grain weight | -0.0009 | 0.0093 | -0.0078 | 0.0010 | -0.0003 | 0.0000 | 0.0010 | 0.0030 | -0.0001 | -0.0878 | **-0.0208** | -0.0115 | -0.0074 | -0.122\* |
| Harvest index | 0.0010 | -0.0049 | 0.0017 | -0.0004 | -0.0029 | -0.0008 | -0.0011 | -0.0030 | -0.0002 | -0.0520 | 0.0005 | **0.4833** | 0.0015 | 0.423\*\* |
| Protein content | 0.0027 | -0.0216 | 0.0048 | -0.0123 | -0.0042 | -0.0001 | -0.0024 | -0.0044 | -0.0004 | -0.1808 | 0.0029 | 0.0138 | **0.0536** | -0.148\* |

Resi-0.0447

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

**Table 3. Genotypic direct and indirect effects of different characters on Grain yield per plant in F2 generation.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Parent/Hybrids | Days to 50% heading | Days to maturity | Plant height | Number of tillers/plant | Leaf area | Number of leaves/ main tiller | Number of spikelets/spike | Spike length | Number of grains/ear | Biological weight | 1000 grain weight | Harvest index | Protein content | Grain yield per plant |
| Days to 50% heading | **-0.0578** | -0.0164 | 0.0332 | -0.0047 | -0.0010 | 0.0003 | -0.0006 | 0.0033 | -0.0148 | -0.0212 | -0.0124 | 0.2173 | 0.0172 | 0.142\* |
| Days to maturity | -0.0220 | **-0.0430** | 0.0241 | -0.0030 | 0.0009 | -0.0001 | -0.0006 | 0.0018 | -0.0066 | 0.0019 | -0.0062 | 0.1309 | 0.0095 | 0.088 |
| Plant height | 0.0211 | 0.0114 | **-0.0910** | -0.0002 | 0.0033 | -0.0003 | 0.0001 | 0.0106 | 0.0156 | -0.1667 | 0.0147 | -0.1473 | -0.0150 | -0.344\*\* |
| Number of tillers/plant | -0.0097 | -0.0046 | -0.0007 | **-0.0283** | 0.0007 | 0.0011 | -0.0012 | 0.0094 | -0.0115 | -0.0086 | -0.0114 | 0.1563 | 0.0074 | 0.099 |
| Leaf area | 0.0039 | -0.0025 | -0.0200 | -0.0013 | **0.0148** | -0.0003 | -0.0002 | 0.0026 | -0.0014 | -0.0352 | 0.0034 | -0.0672 | -0.0070 | -0.111 |
| Number of leaves/main tiller | -0.0058 | 0.0008 | 0.0092 | -0.0120 | -0.0018 | **0.0027** | -0.0004 | -0.0037 | 0.0026 | -0.0295 | -0.0080 | 0.0537 | 0.0046 | 0.012 |
| Number of spikelets/spike | -0.0049 | -0.0039 | 0.0010 | -0.0050 | 0.0003 | 0.0002 | **-0.0068** | 0.0134 | -0.0301 | 0.0633 | -0.0047 | 0.1494 | 0.0072 | 0.179\*\* |
| Spike length | -0.0032 | -0.0013 | -0.0161 | -0.0044 | 0.0006 | -0.0002 | -0.0015 | **0.0598** | -0.0461 | 0.1115 | 0.0037 | 0.0069 | 0.0034 | 0.113 |
| Number of grains/ear | -0.0120 | -0.0040 | 0.0199 | -0.0045 | 0.0003 | -0.0001 | -0.0029 | 0.0386 | **-0.0715** | 0.1578 | -0.0026 | 0.1162 | 0.0048 | 0.240\*\* |
| Biological weight | 0.0016 | -0.0001 | 0.0202 | 0.0003 | -0.0007 | -0.0001 | -0.0006 | 0.0089 | -0.0150 | **0.7506** | 0.0016 | 0.0439 | -0.0063 | 0.804\*\* |
| 1000 grain weight | 0.0237 | 0.0088 | -0.0442 | 0.0107 | 0.0016 | -0.0007 | 0.0011 | 0.0074 | 0.0062 | 0.0404 | **0.0303** | -0.2479 | -0.0185 | -0.181\*\* |
| Harvest index | -0.0221 | -0.0099 | 0.0236 | -0.0078 | -0.0018 | 0.0003 | -0.0018 | 0.0007 | -0.0146 | 0.0579 | -0.0132 | **0.5690** | 0.0104 | 0.591\*\* |
| Protein content | -0.0157 | -0.0064 | 0.0215 | -0.0033 | -0.0016 | 0.0002 | -0.0008 | 0.0032 | -0.0054 | -0.0741 | -0.0088 | 0.0935 | **0.0635** | 0.066 |

Resi- 0.0581

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

**Table 4. Phenotypic direct and indirect effects of different characters on Grain yield per plant in F2 generation.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Parent/Hybrids | Days to 50% heading | Days to maturity | Plant height | Number of tillers/plant | Leaf area | Number of leaves/ main tiller | Number of spikelets/spike | Spike length | Number of grains/ear | Biological weight | 1000 grain weight | Harvest index | Protein content | Grain yield per plant |
| Days to 50% heading | **-0.0383** | -0.0133 | 0.0232 | -0.0036 | -0.0003 | -0.0002 | 0.0001 | 0.0013 | -0.0104 | -0.0051 | -0.0101 | 0.1794 | 0.0158 | 0.138\* |
| Days to maturity | -0.0133 | **-0.0384** | 0.0169 | -0.0024 | 0.0002 | 0.0000 | 0.0001 | 0.0010 | -0.0046 | 0.0003 | -0.0053 | 0.1153 | 0.0088 | 0.079 |
| Plant height | 0.0127 | 0.0093 | **-0.0699** | -0.0001 | 0.0008 | 0.0002 | 0.0000 | 0.0058 | 0.0103 | -0.1635 | 0.0127 | -0.1256 | -0.0142 | -0.322\*\* |
| Number of tillers/plant | -0.0058 | -0.0039 | -0.0004 | **-0.0239** | 0.0002 | -0.0007 | 0.0001 | 0.0054 | -0.0079 | -0.0070 | -0.0101 | 0.1424 | 0.0071 | 0.096 |
| Leaf area | 0.0029 | -0.0020 | -0.0144 | -0.0010 | **0.0038** | 0.0002 | 0.0000 | 0.0015 | -0.0007 | -0.0433 | 0.0030 | -0.0543 | -0.0066 | -0.111 |
| Number of leaves/main tiller | -0.0034 | 0.0001 | 0.0068 | -0.0096 | -0.0005 | **-0.0018** | 0.0000 | -0.0020 | 0.0020 | -0.0234 | -0.0068 | 0.0487 | 0.0043 | 0.015 |
| Number of spikelets/spike | -0.0031 | -0.0035 | 0.0006 | -0.0039 | 0.0001 | -0.0001 | **0.0008** | 0.0063 | -0.0204 | 0.0623 | -0.0035 | 0.1253 | 0.0065 | 0.168\*\* |
| Spike length | -0.0014 | -0.0011 | -0.0114 | -0.0036 | 0.0002 | 0.0001 | 0.0002 | **0.0355** | -0.0315 | 0.1003 | 0.0030 | 0.0125 | 0.0031 | 0.106 |
| Number of grains/ear | -0.0076 | -0.0033 | 0.0137 | -0.0036 | 0.0001 | 0.0001 | 0.0003 | 0.0212 | **-0.0526** | 0.1528 | -0.0022 | 0.1111 | 0.0046 | 0.235\*\* |
| Biological weight | 0.0003 | 0.0000 | 0.0148 | 0.0002 | -0.0002 | 0.0001 | 0.0001 | 0.0046 | -0.0104 | **0.7725** | 0.0015 | -0.0101 | -0.0059 | 0.767\*\* |
| 1000 grain weight | 0.0143 | 0.0075 | -0.0326 | 0.0089 | 0.0004 | 0.0004 | -0.0001 | 0.0039 | 0.0042 | 0.0411 | **0.0272** | -0.2295 | -0.0177 | -0.172\*\* |
| Harvest index | -0.0116 | -0.0074 | 0.0147 | -0.0057 | -0.0004 | -0.0001 | 0.0002 | 0.0008 | -0.0098 | -0.0131 | -0.0105 | **0.5955** | 0.0091 | 0.562\*\* |
| Protein content | -0.0098 | -0.0055 | 0.0161 | -0.0028 | -0.0004 | -0.0001 | 0.0001 | 0.0018 | -0.0039 | -0.0732 | -0.0078 | 0.0873 | **0.0618** | 0.064 |

Resi-0.0705

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