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Character Association and Path Coefficient Analysis of Yield Components in Bread Wheat (Triticum aestivum L.) Hybrids and Parents under Timely and Late Sown Conditions

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Abstract

Grain yield in bread wheat is a complex trait, and the characters that explain it can change when sowing is delayed and the crop meets terminal heat. We estimated phenotypic and genotypic correlations and partitioned them into direct and indirect effects on grain yield per plant for twelve characters in 96 genotypes (72 F_1 hybrids from an 18 line × 4 tester mating design, 22 parents and two checks). The genotypes were grown in a randomised block design with three replications under timely sown (E1) and late sown (E2) conditions in Rabi 2016–17. Biological yield showed the strongest association with grain yield in both environments (phenotypic r = 0.960 in E1 and 0.969 in E2), followed by harvest index (0.400 and 0.565). Chlorophyll content (0.353), tillers per plant (0.282) and days to 50% flowering (0.181) were positively correlated with grain yield only under timely sowing, whereas test weight (0.510) was so only under late sowing, where tillers per plant were negatively correlated (−0.299). In the full path model, biological yield (direct effect 0.92 in E1 and 0.89 in E2) and harvest index (0.25 and 0.23) accounted for nearly all of the variation (residual effect 0.13–0.14). Because these two characters are arithmetic components of grain yield, the model was refitted without them. In the reduced model, chlorophyll content, plant height and days to 50% flowering had the largest positive direct effects in E1, and test weight, plant height and peduncle length in E2 (residual effects 0.83 and 0.75). Selection criteria for yield should therefore be defined separately for timely and late sowing.

1. Introduction

Wheat (*Triticum aestivum* L., 2n = 6x = 42) is a staple food for a large share of the world's population and, after rice, the most important cereal of India. The Ministry of Agriculture and Farmers' Welfare (2026) puts the 2025–26 wheat crop at a record 120.65 million tonnes, against 117.94 million tonnes in 2024–25. Keeping this trend going depends on continued genetic improvement of grain yield.

In the Indo-Gangetic Plains a large part of the wheat area is sown after the optimum window, and the crop then meets rising temperatures during anthesis and grain filling (Joshi et al., 2007). Delayed planting after late-harvested preceding crops is a recognised cause of yield loss in South Asia (Ul-Allah et al., 2023), and warming is expected to depress wheat yield further, by about 6% for each degree Celsius at the global scale (Asseng et al., 2015). Late sowing does not only lower yield; it also changes which characters are associated with yield. Ul-Allah et al. (2023) concluded that the strength of association between traits differed with sowing date and that selection criteria should be evaluated separately for each. In late sown wheat, Hazra et al. (2019) found that only harvest index, among ten yield attributes, was significantly correlated with grain yield per plant, and Mohammad et al. (2008) reported that the genotypic correlation of biological yield with grain yield was not significant under late planting. Conclusions drawn under one sowing date therefore cannot simply be carried over to the other.

Correlation coefficients measure the degree and direction of association but not its cause. Path analysis (Wright, 1921; Dewey and Lu, 1959) separates a correlation into the direct effect of a character on yield and its indirect effects through other characters, which makes it a useful guide for indirect selection. Its results need careful reading when a predictor is itself a component of the dependent variable. Biological yield and harvest index are the two arithmetic components of grain yield (Donald and Hamblin, 1976), so a model that contains both can explain almost all of the variation in yield by construction and will understate the direct effects of the other characters. Several earlier path analyses in wheat identified biological yield and harvest index as the characters with the highest direct effects (Mohammad et al., 2008; Hazra et al., 2019; Kiran et al., 2020), and we examine here how far that finding depends on keeping both in the model.

To our knowledge, little is known about character association in F_1 hybrids from a line × tester design, together with their parents, evaluated under both timely and late sowing in eastern Uttar Pradesh. The objectives of this study were (i) to estimate phenotypic and genotypic correlations among twelve characters and grain yield per plant under timely and late sowing, (ii) to partition these correlations into direct and indirect effects, with and without biological yield and harvest index in the model, and (iii) to identify characters that can serve as selection criteria in each sowing condition.

2. Materials and methods

2.1 Experimental site

The experiment was carried out at the Main Experiment Station of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, India (26°47' N latitude and 82°12' E longitude) at an altitude of 113 m above mean sea level. The climate is subtropical and semi-arid characterized by hot summers and cold winters with a mean annual rainfall of approximately 1,270 mm. The soil of the experimental site was sandy loam in texture. The initial soil properties, including pH, electrical conductivity (EC), organic carbon and available nitrogen, phosphorus and potassium, were determined before the commencement of the experiment. The soil was alkaline in reaction (pH approximately 8.0), with low organic carbon content (0.32%) and available nitrogen (180 kg ha^{-1}), medium available phosphorus (15.25 kg ha^{-1}) and available potassium (270 kg ha^{-1}). The electrical conductivity of the experimental soil should be incorporated from the initial soil analysis report.

2.2 Plant material and experimental design

Eighteen female lines and four male testers were crossed following the line × tester mating design proposed by Kempthorne (1957) during the Rabi season of 2015–16, resulting in 72 F_1 hybrids. During the Rabi season of 2016–17, the 72 F_1 hybrids, 22 parental genotypes (18 female lines and four male testers) and two standard check varieties, comprising a total of 96 genotypes, were evaluated under two sowing environments: timely sown (E_1) and late sown (E_2). Each environment was laid out in a randomized block design (RBD) with three replications. The F_1 hybrids were planted in single rows, whereas the parental genotypes were planted in two rows per plot. Each plot was 3 m long, with 23 cm spacing between rows and 10 cm spacing between plants within rows. The recommended package of practices for wheat cultivation in the region was followed. Nitrogen, phosphorus and potassium fertilizers were applied to support

optimum crop growth and development. Irrigation was scheduled according to the crop growth stages and soil moisture requirements. Weeds were controlled as required, and appropriate plant-protection measures were adopted to minimize the incidence of insect pests and diseases. The timely-sown and late-sown treatments were maintained to evaluate the performance of the genotypes under contrasting sowing conditions.

2.3 Observations

Observations were recorded on five randomly selected plants per plot for twelve characters: days to 50% flowering, days to maturity, plant height (cm), number of tillers per plant, spike length (cm), peduncle length (cm), flag leaf area (cm²), 1000-grain weight (g; test weight), biological yield per plant (g), grain yield per plant (g), harvest index (%) and chlorophyll content. Harvest index was calculated as grain yield divided by biological yield, multiplied by 100.

2.4 Statistical analysis

Analysis of variance for a randomised block design was done separately for each environment (Panse and Sukhatme, 1985). Phenotypic and genotypic correlation coefficients between each character and grain yield, and among the characters, were estimated from the corresponding variance and covariance components (Searle, 1961; Al-Jibouri et al., 1958). Phenotypic coefficients were tested for significance at the 5% and 1% levels against the critical values of r genotypic coefficients were not tested.

Path coefficient analysis followed Dewey and Lu (1959), with grain yield per plant as the dependent variable. The direct effects (p) were obtained by solving the normal equations, p = R⁻¹ r, where R is the matrix of correlations among the predictors and r is the vector of their correlations with grain yield. The indirect effect of character i through character j is r × p, and the residual effect is √(1 − Σ p r). Two models were fitted for each environment and for both phenotypic and genotypic correlations: Model I with all eleven characters as predictors, and Model II without biological yield and harvest index. Multicollinearity among predictors was checked with the variance inflation factor (VIF; Janmohammadi et al., 2014). All statistical analyses, including analysis of variance, correlation analysis, path coefficient analysis and multicollinearity assessment, were performed using OPSTAT statistical software.

3. Results

Analysis Analysis of variance revealed significant differences among the genotypes for the characters studied, indicating the presence of considerable genetic variability among the bread wheat hybrids, their parental lines and the standard checks. The genotypic variation was evaluated separately under timely-sown (E_1) and late-sown (E_2) conditions to assess the performance of the genotypes under contrasting sowing environments. The significance of the variation attributed to the standard checks was also reported in the original draft. However, the corresponding mean squares and mean performance values were not available in the manuscript. Therefore, the comparative performance of the F_1 hybrids, parents and standard checks in each environment requires confirmation using the original experimental data.

3.1 Correlations under timely sowing (E1)

In E1, grain yield per plant was significantly and positively correlated (phenotypic coefficients, Table 1) with biological yield (0.960), harvest index (0.400), chlorophyll content (0.353), tillers per plant (0.282), plant height (0.240), flag leaf area (0.196), peduncle length (0.182) and days to 50% flowering (0.181), and negatively with spike length (−0.149, $P < 0.05$). Days to maturity (0.083) and test weight (0.114) were not significantly associated with grain yield. Genotypic coefficients had the same signs and were generally slightly larger, for example 0.973 for biological yield and 0.436 for harvest index. Among the characters, days to 50% flowering was strongly correlated with days to maturity (0.794), plant height with peduncle length (0.574), and flag leaf area with peduncle length (0.476) and tillers per plant (0.445). Biological yield was positively correlated with chlorophyll content (0.347), tillers per plant (0.299) and plant height (0.296).

3.2 Correlations under late sowing (E2)

The pattern in E2 (Table 2) differed in several respects. Grain yield per plant was positively correlated with biological yield (0.969), harvest index (0.565), test weight (0.510), peduncle length (0.384), plant height (0.327) and flag leaf area (0.151, $P < 0.05$). Tillers per plant were negatively correlated with grain yield (−0.299) and with biological yield (−0.296), and days to 50% flowering was negatively correlated with tillers per plant (−0.240). Chlorophyll content (−0.077) and days to 50% flowering (0.095) were no longer significantly associated with grain yield. Biological yield was correlated with test weight (0.513), peduncle length (0.408) and chlorophyll content (0.385), and plant height with peduncle length (0.535) and test weight (0.363). Between the two environments, therefore, the association of grain yield with tillers per plant changed sign, that with chlorophyll content and days to 50% flowering disappeared, and test weight became one of the strongest correlates.

3.3 Path analysis with all characters (Model I)

The direct effects from Model I are given in the diagonals of Tables 3 (E1) and 4 (E2). Biological yield had by far the largest direct effect on grain yield per plant (phenotypic 0.920 in E1 and 0.888 in E2; genotypic 0.926 and 0.899), followed by harvest index (0.246 and 0.229; genotypic 0.240 and 0.222). The direct effects of all other characters were negligible (absolute value 0.04 or less) and of mixed sign. Their correlations with grain yield arose almost entirely through biological yield. In E1, for instance, chlorophyll content had a correlation of 0.353 with grain yield, of which 0.32 was the indirect effect through biological yield; in E2 the correlation of test weight with grain yield (0.510) comprised a direct effect of −0.018, an indirect effect of 0.456 through biological

yield and 0.068 through harvest index. The residual effect was 0.143 (E1) and 0.131 (E2) for phenotypic and only 0.014 and 0.027 for genotypic coefficients. All VIF values were below 4 (maximum 2.93 in E1 and 3.72 in E2).

3.4 Path analysis without biological yield and harvest index (Model II)

When biological yield and harvest index were removed, the direct effects of the remaining nine characters became substantial and differed between environments (Table 5). In E1 the largest positive direct effects were those of chlorophyll content (0.353), plant height (0.277), days to 50% flowering (0.223) and tillers per plant (0.157), and the largest negative ones those of spike length (−0.256) and days to maturity (−0.126). In E2 the largest positive direct effects were those of test weight (0.382), plant height (0.175) and peduncle length (0.169), and the largest negative ones those of tillers per plant (−0.359) and days to maturity (−0.174). Genotypic direct effects had the same signs for the larger effects, although those of days to 50% flowering and days to maturity were roughly twice as large as the phenotypic ones. The residual effects were 0.828 in E1 and 0.750 in E2 (phenotypic), so that about two-thirds of the variation in grain yield per plant remained unexplained by these nine characters.

4. Discussion

Biological yield and harvest index dominate the full model: The very high correlation of biological yield with grain yield (0.96–0.97) and its direct effect of about 0.9 agree with earlier reports from timely and late sown wheat, in which biological yield and harvest index had the highest direct effects (Mohammad et al., 2008; Hazra et al., 2019; Kiran et al., 2020). Pandey et al. (2013), working at the same experiment station on reclaimed saline-sodic soil, obtained direct effects of 0.925 for biological yield and 0.242 for harvest index and a residual effect of 0.14, almost the same as our phenotypic values. Positive associations of biological yield with grain yield have also been noted by Prasad et al. (2006) and Chaitali Sen and Toms (2007). The near-zero genotypic residual effect (0.014–0.027) shows how much of this result is arithmetic: grain yield equals biological yield multiplied by harvest index (Donald and Hamblin, 1976), so a model containing both leaves almost nothing unexplained. Biological yield and harvest index are better read as the integrated outcome of the other characters than as independent causes of yield, which is also why every other character acted through biological yield in Tables 3 and 4.

Association with yield depends on sowing date: The changes between E1 and E2 are consistent with the finding of Ul-Allah et al. (2023) that late sowing reduced yield and altered the association among traits, probably because of terminal heat stress. Chlorophyll content, tillers per plant and days to 50% flowering were positively associated with grain yield only under timely sowing, and in Model II chlorophyll content had the largest direct effect in E1 (0.353) and a small negative one in E2 (−0.072). A possible reason is that under late sowing the higher temperature during grain filling shortens the period in which green leaf area can contribute to yield. The negative association of tillers per plant with grain yield and biological yield in E2 may reflect tillers formed late that do not produce a grain-bearing spike; productive tillers or spikes per unit area were not recorded, which limits interpretation. Test weight, in contrast, became the most influential character in E2 (correlation 0.510, direct effect 0.382 in Model II). This suggests that in late sown wheat, where the grain-filling period is short, grain size is a strong determinant of yield, and it fits the reduced duration of the crop cycle under delayed sowing described by Ul-Allah et al. (2023).

Implications for selection: Selection for biological yield and harvest index will raise yield under both sowing conditions, as their correlations and direct effects were high in both. Beyond these two, our results suggest different secondary criteria for each condition: chlorophyll content, plant height and tillers per plant under timely sowing, and test weight, peduncle length and plant height under late sowing. Selecting for tillers per plant alone is not advisable under late sowing, where its association with yield was negative. Plant height had a positive direct effect in both environments in Model II; this should be treated with caution in view of lodging risk, and positive direct effects of plant height have been reported previously (Aycicek and Yildirim, 2006). Ul-Allah et al. (2023) also found spike length and spikelets per spike to be important together with biological yield; grains per spike and spikelets per spike were not measured here and probably account for part of the high residual effect in Model II.

Limitations: The results come from one season of evaluation and from a mixed population of F_1 hybrids, parents and checks, so correlations may be influenced by heterosis and by differences between these groups. The significance of genotypic coefficients was not tested, and path coefficients were computed from correlation coefficients, so they inherit any error in those estimates. The conclusions should be confirmed over seasons and locations, and in segregating generations, before being used in a breeding programme.

5. Conclusions

Under both timely and late sowing, biological yield and harvest index were the characters most strongly correlated with grain yield per plant and the only ones with substantial direct effects in the full path model; their dominance is largely arithmetic. With these two removed, the structure of association differed by sowing date: chlorophyll content, plant height, days to 50% flowering and tillers per plant had positive direct effects under timely sowing, whereas test weight, plant height and peduncle length did so under late sowing, and tillers per plant had a negative effect. Selection criteria for yield in wheat hybrids should therefore be set separately for timely and late sown conditions and validated over seasons and locations.

Declarations

Author contributions: Tejasvi Singh: Conceptualization, investigation, data curation, formal analysis, writing original draft. **Vinod Singh:** Conceptualization, resources, methodology, supervision. **K. K. Mishra:** Validation, writing review and editing. **Arun Shankar:** Resources, writing review and editing. All authors read and approved the final manuscript.

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Data availability: The data supporting the findings of this study are available from the corresponding author K. K. Mishra upon reasonable request.

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References

1. Al-Jibouri, H.A., Miller, P.A., Robinson, H.F., 1958. Genotypic and environmental variances and covariances in an upland cotton cross of interspecific origin. Agron. J. 50(10), 633–636.
2. Asseng, S., Ewert, F., Martre, P., et al., 2015. Rising temperatures reduce global wheat production. Nat. Clim. Change 5, 143–147. https://doi.org/10.1038/nclimate2470
3. Aycicek, M., Yildirim, T., 2006. Path coefficient analysis of yield and yield components in bread wheat (*Triticum aestivum* L.) genotypes. Pak. J. Bot. 38(2), 417–424.
4. Chaitali Sen, Bini Toms, 2007. Character association and component analysis in wheat (*Triticum aestivum* L.). Crop Res. (Hisar) 34(1–3), 166–170.
5. Dewey, D.R., Lu, K.H., 1959. A correlation and path-coefficient analysis of components of crested wheatgrass seed production. Agron. J. 51(9), 515–518. https://doi.org/10.2134/agronj1959.00021962005100090002x
6. Donald, C.M., Hamblin, J., 1976. The biological yield and harvest index of cereals as agronomic and breeding criteria. Adv. Agron. 28, 361–405.
7. Hazra, S., Chaterjee, S., Kumar, V.U., Mukherjee, S., Maji, A., 2019. Genetic variability and character association in late sown wheat genotypes. J. Pharmacogn. Phytochem. 8(5), 707–712.
8. Janmohammadi, M., Sabaghnia, N., Nouraein, M., 2014. Path analysis of grain yield and yield components and some agronomic traits in bread wheat. Acta Univ. Agric. Silvic. Mendelianae Brun. 62(5), 945–952. https://doi.org/10.11118/actaun201462050945
9. Joshi, A.K., Mishra, B., Chatrath, R., Ortiz Ferrara, G., Singh, R.P., 2007. Wheat improvement in India: present status, emerging challenges and future prospects. Euphytica 157, 431–446.
10. Kempthorne, O., 1957. An Introduction to Genetic Statistics. John Wiley & Sons, New York.
11. Kiran, Solanki, Y.P.S., Singh, V., 2020. Correlation and path coefficient analysis between yield and its contributing traits in advance wheat (*Triticum aestivum* L. em. Thell) genotypes under late sown conditions. J. Pharmacogn. Phytochem. 9(3), 1590–1593.
12. Ministry of Agriculture and Farmers' Welfare, 2026. Third Advance Estimates of Production of Major Crops for 2025–26. Government of India, New Delhi (released May 2026).
13. Mohammad, T., Amin, M., Fazal-e-Subhan, Khan, M.I., Khan, A.J., 2008. Identification of traits in bread wheat genotypes (*Triticum aestivum* L.) contributing to grain yield through correlation and path coefficient analysis. Pak. J. Bot. 40(6), 2393–2402.
14. Panse, V.G., Sukhatme, P.V., 1985. Statistical Methods for Agricultural Workers, 4th ed. Indian Council of Agricultural Research, New Delhi.
15. Pandey, M.K., Bhushan, B., Bind, H.N., Singh, B.N., Kumar, A., 2013. Analysis of yield components and their association for enhancing grain yield in bread wheat (*Triticum aestivum* L. em Thell.) under saline-sodicity reclaimed condition. J. Cereal Res. 5(2), 35–38. https://doi.org/10.25174/m39fry94
16. Prasad, J., Kerketta, V., Prasad, K.D., Verma, A.K., 2006. Study of genetic parameters under different environment conditions in wheat (*Triticum aestivum* L.). J. Res. Birsa Agric. Univ. 18(1), 135–140.
17. Searle, S.R., 1961. Phenotypic, genotypic and environmental correlations. Biometrics 17(3), 474–480.
18. Ul-Allah, S., Hussain, S., Mumtaz, R. 2023. Phenotypic characterization of wheat germplasm for heritability and dissection of association among post anthesis traits under variable sowing dates. J. King Saud Univ. Sci. 35(3), 102578. https://doi.org/10.1016/j.jksus.2023.102578
19. Wright, S., 1921. Correlation and causation. J. Agric. Res. 20, 557–585.

Tables

Table 1. Phenotypic (P) and genotypic (G) correlation coefficients among twelve characters under timely sown condition (E1) in wheat.

Character		DF	FLA	DM	PH	TPP	SL	PL	BY	TW	HI	CHL
Days to 50% flowering	P	**1.0000**	0.0953	0.7942**	0.1285*	−0.0750	−0.0410	0.1068	0.2156	0.0208	−0.0890	0.0605
	G	**1.0000**	0.1095	0.8597	0.1669	−0.0757	−0.0915	0.1284	0.2747	0.0364	−0.0753	0.0733
Flag leaf area (cm²)	P		**1.0000**	0.0688	0.2230**	0.4452**	0.2717**	0.4760**	0.2177**	0.2279**	0.0143	0.2698**
	G		**1.0000**	0.0918	0.2281	0.4710	0.3092	0.5069	0.2276	0.2595	0.0144	0.2795
Days to maturity	P			**1.0000**	0.1710**	−0.1390*	−0.1001	0.1300*	0.1040	−0.0181	−0.1046	−0.0518
	G			**1.0000**	0.2177	−0.1677	−0.1738	0.1583	0.1402	−0.0325	−0.0991	−0.0653
Plant height (cm)	P				**1.0000**	0.1492*	−0.0797	0.5736**	0.2957**	−0.0489	−0.1344*	−0.2462**
	G				**1.0000**	0.1561	−0.0993	0.6022	0.3012	−0.0631	−0.1556	−0.2528
Tillers/plant	P					**1.0000**	0.3243**	0.3423**	0.2985**	0.3361**	0.0315	0.3804**
	G					**1.0000**	0.4002	0.3733	0.3030	0.3723	0.0355	0.4014
Spike length (cm)	P						**1.0000**	0.2710**	−0.1223*	0.3582**	−0.1469*	0.1184*
	G						**1.0000**	0.2866	−0.1259	0.3947	−0.2154	0.1499
Peduncle length (cm)	P							**1.0000**	0.2403**	0.1005	−0.1805**	0.0452
	G							**1.0000**	0.2581	0.0882	−0.2244	0.0507
Biological yield/plant (g)	P								**1.0000**	0.1185*	0.1719	0.3474**
	G								**1.0000**	0.1143	0.2173	0.3550
Test weight (g)	P									**1.0000**	0.0674	0.2040**
	G									**1.0000**	0.0500	0.2239
Harvest index (%)	P										**1.0000**	0.1449*
	G										**1.0000**	0.1954
Chlorophyll content	P											**1.0000**
	G											**1.0000**

* and ** significant at 5% and 1% (phenotypic coefficients only). DF, days to 50% flowering; FLA, flag leaf area; DM, days to maturity; PH, plant height; TPP, tillers per plant; SL, spike length; PL, peduncle length; BY, biological yield per plant; TW, test weight (1000-grain weight); HI, harvest index; CHL, chlorophyll content; GY, grain yield per plant.

Table 2. Phenotypic (P) and genotypic (G) correlation coefficients among twelve characters under late sown condition (E2) in wheat.

Character		DF	FLA	DM	PH	TPP	SL	PL	BY	TW	HI	CHL
Days to 50% flowering	P	**1.0000**	0.0585	0.8465**	0.0665	−0.2403**	0.0131	0.0466	0.0837	0.0443	0.1131	−0.0588
	G	**1.0000**	0.0560	0.9305	0.0705	−0.3143	0.0196	0.0864	0.1048	0.0742	0.1501	−0.0823
Flag leaf area (cm²)	P		**1.0000**	0.0885	0.3382**	0.2216**	0.2337**	0.4186**	0.1540*	0.2606**	0.0597	0.2018**
	G		**1.0000**	0.1165	0.3731	0.2408	0.2807	0.4469	0.1631	0.2787	0.0701	0.2310
Days to maturity	P			**1.0000**	0.0770	−0.1823**	0.0776	0.0890	0.0287	0.0441	0.0748	−0.0117
	G			**1.0000**	0.0803	−0.2105	0.1449	0.1633	0.0447	0.0718	0.0799	−0.0303
Plant height (cm)	P				**1.0000**	0.2473**	0.0646	0.5346**	0.3399**	0.3631**	0.1514*	−0.1328*
	G				**1.0000**	0.2658	0.0722	0.5862	0.3475	0.3779	0.1840	−0.1709
Tillers/plant	P					**1.0000**	0.2402**	0.0981	−0.2956**	−0.0158	−0.1249*	0.0395
	G					**1.0000**	0.1978	0.0658	−0.3401	−0.0379	−0.1327	−0.0060
Spike length (cm)	P						**1.0000**	0.3014**	0.0688	0.1994**	−0.0986	0.0907
	G						**1.0000**	0.3095	0.0775	0.2227	−0.1207	−0.0534
Peduncle length (cm)	P							**1.0000**	0.4078**	0.3864**	0.1423*	−0.1296*
	G							**1.0000**	0.4277	0.3944	0.1843	−0.2360
Biological yield/plant (g)	P								**1.0000**	0.5133**	0.3852**	−0.0864
	G								**1.0000**	0.5263	0.4553	−0.1221
Test weight (g)	P									**1.0000**	0.2977**	0.1412*
	G									**1.0000**	0.3525	0.1449
Harvest index (%)	P										**1.0000**	−0.0692
	G										**1.0000**	−0.0627
Chlorophyll content	P											**1.0000**
	G											**1.0000**

* and ** significant at 5% and 1% (phenotypic coefficients only). DF, days to 50% flowering; FLA, flag leaf area; DM, days to maturity; PH, plant height; TPP, tillers per plant; SL, spike length; PL, peduncle length; BY, biological yield per plant; TW, test weight (1000-grain weight); HI, harvest index; CHL, chlorophyll content; GY, grain yield per plant.

Table 3. Direct (diagonal, bold) and indirect effects of eleven characters on grain yield per plant at phenotypic (P) and genotypic (G) level under timely sown condition (E1), Model I.

Character		DF	FLA	DM	PH	TPP	SL	PL	BY	TW	HI	CHL	r with
Days to 50% flowering	P	**−0.0142**	−0.0014	0.0212	−0.0007	−0.0007	−0.0002	0.0011	0.1983	−0.0003	−0.0219	0.0001	0.1813
	G	**−0.0107**	−0.0019	0.0169	−0.0023	−0.0014	−0.0001	0.0016	0.2544	−0.0006	−0.0181	−0.0009	0.2370
Flag leaf area (cm²)	P	−0.0014	**−0.0146**	0.0018	−0.0013	0.0043	0.0011	0.0049	0.2002	−0.0032	0.0035	0.0003	0.1957
	G	−0.0012	**−0.0170**	0.0018	−0.0031	0.0089	0.0004	0.0065	0.2108	−0.0042	0.0035	−0.0036	0.2028
Days to maturity	P	−0.0113	−0.0010	**0.0267**	−0.0010	−0.0013	−0.0004	0.0013	0.0957	0.0003	−0.0257	−0.0001	0.0832
	G	−0.0092	−0.0016	**0.0197**	−0.0030	−0.0032	−0.0002	0.0020	0.1298	0.0005	−0.0238	0.0008	0.1120
Plant height (cm)	P	−0.0018	−0.0033	0.0046	**−0.0058**	0.0014	−0.0003	0.0059	0.2720	0.0007	−0.0330	−0.0002	0.2401
	G	−0.0018	−0.0039	0.0043	**−0.0138**	0.0030	−0.0001	0.0077	0.2789	0.0010	−0.0374	0.0032	0.2412
Tillers/plant	P	0.0011	−0.0065	−0.0037	−0.0009	**0.0096**	0.0013	0.0035	0.2745	−0.0047	0.0077	0.0004	0.2824
	G	0.0008	−0.0080	−0.0033	−0.0021	**0.0190**	0.0005	0.0048	0.2806	−0.0060	0.0085	−0.0051	0.2896
Spike length (cm)	P	0.0006	−0.0040	−0.0027	0.0005	0.0031	**0.0041**	0.0028	−0.1125	−0.0050	−0.0361	0.0001	−0.149
	G	0.0010	−0.0052	−0.0034	0.0014	0.0076	**0.0013**	0.0036	−0.1166	−0.0063	−0.0517	−0.0019	−0.170
Peduncle length (cm)	P	−0.0015	−0.0070	0.0035	−0.0033	0.0033	0.0011	**0.0103**	0.2210	−0.0014	−0.0443	0.0000	0.1817
	G	−0.0014	−0.0086	0.0031	−0.0083	0.0071	0.0004	**0.0127**	0.2390	−0.0014	−0.0539	−0.0006	0.1881
Biological yield/plant (g)	P	−0.0031	−0.0032	0.0028	−0.0017	0.0029	−0.0005	0.0025	**0.9198**	−0.0017	0.0422	0.0004	0.9603
	G	−0.0029	−0.0039	0.0028	−0.0041	0.0057	−0.0002	0.0033	**0.9261**	−0.0018	0.0522	−0.0045	0.9726
Test weight (g)	P	−0.0003	−0.0033	−0.0005	0.0003	0.0032	0.0015	0.0010	0.1090	**−0.0140**	0.0165	0.0002	0.1137
	G	−0.0004	−0.0044	−0.0006	0.0009	0.0071	0.0005	0.0011	0.1059	**−0.0160**	0.0120	−0.0029	0.1031
Harvest index (%)	P	0.0013	−0.0002	−0.0028	0.0008	0.0003	−0.0006	−0.0019	0.1581	−0.0009	**0.2455**	0.0001	0.3997
	G	0.0008	−0.0002	−0.0020	0.0021	0.0007	−0.0003	−0.0029	0.2012	−0.0008	**0.2402**	−0.0025	0.4364
Chlorophyll content	P	−0.0009	−0.0039	−0.0014	0.0014	0.0036	0.0005	0.0005	0.3195	−0.0028	0.0356	**0.0010**	0.3531
	G	−0.0008	−0.0047	−0.0013	0.0035	0.0076	0.0002	0.0006	0.3288	−0.0036	0.0469	**−0.0128**	0.3644

Residual effect: 0.143 (P), 0.014 (G). Indirect effect of the row character through the column character = r × direct effect of the column character; row sums equal the correlation with GY. DF, days to 50% flowering; FLA, flag leaf area; DM, days to maturity; PH, plant height; TPP, tillers per plant; SL, spike length; PL, peduncle length; BY, biological yield per plant; TW, test weight (1000-grain weight); HI, harvest index; CHL, chlorophyll content; GY, grain yield per plant.

Table 4. Direct (diagonal, bold) and indirect effects of eleven characters on grain yield per plant at phenotypic (P) and genotypic (G) level under late sown condition (E2), Model I.

Character		DF	FLA	DM	PH	TPP	SL	PL	BY	TW	HI	CHL	r with
Days to 50% flowering	P	**0.0016**	0.0003	−0.0081	0.0003	0.0031	0.0001	−0.0003	0.0743	−0.0008	0.0259	−0.0010	0.095
	G	**−0.0010**	−0.0005	−0.0026	0.0003	0.0011	0.0001	0.0008	0.0942	−0.0029	0.0333	−0.0029	0.119
Flag leaf area (cm²)	P	0.0001	**0.0056**	−0.0008	0.0013	−0.0028	0.0010	−0.0024	0.1367	−0.0047	0.0137	0.0034	0.151
	G	−0.0001	**−0.0097**	−0.0003	0.0017	−0.0008	0.0016	0.0042	0.1466	−0.0107	0.0155	0.0082	0.156
Days to maturity	P	0.0014	0.0005	**−0.0096**	0.0003	0.0023	0.0003	−0.0005	0.0255	−0.0008	0.0171	−0.0002	0.036
	G	−0.0009	−0.0011	**−0.0028**	0.0004	0.0007	0.0009	0.0015	0.0402	−0.0028	0.0177	−0.0011	0.052
Plant height (cm)	P	0.0001	0.0019	−0.0007	**0.0040**	−0.0032	0.0003	−0.0030	0.3017	−0.0065	0.0347	−0.0022	0.326
	G	−0.0001	−0.0036	−0.0002	**0.0046**	−0.0009	0.0004	0.0055	0.3123	−0.0146	0.0408	−0.0061	0.338
Tillers/plant	P	−0.0004	0.0013	0.0017	0.0010	**−0.0129**	0.0011	−0.0006	−0.2624	0.0003	−0.0286	0.0007	−0.29
	G	0.0003	−0.0023	0.0006	0.0012	**−0.0034**	0.0012	0.0006	−0.3057	0.0015	−0.0294	−0.0002	−0.33
Spike length (cm)	P	0.0000	0.0013	−0.0007	0.0003	−0.0031	**0.0044**	−0.0017	0.0611	−0.0036	−0.0226	0.0015	0.036
	G	−0.0000	−0.0027	−0.0004	0.0003	−0.0007	**0.0059**	0.0029	0.0697	−0.0086	−0.0268	−0.0019	0.037
Peduncle length (cm)	P	0.0001	0.0024	−0.0009	0.0021	−0.0013	0.0013	**−0.0057**	0.3620	−0.0070	0.0326	−0.0022	0.383
	G	−0.0001	−0.0043	−0.0005	0.0027	−0.0002	0.0018	**0.0094**	0.3844	−0.0152	0.0409	−0.0084	0.410
Biological yield/plant (g)	P	0.0001	0.0009	−0.0003	0.0013	0.0038	0.0003	−0.0023	**0.8876**	−0.0093	0.0882	−0.0015	0.969
	G	−0.0001	−0.0016	−0.0001	0.0016	0.0012	0.0005	0.0040	**0.8987**	−0.0203	0.1010	−0.0043	0.980
Test weight (g)	P	0.0001	0.0015	−0.0004	0.0014	0.0002	0.0009	−0.0022	0.4556	**−0.0180**	0.0682	0.0024	0.509
	G	−0.0001	−0.0027	−0.0002	0.0017	0.0001	0.0013	0.0037	0.4730	**−0.0385**	0.0782	0.0052	0.521
Harvest index (%)	P	0.0002	0.0003	−0.0007	0.0006	0.0016	−0.0004	−0.0008	0.3419	−0.0054	**0.2291**	−0.0012	0.565
	G	−0.0001	−0.0007	−0.0002	0.0008	0.0005	−0.0007	0.0017	0.4092	−0.0136	**0.2217**	−0.0022	0.616
Chlorophyll content	P	−0.0001	0.0011	0.0001	−0.0005	−0.0005	0.0004	0.0007	−0.0767	−0.0025	−0.0159	**0.0168**	−0.07
	G	0.0001	−0.0022	0.0001	−0.0008	0.0000	−0.0003	−0.0022	−0.1097	−0.0056	−0.0139	**0.0356**	−0.09

Residual effect: 0.131 (P), 0.027 (G). Indirect effect of the row character through the column character = r × direct effect of the column character; row sums equal the correlation with GY. DF, days to 50% flowering; FLA, flag leaf area; DM, days to maturity; PH, plant height; TPP, tillers per plant; SL, spike length; PL, peduncle length; BY, biological yield per plant; TW, test weight (1000-grain weight); HI, harvest index; CHL, chlorophyll content; GY, grain yield per plant.

Table 5. Correlation with grain yield per plant and direct effects at phenotypic (P) and genotypic (G) level when biological yield and harvest index are excluded from the path model (Model II).

Character	E1 (timely sown)			E2 (late sown)		
	r (P)	Direct (P)	Direct (G)	r (P)	Direct (P)	Direct (G)
Days to 50% flowering	0.1813**	**0.2234**	**0.3995**	0.0954	0.1145	**0.2366**
Flag leaf area (cm²)	0.1957**	0.0041	0.0190	0.1511*	0.0252	0.0464
Days to maturity	0.0832	−0.1264	**−0.2927**	0.0364	**−0.1741**	**−0.3238**
Plant height (cm)	0.2401**	**0.2766**	**0.2433**	0.3269**	**0.1746**	**0.1652**
Tillers/plant	0.2824**	**0.1568**	**0.1844**	−0.2988**	**−0.3588**	**−0.3795**
Spike length (cm)	−0.1490*	**−0.2563**	**−0.3268**	0.0369	−0.0026	−0.0166
Peduncle length (cm)	0.1817**	0.0049	0.0286	0.3835**	**0.1689**	**0.1847**
Test weight (g)	0.1137	0.0860	0.0736	0.5096**	**0.3820**	**0.3810**
Chlorophyll content	0.3531**	**0.3530**	**0.3293**	−0.0770	−0.0718	−0.0866
Residual effect		**0.828**	**0.796**		**0.750**	**0.718**

Values in bold: direct effect of 0.15 or more in absolute value. r (P) with * or ** is significant at 5% or 1%. DF, days to 50% flowering; FLA, flag leaf area; DM, days to maturity; PH, plant height; TPP, tillers per plant; SL, spike length; PL, peduncle length; BY, biological yield per plant; TW, test weight (1000-grain weight); HI, harvest index; CHL, chlorophyll content; GY, grain yield per plant.