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Unveiling true association between grain yield and its contributing traits of bread wheat through association studies and path coefficient analysis

Sarilla Jeannie, Rajiv Kumar, SB Chaudhari, K Ujwala and B Sriram Kumar

Abstract
The current investigation was carried out during *rabi*, 2020-21 following Randomized Block Design (RBD) with two replications using fifty genotypes of wheat germplasm that were collected from Wheat Research Station, JAU through 19th High-Temperature Wheat Yield Trails under International Maize and Wheat Improvement Center, Mexico (CIMMYT). Accessions were screened for characters association and path analysis using 21 quantitative traits. Association studies unveiled the presence of significant and positive association of Grain yield per plant with Harvest index (%), Biological yield per plant, LWR at 45 DAS, Number of productive tillers per plant, LAR at 45 DAS, and LAR at 75 DAS implying them as major component traits towards grain yield. Besides, findings from path analysis manifested that Biological yield per plant and Harvest index% were the characters that displayed a true relationship with grain yield.

Keywords: Correlation, direct effect, indirect effect, residual effect and path analysis

Introduction
Wheat (*Triticum aestivum* L.) is an important cereal that is the mainstay of global food security. It is employing a commanding position in Indian agriculture by occupying 28% area under cereals and by contributing 33% of the total food grain production in the country. Besides, it is considered as a staple food for about 40% of the world's population *i.e.*, more than one-third of the world. Globally, wheat is cultivated on an area of about 215.9 million hectares with a production of about 765.76 million tonnes and productivity of 3.54 tonnes per hectare (Anon., 2019b) [3]. World trade in wheat is greater than for all the other crops combined. While, India holds the prestigious position of being the second-largest wheat producing country in the world with an area of cultivation of about 31.36 million hectares with a production of 107.86 million tonnes and productivity of 3.44 tonnes per hectare (Anon., 2019a) [2]. In Gujarat, wheat is grown in about 1.02 million hectares with a total production of 3.33 million tonnes and productivity of 3.2 7 tonnes per hectare (Anon., 2019a) [2].

As it is known, to meet the increased demand of the exploding world population by 2050, wheat production needs to increase by 60% which can be achieved through horizontal approach *i.e.*, by increasing the area under cultivation, or through vertical approach *i.e.*, varietal/hybrid improvement. Among both, the reliable alternative is to increase productivity by improving the traits using genetic diversity as the crucial platform in varietal improvement. Undoubtedly, this can be the strongest tool to take a quantum jump in production and productivity under various agro-climatic conditions. On the contrary, it is a challenging task before the breeders to enhance the production level without increasing the area under production. Furthermore, the study of various traits and their association with each other is an important strategy designed to break genetic barriers of yield. Correlation studies help in determining the composition of a complex trait by providing the information on nature and magnitude of the correlation coefficient which helps the breeder to determine the selection criteria for simultaneous improvement of various characters along with the seed yield. Furthermore, a study on correlation alone is not enough to give an exact picture of the relative importance of the direct and indirect influence of each component character on seed yield. In this context, path coefficient analysis can be an important tool in partitioning the correlation coefficients into direct and indirect effects of independent variables on the dependent variable *i.e*., grain yield.

Materials and methods

The present investigation was carried out during the *rabi* 2020-21 at Wheat Research Station, Junagadh Agricultural University, Junagadh. Fifty genotypes of bread wheat were sown on 19th November, 2020 in a Randomized Block Design with two replications. Accessions were collected from Wheat Research Station, JAU, Junagadh through 19th High-Temperature Wheat Yield Trails under International Maize and Wheat Improvement Center, Mexico (CIMMYT). Each genotype was sown with a spacing of 20 cm × 10 cm in a six-row plot of 3.0 m length. The observations were recorded on these five randomly selected plants in each entry as well as in each replication and their mean values were used for statistical analysis except in case of Days to 50% flowering and Days to maturity where the observations were plot-based. Under the current study, 21 quantitative characters were studied *viz*., Days to 50% flowering, Chlorophyll content at 45 DAS, Chlorophyll content at 75 DAS, Leaf Area Ratio at 45 DAS, Leaf Weight Ratio at 45 DAS, Specific Leaf Area at 45 DAS, Specific Leaf Weight at 45 DAS, Leaf Area Ratio at 75 DAS, Leaf Weight Ratio at 75 DAS, Specific Leaf Area at 75 DAS, Specific Leaf Weight at 75 DAS, Days to maturity, Plant height, Number of productive tillers per plant, Spike length, Number of spikelets per main spike, Number of grains per main spike, 1000 grain weight, Grain yield per plant, Biological yield per plant, Harvest index (%).The data were subjected to the analysis of variance and covariance for the estimation of correlation coefficient as per the method suggested by (Searle 1961) [25]. Correlation coefficients between all possible pairs of characters were calculated at genotypic and phenotypic level. The phenotypic and genotypic correlation coefficients were further partitioned into direct and indirect effects with the help of path coefficient analysis as suggested by Wright (1921) [32] and explained by (Dewey and Lu 1959) [10].

Results and discussion

Estimates of correlation coefficient measures the degree of relationship between pairs of characters. A higher magnitude of genotypic correlation helps in carrying out selection for characters under genetic control which can give a better response for seed yield improvement in comparison to trait selection that would be based on phenotypic association alone. Hence, the association between traits at both levels was taken into consideration. The results of phenotypic and genotypic correlations among different attributes are presented in Table 1.

Findings from association analysis manifested that, most of the character pairs had higher values of genotypic correlation than their corresponding phenotypic correlation. This implies that most of the characters under study are less influenced by environment.

- **Associations between yield and it's component traits**

Among all the component traits, Grain yield per plant displayed significant and positive association both at genotypic and phenotypic levels with Harvest index (%), Biological yield per plant, Number of productive tillers per plant, LAR at 45 DAS, LAR at 75 DAS, and LWR at 45 DAS. Henceforth, profound importance should be given to these traits for bringing improvement in grain yield. Perhaps, following assumptions could be the potential reasons behind the above found inter-variable associations having grain yield per plant as a common variable. Leaf area ratio is nothing but the proportion of plant engaged in the photosynthetic process. Hence, it is better known as the "capacity factor" of a plant. In addition, it also represents the relative size of the assimilatory apparatus of a plant. Hence, if more is the leaf area, more is the efficiency with which a plant can deploy its photosynthetic resources in turn; more is the amount of dry matter distributed to economic parts of the plant. So, having more Leaf Area Ratio at 45 DAS (could be probably the stage of tillering of a plant) especially makes the crop get more tillers. This assumption was based on the popular explanation given by the "nutritional hypothesis" (frequently cited for explaining tiller outgrowth *i.e.*, (Lafarge *et al.* 2002; Luquest *et al.* 2006) [17] which states that axillary bud development in wheat is dependent upon the supply of photo assimilates. By time run, these tillers would bear spikes and grains *i.e.*, productive tillers. Next, 75 DAS is the phase that coincides with the growth stage of wheat with a profound effect on grain yield *i.e.*, stage of grain filling. It was apparent that high LAR at 75 DAS, makes the plant accumulate more dry matter among which, the major portion could be diverted mostly towards grains as it the stage of grain filling. Henceforth, it could enhance the grain yield. Besides, LWR represents the leafiness of plants on a weight basis. So, probably, it could show a similar effect as LAR. So, all these inter-related factors could be the potential aids that made the plant accumulate more biomass thereby the total biological yield of the plant also. In other words, as harvest index (%) is in direct proportion to grain yield, more Harvest index obviously manifests more grain yield per plant. To wind up, the above-found association seems to deserve strategic importance. Hence, the breeder should keep all these factors in mind while formulating a breeding program for yield enhancement.

The above-found associations were in line with the findings of earlier workers *viz.*, significant and positive association of grain yield per plant with Harvest index (%) by Baye *et al*. (2020) [5], Alipour *et al.* (2020) [1], and Vaghela *et al.* (2021) [30]; Grain yield with Biological yield per plant by Chaudhary *et al.* (2020) [8], Baye *et al*. (2020) [5], and Alipour *et al.* (2020) [1]; Grain yield with Number of productive tillers per plant by Chaudhary *et al.* (2020) [8], Bazai *et al.* (2020) [6], and Rajaneesh *et al.* (2019) [21]; Grain yield with Leaf Area Ratio at 45 DAS by Vaghela *et al.* (2021) [30]; Grain yield per plant with Leaf Area Ratio at 75 DAS by Vaghela *et al.* (2021) [30].

- **Associations among yield component traits**

Days to 50% flowering exhibited a significant and positive association with Chlorophyll content at 75 DAS, Leaf Area Ratio at 45 DAS, Leaf Weight Ratio at 45 DAS, Leaf Area Ratio at 75 DAS, Days to maturity, Plant height, and Number of grains per main spike at both genotypic and phenotypic levels. So, these attributes can be used in identifying the duration crop.

These results were in line with the findings of Singh *et al.* (2003) [27], Sidharthan and Malik (2006) [26], and Mehmet and Telat (2006) [19] for the association of Days to 50% flowering with Number of grains per main spike; Kabir *et al.* (2017) [14] Ullah *et al.* (2018) [29] for the association of Days to 50% flowering with plant height.

Chlorophyll content at 45 DAS manifested a highly significant and positive association at both genotypic and phenotypic levels with Chlorophyll content at 75 DAS.

Chlorophyll content at 75 DAS displayed a positive and significant correlation with Days to maturity and Number of grains per main spike at both phenotypic and genotypic levels.

Leaf Area Ratio at 45 DAS showed a highly significant and positive association with Leaf Weight Ratio at 45 DAS, Specific Leaf Area at 45 DAS, Leaf Area Ratio at 75 DAS, Leaf Weight Ratio at 75 DAS, Number of productive tillers per plant, and Biological yield per plant. On the other hand, a highly significant yet negative association was found with Specific Leaf Weight at 45 DAS at both genotypic and phenotypic levels.

Leaf Weight Ratio at 45 DAS correlated significantly and positively with Leaf Area Ratio at 75 DAS, Number of productive tillers per plant, biological yield per plant, Specific Leaf Area at 75 DAS, and Specific Leaf Area at 45 DAS. Moreover, this trait displayed a significant but negative association with Specific Leaf Weight at 45 DAS.

Specific Leaf Area at 45 DAS had a significant and positive association with the Number of productive tillers per plant. Besides, it had displayed a negative yet highly significant association with Specific Leaf Weight at 45 DAS.

Specific Leaf Weight at 45 DAS was positive and significantly correlated with none of the characters. In contrast, it was correlated negatively yet significantly with Number of productive tillers per plant.

Leaf Area Ratio at 75 DAS correlated significantly and positively with Leaf Weight Ratio at 75 DAS, Specific Leaf Area at 75 DAS, and Number of grains per main spike. On the contrary, it had a highly significant and negative association with Specific Leaf Weight at 75 DAS.

Leaf Weight Ratio at 75 DAS associated positively and significantly with Specific Leaf Weight at 75 DAS. In contrast to this, it was correlated significantly in a negative manner with Specific Leaf Area at 75 DAS.

Specific Leaf Area at 75 DAS had a significant and positive correlation with Biological yield per plant. On the other side, it was correlated negatively in a highly significant manner with Specific Leaf Weight at 75 DAS.

Specific Leaf Weight at 75 DAS correlated positively in a significant manner with 1000 grain weight while it had displayed significant and negative association with Number of grains per main spike.

Days to maturity correlated significantly and positively with Plant height, Spike length whereas, it showed a significant yet negative association with 1000 grain weight.

These results were in line with the findings of Singh *et al.* (2003) [27], Sidharthan and Malik (2006) [26], Mehmet and Telat (2006) [19] for the association of Days to maturity with spike length; findings of Kabir *et al.* (2017) [14] and Ullah *et al*. (2018) [29] for plant height.

Number of productive tillers per plant displayed a significant and positive association with Number of spikelets per main spike and Biological yield per plant which was tie well with the findings of Desheva (2016) [9].

Number of spikelets per main spike correlated positively and significantly with Number of grains per main spike as reported earlier by Desheva (2016) [9].

1000 grain weight manifested positive and significant association with Harvest index.

Following presumptions could be the potential rationale behind the above found inter-variable associations (inter-independent variable associations).

Days to 50% flowering implies the duration of the crop. If more time crop needs to flower, longer would be the duration of the crop *i.e.*, to complete its life cycle crop needs a relatively long time. As a consequence, the opportunity to accumulate assimilates by the plant would be more. This could result in a more biological yield of the plant. This assumption ties well with the findings of Pathania *et al.* (2018) [20]. Besides that, this long duration of the crop would increase spike fertility through improving floret primordial survival as a consequence of extending the late reproductive phase which was also reported earlier by Basavaraddi *et al.* (2021) [4]. Thus, both these factors could be the reasons for more Number of grains per main spike. On the other hand, since the crop is maturing late, it is obvious that it could have more chlorophyll at 75 DAS because the crop would retain its green nature for a long time. Besides, physiological traits such as LAR as well as LWR at 45 and 75 DAS which represents the capacity of dry matter accumulation by the crop, showed high values in late-maturing varieties which implies that crop with relatively long duration could be a high yielding one. This report was contrary to the findings of Mehmet and Telat (2006) [19] and Bhushan *et al.* (2013) [7] who reported that early maturing variety could be the high-yielding one. Specific leaf area represents the relative thickness of leaves. Leaves with high Specific Leaf Area have more chlorophyll per unit area which could contribute to heavy grain weight because of relatively greater photosynthetic efficiency. Besides, productive tillers contributed positively to the biological yield of plant. Next, individual grain weight contributed positively towards grain yield per plant. Hence, it would automatically increase the Harvest index which is nothing but the ratio of grain yield to biological yield. If more is the number of spikelets per main spike observed, it is obvious that we could obtain more grains from it. Surprisingly, this association is unleashing the greater floret fertility of the main spike in bread wheat.

To wrap up, on scrutiny of above-found associations the following were the engrossing findings: taller varieties exhibited longer crop duration. Likely, late-maturing varieties were found to have tall stature and long spikes. Hence, this association could be useful for the breeders in identifying early maturing varieties which perhaps have short stature. It is notable that, genotypes showing high Specific Leaf Area, high Leaf Area Ratio, and high Leaf Weight Ratio are preferable for yield enhancement. Having relatively thicker leaves *i.e.*, with high Specific Leaf Weight is not a needed criterion to consider since plants with thicker leaves had less productive tillers with reduced biological yield and harvest index. Moreover, plants with more no. of productive tillers also displayed greater floret fertility of the main spike. Besides, the main spike was observed with great floret fertility. Taking all the above associations into consideration, one point of view is that, all these associations seem to deserve strategic importance while designing breeding programs to achieve yield enhancement in bread wheat.

Path analysis to unveil true associations

Two characters may demonstrate correlation as they are associated with a common third one. Thus, it is essential to employ a method that considers the true relationship between the variables. In addition to the extent of such relationships, path coefficient analysis estimates the direct effect of one variable upon the other and allows separation of correlation coefficients into components of direct and indirect effects. Partitioning of correlations provides a direct and indirect involvement of characters on dependent attribute and thus forms the basis for upgrading in plant breeding. Direct and indirect effects of various independent variables on the dependent variable (grain yield per plant) were calculated at genotypic and phenotypic levels with the aid of path coefficient analysis to achieve a clear picture of inter-relationships of various components traits with yield.

On scrutinizing the results from path coefficient analysis, there was no significant differences observed between phenotypic and genotypic path coefficient analysis. From that, it was manifesting that the studied characters are more heritable. Besides, as there is no considerable difference, the results from phenotypic path coefficient analysis is discussed below.

The residual effect was found to be very low (0.0932) manifesting that, the characters included in the present study account for 90.68% variation in the yield. Notable is, the magnitude of the residual effect was found very low implying that, majority of the yield attributes have been already included in the present study. Hence, the role of other possible independent variables which are not included in the current study is low. These results were in line with previous studies by Vaghela *et al.* (2021) [30].

High and positive direct effect on grain yield per plant was displayed by Harvest index and (%) and Biological yield per plant. Therefore, both these traits turned out to be the major components effecting grain yield per plant. Hence, direct selection of both these traits leads to an increase in grain yield per plant.

These findings were also reported earlier as follows; Harvest index (%) by Vaghela *et al.* (2021) [30], Kumari and Kumari (2020) [16], Jan *et al*. (2020) [13]; Biological yield per plant by Jan *et al*. (2020) [13], Verma *et al*. (2019) [31].

Besides, a moderate and positive direct effect on grain yield per plant was shown by Days to 50% flowering as reported by Tabassum *et al*. (2018) [28], Sabit *et al.* (2017) [24], Rathwa (2017) [23].

Coming to indirect effects, positive and moderate level of effects was shown by Days to 50% flowering via Biological yield per plant as found by Dwivedi *et al*. (2002) [11], Leaf Weight Ratio at 45 DAS via Biological yield per plant, Number of productive tillers per plant via Biological yield per plant as reported by Dwivedi *et al*. (2002) [11] and 1000 grain weight via Harvest index and (%) as reported by Kiran and Singh (2020) [15]; Elmassry and Shal (2020) [12] Rajput (2018) [22] while rest of all traits showed the negligible level of indirect effects.

On scrutinizing the results the following could be interpreted from the findings of the current study:

1. In case of traits *viz.*, Harvest index and Biological yield per plant correlation coefficients are almost equal to their direct effect. This articulates the true relationship and hence direct selection through this trait will be effective.
2. In case of traits *viz.*, Leaf Area Ratio at 45 DAS, Leaf Weight Ratio at 45 DAS, Leaf Area Ratio at 75 DAS and Number of productive tillers per plant correlation coefficient is having positive and high magnitude while the direct effect is negligible. Hence, indirect effects through Harvest index and Biological yield per plant other seems to be the cause of correlation.
3. The residual effect was found to be very low (0.0932) manifesting that, the characters included in the present study account for 90.68% variation in the yield.

To sum up, path analysis revealed that, Harvest index is an important component of grain yield per plant because of its high and positive direct effect. The magnitude of the direct effect of Biological yield per plant is next to the Harvest index and hence may be regarded as another trait of paramount importance. Although correlation between Grain yield per plant with Leaf Area Ratio at 45 DAS, Leaf Weight Ratio at 45 DAS, Leaf Area Ratio at 75 DAS, and Number of productive tillers per plant is positive and considerably large, the direct effect of these attributes on grain yield per plant is negligible. Henceforth, these two traits can be considered as the most important yield contributing traits, and due emphasis should be placed on these components while breeding for grain yield improvement in bread wheat.

Conclusion

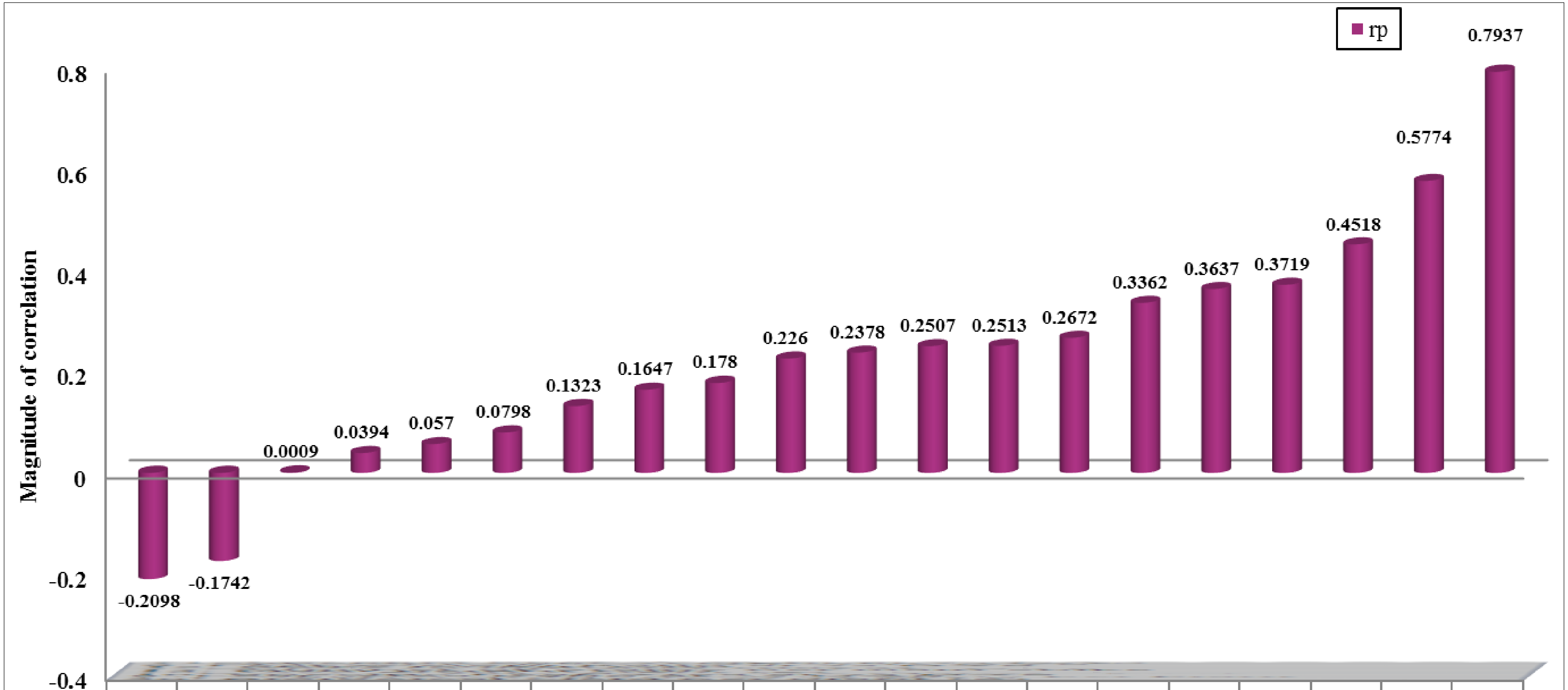
In a nutshell, through the current research investigation, traits *viz.*, Biological yield per plant and Harvest index% were the characters that displayed a true relationship with grain yield displaying positive and significant association along with the great and positive direct effect on it. Hence, these traits deserve strategic importance while formulating effective breeding strategies with the aim of yield enhancement to feed every head in the world of exploding population.

Table 1: Estimates of genotypic (r_g) and phenotypic correlation (r_p) coefficients among 21 characters in bread wheat

Character		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20	21
19	r_g	0.2556	-0.0085	0.1734	0.3840**	0.4712**	0.134	-0.1744	0.3446*	0.0456	0.2722	-0.2158	0.0989	0.2381	0.4044**	0.0557	0.2760	0.1830	0.2671	0.5924**	0.7922**
	r_p	0.2513	0.0009	0.1647	0.3719**	0.4518**	0.1323	-0.1742	0.3362*	0.0394	0.2672	-0.2098	0.0798	0.2260	0.3637**	0.0570	0.2507	0.1780	0.2378	0.5774**	0.7937**
1	r_g		0.1941	0.5517**	0.5408**	0.5400**	0.1968	-0.1457	0.3788**	0.2311	0.2161	-0.3006*	0.8878**	0.4397**	0.3117*	0.3081*	0.2556	0.3012*	-0.4840**	0.2605	0.1199
	r_p		0.1791	0.5131**	0.5144**	0.5122**	0.1801	-0.1407	0.3622**	0.2189	0.2010	-0.2752	0.8182**	0.3976**	0.2531	0.2737	0.2240	0.2852*	-0.4464**	0.2441	0.1237
2	r_g			0.7960**	-0.0278	0.0932	-0.1924	0.2340	0.0234	-0.2375	0.1766	-0.2614	0.1391	0.0738	-0.2294	-0.0303	-0.1572	0.2716	-0.1375	0.0352	0.0026
	r_p			0.7611**	-0.026	0.0909	-0.1873	0.2134	0.0196	-0.2369	0.1752	-0.2484	0.1166	0.0672	-0.2168	-0.021	-0.1488	0.2676	-0.131	0.0392	0.0095
3	r_g				0.1157	0.2375	-0.1492	0.1556	0.1309	-0.2397	0.2289	-0.3604*	0.5080**	0.2169	-0.0512	0.1903	-0.0746	0.4430**	-0.2012	0.2810*	0.0284
	r_p				0.1063	0.2272	-0.1488	0.1524	0.1277	-0.2329	0.2222	-0.3450*	0.4259**	0.2144	-0.0457	0.1635	-0.0696	0.4299**	-0.1619	0.2642	0.0275
4	r_g					0.8879**	0.7099**	-0.6674**	0.4031**	0.3170*	0.1574	-0.1768	0.2380	0.2808*	0.4862**	0.0163	0.0998	-0.0095	-0.2400	0.2868*	0.2408
	r_p					0.8832**	0.6931**	-0.6506**	0.3962**	0.3075*	0.1550	-0.171	0.2225	0.2741	0.4600**	0.0212	0.0903	-0.0067	-0.2275	0.2837*	0.2273
5	r_g						0.3508*	-0.3486*	0.5331**	0.2737	0.3317*	-0.2751	0.2851*	0.2842*	0.4667**	-0.0198	0.0483	0.012	-0.1954	0.4337**	0.2533
	r_p						0.3196*	-0.3156*	0.5234**	0.2658	0.3255*	-0.2674	0.263	0.2780	0.4331**	-0.017	0.0515	0.0138	-0.1817	0.4278**	0.2343
6	r_g							-0.9647**	0.0363	0.1924	-0.1284	0.0455	-0.0688	0.1085	0.3917**	0.0573	0.1381	-0.0878	-0.1873	0.0607	0.0894
	r_p							-0.9676**	0.0331	0.1847	-0.1259	0.0511	-0.0593	0.0975	0.3652**	0.0605	0.1215	-0.0825	-0.1764	0.0562	0.0900
7	r_g								-0.0278	-0.1488	0.1183	-0.0427	0.1235	-0.101	-0.3912**	-0.0125	-0.1745	0.1323	0.1343	-0.1021	-0.0981
	r_p								-0.0271	-0.1478	0.1159	-0.0457	0.0973	-0.0992	-0.3691**	-0.0265	-0.1540	0.1221	0.1181	-0.1009	-0.0999
8	r_g									0.3305*	0.7328**	-0.6567**	0.1700	-0.1261	0.2681	-0.0742	0.1767	0.2990*	-0.2843*	0.2563	0.2591
	r_p									0.3361*	0.7221**	-0.6484**	0.1453	-0.117	0.2396	-0.072	0.1704	0.2926*	-0.265	0.2573	0.2457
9	r_g										-0.3286*	0.3601*	0.1115	0.0004	-0.0154	-0.2181	0.2644	-0.0318	-0.0831	-0.1908	0.2099
	r_p										-0.3338*	0.3636**	0.0953	0.0087	-0.0108	-0.1947	0.2461	-0.0236	-0.0670	-0.1737	0.1854
10	r_g											-0.8162**	0.0578	-0.0596	0.2661	0.0495	-0.0334	0.2344	-0.2476	0.3401*	0.1092
	r_p											-0.8105**	0.0551	-0.0618	0.2384	0.0482	-0.0262	0.2220	-0.2370	0.3314*	0.1098
11	r_g												-0.2309	0.1397	-0.2321	-0.2600	-0.0367	-0.3776**	0.3328*	-0.2780	-0.0829
	r_p												-0.188	0.1432	-0.2021	-0.2298	-0.0319	-0.3609*	0.3211*	-0.2687	-0.0798
12	r_g													0.4424**	-0.0077	0.4077**	0.0890	0.2315	-0.5112**	0.1556	0.0151
	r_p													0.3682**	0.0071	0.3465*	0.0653	0.2071	-0.4430**	0.1414	0.005
13	r_g														-0.1256	0.2347	-0.0125	-0.1859	-0.0856	0.0962	0.1542
	r_p														-0.0909	0.2027	-0.0194	-0.1848	-0.0789	0.0956	0.1416
14	r_g															0.1257	0.4667**	0.0245	-0.0654	0.5383**	0.0689
	r_p															0.1187	0.4023**	0.0436	-0.0604	0.4978**	0.0530
15	r_g																0.2063	0.2104	-0.2589	-0.0175	0.0721
	r_p																0.1952	0.1968	-0.2402	-0.0282	0.0811
16	r_g																	0.3413*	-0.0575	0.2018	0.1510
	r_p																	0.3342*	-0.0582	0.1972	0.1290
17	r_g																		-0.0821	0.0430	0.2212
	r_p																		-0.0801	0.0468	0.2085
18	r_g																			-0.1146	0.4064**
	r_p																			-0.1116	0.3630**
20	r_g																				-0.0041
	r_p																				-0.0196

1. Days to 50% flowering 2. Chlorophyll content at 45 DAS 3. Chlorophyll content at 75 DAS 4. Leaf Area Ratio at 45 DAS 5. Leaf Weight Ratio at 45 DAS
6. Specific Leaf Area at 45 DAS 7. Specific Leaf Weight at 45 DAS 8. Leaf Area Ratio at 75 DAS 9. Leaf Weight Ratio at 75 DAS 10. Specific Leaf Area at 75 DAS
11. Specific Leaf Weight at 75 DAS 12. Days to maturity 13. Plant height 14. No. of productive tillers per plant 15. Spike length

16. No. of spikelets per main spike 17. No. of grains per main spike 18. 1000 Grain weight 19. Grain yield per plant 20. Biological yield per plant
21. Harvest index (%)



	11. Specific Leaf Weight at 75 DAS	7. Specific Leaf Weight at 45 DAS	2. Chlorophyll content at 45 DAS	9. Leaf Weight Ratio at 75 DAS	15. Spike length (cm)	12. Days to maturity (days)	6. Specific Leaf Area at 45 DAS	3. Chlorophyll content at 75 DAS	17. Number of grains per main spike	13. Plant height (cm)	18. 1000 grain weight (g)	16. Number of spikelets per main spike)	1. Days to 50% flowering (days)	10. Specific Leaf Area at 75 DAS	8. Leaf Area Ratio at 75 DAS	14. Number of productive tillers per plant	4. Leaf Area Ratio at 45 DAS	5. Leaf Weight Ratio at 45 DAS	20. Biological yield per plant (g)	21. Harvest index (%)
rp	-0.2098	-0.1742	0.0009	0.0394	0.057	0.0798	0.1323	0.1647	0.178	0.226	0.2378	0.2507	0.2513	0.2672	0.3362	0.3637	0.3719	0.4518	0.5774	0.7937

Fig 1: Graphical depiction of strength as well as nature of association (phenotypic correlation) between grain yield and its contributing traits in bread wheat (increasing order)

Table 2: Phenotypic path coefficient analysis showing direct (diagonal and bold) and indirect effects (off-diagonal) of different characters on grain yield per plant in 50 genotypes of bread wheat

Characters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20	21	r_p Values
1. Days to 50% flowering	0.0253	-0.0019	-0.0065	0.0522	-0.0415	-0.0286	0.0155	0.0641	-0.0311	-0.0302	-0.0097	-0.0394	0.0327	0.0101	-0.0008	0.0044	-0.0005	0.0033	0.1362	0.0978	0.2513
2. Chlorophyll content at 45 DAS	0.0045	-0.0110	-0.0097	-0.0026	-0.0074	0.0297	-0.0234	0.0035	0.0336	-0.0263	-0.0088	-0.0056	0.0055	-0.0086	0.0001	-0.0029	-0.0005	0.0010	0.0219	0.0075	0.0009
3. Chlorophyll content at 75 DAS	0.0130	-0.008	-0.0127	0.0108	-0.0184	0.0236	-0.0167	0.0226	0.0330	-0.0334	-0.0122	-0.0205	0.0177	-0.0018	-0.0005	-0.0014	-0.0008	0.0012	0.1474	0.0218	0.1647
4. LAR at 45 DAS	0.0130	0.0003	-0.0013	0.1014	-0.0715	-0.1100	0.0715	0.0701	-0.0436	-0.0233	-0.006	-0.0107	0.0226	0.0183	-0.0001	0.0018	0.0000	0.0017	0.1583	0.1797	0.3719**
5. LWR at 45 DAS	0.0130	-0.0010	-0.0029	0.0896	-0.0810	-0.0507	0.0347	0.0926	-0.0377	-0.0490	-0.0094	-0.0127	0.0229	0.0172	0.0000	0.0010	0.0000	0.0013	0.2386	0.1852	0.4518**
6. SLA at 45 DAS	0.0046	0.002	0.0019	0.0703	-0.0259	-0.1587	0.1063	0.0059	-0.0262	0.0189	0.0018	0.0029	0.0080	0.0145	-0.0002	0.0024	0.0002	0.0013	0.0313	0.0711	0.1323
7. SLW at at 45 DAS	-0.0036	-0.0022	-0.0019	-0.0660	0.0256	0.1536	-0.1099	-0.0048	0.021	-0.0174	-0.0016	-0.0047	-0.0082	-0.0147	0.0001	-0.0030	-0.0002	-0.0009	-0.0563	-0.0790	-0.1742
8. LAR at 75 DAS	0.0092	-0.0002	-0.0016	0.0402	-0.0424	-0.0053	0.0030	0.1769	-0.0477	-0.1086	-0.0228	-0.007	-0.0096	0.0095	0.0002	0.0033	-0.0005	0.002	0.1435	0.1942	0.3362*
9. LWR at 75 DAS	0.0055	0.0025	0.0030	0.0312	-0.0215	-0.0293	0.0162	0.0594	-0.1419	0.0502	0.0128	-0.0046	0.0007	-0.0004	0.0005	0.0048	0.000	0.0005	-0.0969	0.1466	0.0394
10. SLA at 75 DAS	0.0051	-0.0018	-0.0028	0.0157	-0.0264	0.0200	-0.0127	0.1277	0.0474	-0.1504	-0.0286	-0.0026	-0.0051	0.0095	-0.0001	-0.0005	-0.0004	0.0018	0.1848	0.0868	0.2672
11. SLW at 75 DAS	-0.0070	0.0026	0.0044	-0.0173	0.0217	-0.0081	0.005	-0.1147	-0.0516	0.1219	0.0352	0.0090	0.0118	-0.0080	0.0006	-0.0006	0.0007	-0.0024	-0.1499	-0.0631	-0.2098
12. Days to maturity	0.0207	-0.0012	-0.0054	0.0226	-0.0213	0.0094	-0.0107	0.0257	-0.0135	-0.0083	-0.0066	-0.0481	0.0303	0.0003	-0.0010	0.0013	-0.0004	0.0033	0.0789	0.0039	0.0798
13. Plant height	0.0101	-0.0007	-0.0027	0.0278	-0.0225	-0.0155	0.0109	-0.0207	-0.0012	0.0093	0.0050	-0.0177	0.0823	-0.0036	-0.0006	-0.0004	0.0003	0.0006	0.0533	0.1119	0.2260
14. No. of productive tillers per plant	0.0064	0.0023	0.0006	0.0467	-0.0351	-0.0580	0.0406	0.0424	0.0015	-0.0359	-0.0071	-0.0003	-0.0075	0.0397	-0.0003	0.0078	-0.0001	0.0004	0.2776	0.0419	0.3637**
15. Spike length	0.0069	0.0002	-0.0021	0.0022	0.0014	-0.0096	0.0029	-0.0127	0.0276	-0.0073	-0.0081	-0.0167	0.0167	0.0047	-0.0028	0.0038	-0.0004	0.0018	-0.0157	0.0641	0.0570
16. No. of spikelets per main spike	0.0057	0.0016	0.0009	0.0092	-0.0042	-0.0193	0.0169	0.0301	-0.0349	0.0039	-0.0011	-0.0031	-0.0016	0.0160	-0.0005	0.0195	-0.0006	0.0004	0.1100	0.1020	0.2507
17. No. of grains per main spike	0.0072	-0.0028	-0.0055	-0.0007	-0.0011	0.0131	-0.0134	0.0517	0.0033	-0.0334	-0.0127	-0.0100	-0.0152	0.0017	-0.0005	0.0065	-0.0019	0.0006	0.0261	0.1648	0.1780
18. 1000 grain weight	-0.0113	0.0014	0.0021	-0.0231	0.0147	0.0280	-0.0130	-0.0469	0.0095	0.0356	0.0113	0.0213	-0.0065	-0.0024	0.0007	-0.0011	0.0001	-0.0074	-0.0623	0.2870	0.2378
20. Biological yield per plant	0.0062	-0.0004	-0.0034	0.0288	-0.0346	-0.0089	0.0111	0.0455	0.0247	-0.0498	-0.0095	-0.0068	0.0079	0.0198	0.0001	0.0038	-0.0001	0.0008	0.5578	-0.0155	0.5774**
21. Harvest index (%)	0.0031	-0.0001	-0.0003	0.0231	-0.0190	-0.0143	0.0110	0.0434	-0.0263	-0.0165	-0.0028	-0.0002	0.0117	0.0021	-0.0002	0.0025	-0.0004	-0.0027	-0.0109	0.7906	0.7937**

*, ** represents significance of values at 5% and 1% levels respectively. Residual effect = 0.0932

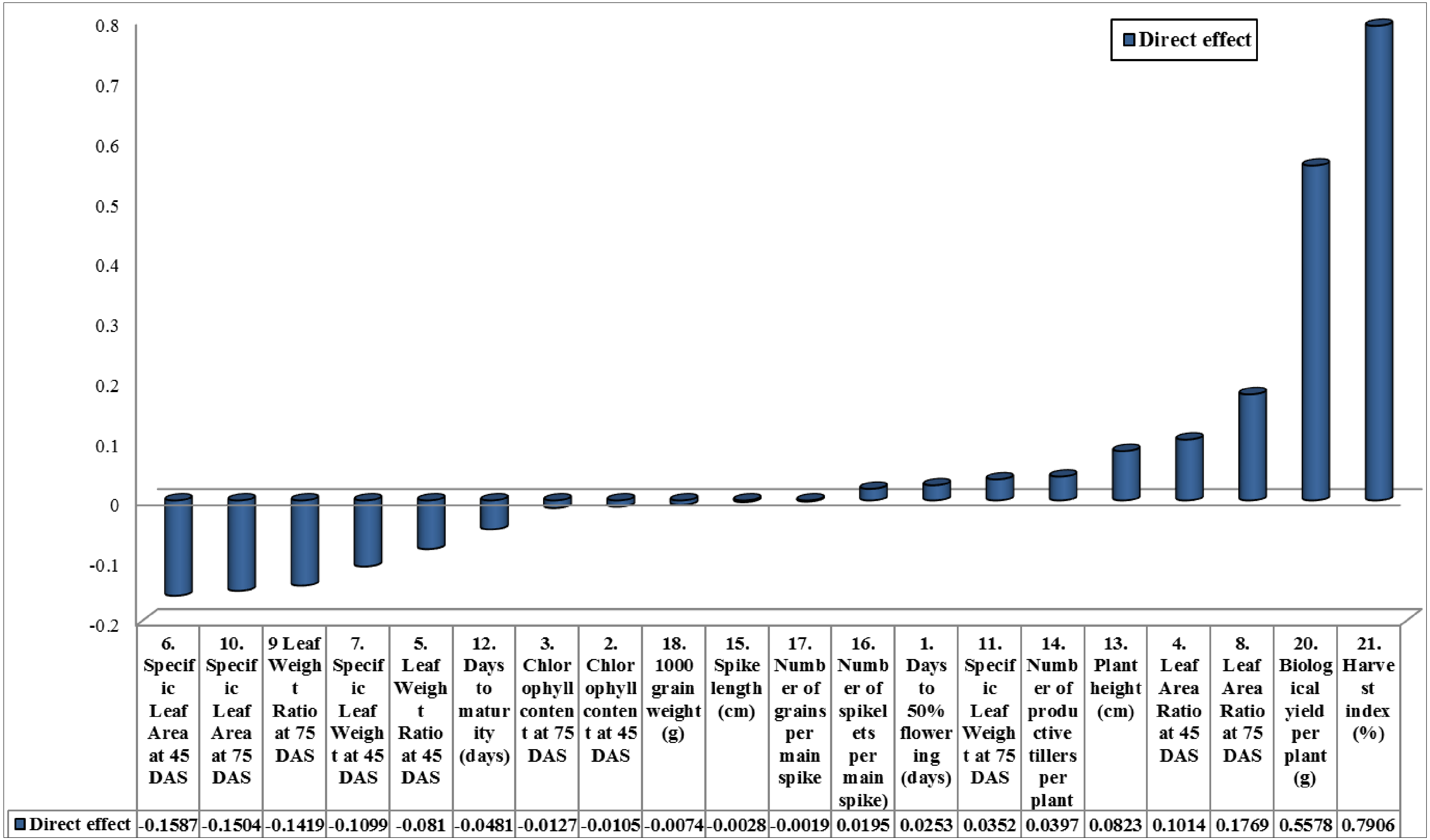


Fig 2: Graphical representation showing nature and magnitude of direct effects (phenotypic path coefficient analysis) by various yield contributing traits on grain yield in bread wheat by (ascending order)

Table 3: Genotypic path coefficient analysis showing direct (diagonal and bold) and indirect effects (off-diagonal) of different characters on grain yield per plant in 50 genotypes of bread wheat

Characters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20	21	r_g Values
1. Days to 50% flowering	0.0324	-0.0058	0.0068	0.0549	-0.0481	-0.0339	0.0135	0.0905	-0.0410	-0.0491	-0.0087	-0.0884	0.0535	0.0233	-0.0040	0.0025	0.0011	0.0201	0.1412	0.0948	0.2556
2. Chlorophyll content at 45 DAS	0.0063	-0.0297	0.0099	-0.0028	-0.0083	0.0332	-0.0217	0.0056	0.0421	-0.0402	-0.0076	-0.0138	0.0090	-0.0171	0.0004	-0.0015	0.0010	0.0057	0.0191	0.0021	-0.0085
3. Chlorophyll content at 75 DAS	0.0179	-0.0237	0.0124	0.0117	-0.0212	0.0257	-0.0144	0.0313	0.0425	-0.0521	-0.0105	-0.0506	0.0264	-0.0038	-0.0024	-0.0007	0.0017	0.0084	0.1523	0.0224	0.1734
4. LAR at 45 DAS	0.0175	0.0008	0.0014	0.1016	-0.0791	-0.1224	0.0618	0.0963	-0.0563	-0.0358	-0.0051	-0.0237	0.0342	0.0363	-0.0002	0.0010	0.0000	0.0100	0.1554	0.1903	0.3840**
5. LWR at 45 DAS	0.0175	-0.0028	0.0029	0.0902	-0.0891	-0.0605	0.0323	0.1274	-0.0486	-0.0754	-0.0080	-0.0284	0.0346	0.0348	0.0003	0.0005	0.0000	0.0081	0.2351	0.2002	0.4712**
6. SLA at 45 DAS	0.0064	0.0057	-0.0018	0.0721	-0.0313	-0.1725	0.0894	0.0087	-0.0342	0.0292	0.0013	0.0069	0.0132	0.0292	-0.0007	0.0013	-0.0003	0.0078	0.0329	0.0707	0.1340
7. SLW at 45 DAS	-0.0047	-0.0070	0.0019	-0.0678	0.0311	0.1664	-0.0927	-0.0067	0.0264	-0.0269	-0.0012	-0.0123	-0.0123	-0.0292	0.0002	-0.0017	0.0005	-0.0056	-0.0553	-0.0775	-0.1744
8. LAR at 75 DAS	0.0123	-0.0007	0.0016	0.0409	-0.0475	-0.0063	0.0026	0.2389	-0.0587	-0.1666	-0.0190	-0.0169	-0.0154	0.0200	0.0010	0.0017	0.0011	0.0118	0.1389	0.2048	0.3446*
9. LWR at 75 DAS	0.0075	0.0071	-0.0030	0.0322	-0.0244	-0.0332	0.0138	0.0790	-0.1775	0.0747	0.0104	-0.0111	0.0001	-0.0011	0.0028	0.0026	-0.0001	0.0035	-0.1034	0.1659	0.0456
10. SLA at 75 DAS	0.0070	-0.0052	0.0028	0.0160	-0.0296	0.0221	-0.0110	0.1751	0.0583	-0.2274	-0.0237	-0.0058	-0.0073	0.0199	-0.0006	-0.0003	0.0009	0.0103	0.1844	0.0863	0.2722
11. SLW at 75 DAS	-0.0098	0.0078	-0.0045	-0.0180	0.0245	-0.0078	0.0040	-0.1569	-0.0639	0.1856	0.0290	0.0230	0.0170	-0.0173	0.0033	-0.0004	-0.0014	-0.0138	-0.1507	-0.0655	-0.2158
12. Days to maturity	0.0288	-0.0041	0.0063	0.0242	-0.0254	0.0119	-0.0114	0.0406	-0.0198	-0.0131	-0.0067	-0.0995	0.0539	-0.0006	-0.0052	0.0009	0.0009	0.0212	0.0843	0.0119	0.0989
13. Plant height	0.0143	-0.0022	0.0027	0.0285	-0.0253	-0.0187	0.0094	-0.0301	-0.0001	0.0136	0.0041	-0.0440	0.1218	-0.0094	-0.0030	-0.0001	-0.0007	0.0036	0.0521	0.1219	0.2381
14. No. of productive tillers per plant	0.0101	0.0068	-0.0006	0.0494	-0.0416	-0.0676	0.0362	0.0641	0.0027	-0.0605	-0.0067	0.0008	-0.0153	0.0746	-0.0016	0.0046	0.0001	0.0027	0.2918	0.0544	0.4044**
15. Spike length	0.0100	0.0009	0.0024	0.0017	0.0018	-0.0099	0.0012	-0.0177	0.0387	-0.0113	-0.0075	-0.0406	0.0286	0.0094	-0.0129	0.0020	0.0008	0.0108	-0.0095	0.0570	0.0557
16. No. of spikelets per main spike	0.0083	0.0047	-0.0009	0.0101	-0.0043	-0.0238	0.0162	0.0422	-0.0469	0.0076	-0.0011	-0.0089	-0.0015	0.0348	-0.0027	0.0098	0.0013	0.0024	0.1094	0.1193	0.2760
17. No. of grains per main spike	0.0098	-0.0081	0.0055	-0.001	-0.0011	0.0151	-0.0123	0.0714	0.0056	-0.0533	-0.011	-0.023	-0.0226	0.0018	-0.0027	0.0033	0.0038	0.0034	0.0233	0.1748	0.1830
18. 1000 grain weight	-0.0157	0.0041	-0.0025	-0.0244	0.0174	0.0323	-0.0124	-0.0679	0.0148	0.0563	0.0097	0.0509	-0.0104	-0.0049	0.0033	-0.0006	-0.0003	-0.0415	-0.0621	0.3212	0.2671
20. Biological yield per plant	0.0085	-0.001	0.0035	0.0291	-0.0387	-0.0105	0.0095	0.0612	0.0339	-0.0773	-0.0081	-0.0155	0.0117	0.0402	0.0002	0.0020	0.0002	0.0048	0.5420	-0.0033	0.5924**
21. Harvest index (%)	0.0039	-0.0001	0.0004	0.0245	-0.0226	-0.0154	0.0091	0.0619	-0.0373	-0.0248	-0.0024	-0.0015	0.0188	0.0051	-0.0009	0.0015	0.0008	-0.0169	-0.0022	0.7904	0.7922**

*, ** represents significance of values at 5% and 1% levels respectively. Residual effect = 0.0710

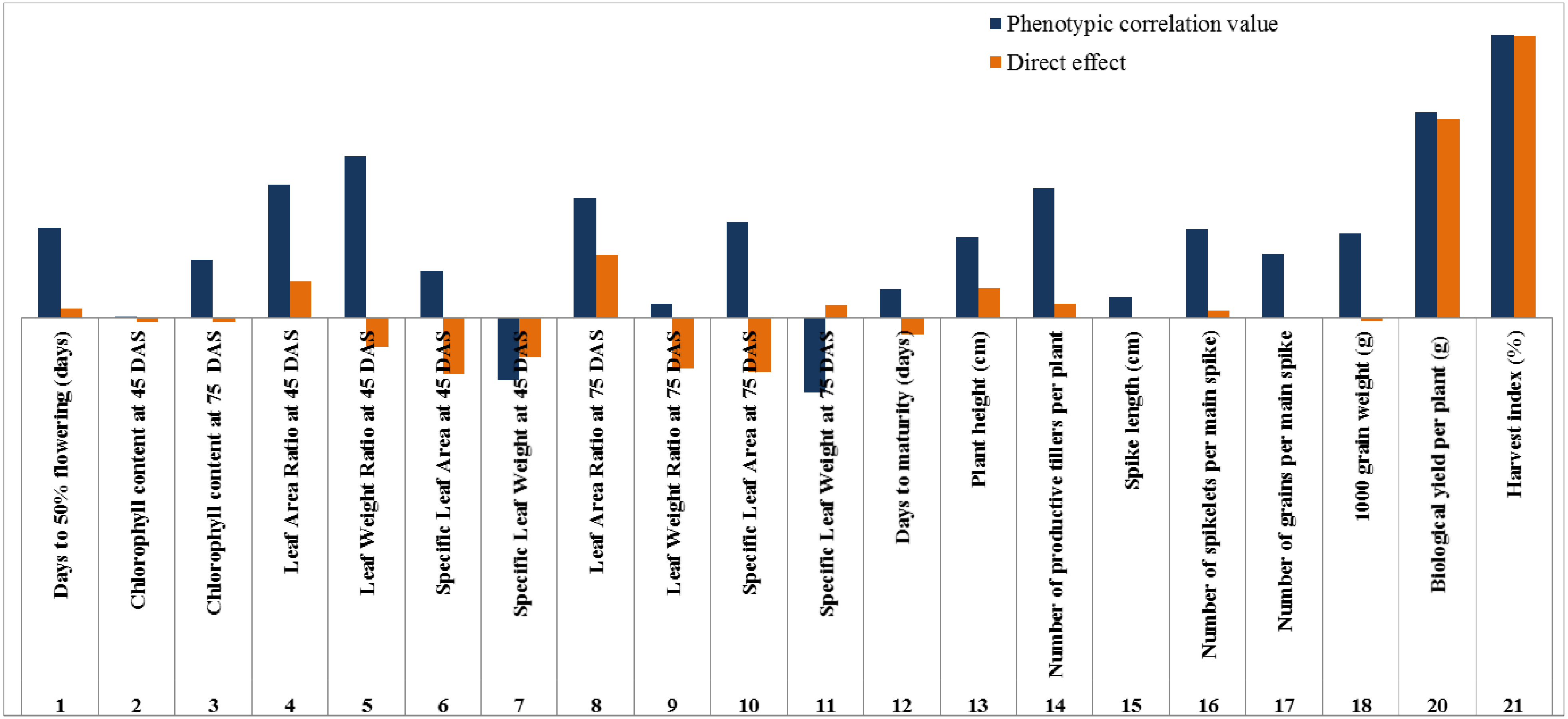


Fig 3: Graphical representation showing strength and nature of association (Phenotypic correlation) in comparison to magnitude of direct effects (from phenotypic path coefficient analysis) displayed by 21 quantitative traits among 50 bread wheat genotypes.

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