Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2018; 7(4): 2265-2269
Received: 19-05-2018
Accepted: 23-06-2018

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Study of indirect selection parameter in bread wheat (*Triticum aestivum* L.)

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Abstract
The present experiment on bread wheat (*Triticum aestivum* L.) was carried out with 17 parents and 52 F_1's developed from line x tester mating design to find out the genetic association among various important economic characters for the purpose of genetic enhancement in the grain yield of wheat. The parental lines (13 lines and 4 testers) were grown during *rabi*, 2015-2016 and 52 cross combinations among lines and testers were made and the seeds of parental lines and 52 crosses were procured. The experiment was conducted at Crop Research Center (Chirodi Block) of Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut (U.P.) under timely sown conditions during *rabi*, 2016-17. Estimation of correlation coefficient at phenotypic level, grain yield per plant exhibited highly significant and positive association with harvest index, biological yield per plant, grain per spike, days to 50 % flowering, spikelets per spike, spike length, gluten content and productive tillers per plant indicated that by improving these traits could made improvement in yield. Genotypic and phenotypic path coefficient revealed that harvest index and biological yield per plant had high (0.30 to 1.00) direct effect on grain yield. Therefore, direct selection for these two traits would be effective for further yield improvement in wheat genotypes.

Keywords: correlation coefficient, path analysis and bread wheat

Introduction
Wheat belongs to the family poecea and comes under *Triticum* genera. Among cultivable species hexaploid wheat (*Triticum aestivum* L., 2n=42) is the most common wheat and occupies more than 90% of the total area under wheat cultivation. Other cultivable species are *Triticum durum* (tetraploid 2n=28) and *Triticum dicoccum* (Tetraploid, 2n=28). Out of these species *Triticum dicoccum* is under least cultivation in peninsular zone of India. *Triticum durum* is a macaroni and related product wheat, which is specially cultivated for macaroni purpose. The most popular and common wheat is *Triticum aestivum* (hexaploid) which is under cultivation worldwide and is a major staple food for every sector of the society in the world. Wheat has three genetically related genomes A, B and D. Early cytogenetic studies suggested that the A genome of the tetraploids in both evolutionary lineages (*T. turgidum* and *T. timopheevi*) were contributed by *T. monococcum. Aegilops speltoides* is considered as the most probable B genome donor to bread wheat and *durum* wheat (Breiman and Graur, 1985; Feldman, 2001; Li *et al*., 2004; Moore *et al*., 1995; Pestsova *et al*., 2000) [3, 5, 9, 10, 12]. In India, wheat is grown on an area of 30.23 m ha with a production of 95.90 million tons and productivity of 3144 kg /ha. In Uttar Pradesh, wheat is grown on an area of 9.65 m ha with a production of 26.87 million tonnes and productivity of 2785 kg /ha (Agriculture statistics at a glance 2016). Total production of wheat in the world is around 751.99 m tonnes covering an area of about 222.16 m ha and productivity of 3.38 mt/ha. (USDA report, 2017) [19]. Yield is a complex character, which is highly influenced by the environment, hence direct selection for yield alone limit the selection efficiency and ultimately results in limited success in yield improvement. Thus, effective improvement in yield may be brought about through selection of yield component characters. Yield component characters show association among themselves and also with yield. Correlation is the measure of mutual relationship between two variables and measures the degree of closeness and the linear relationship between them. Path coefficient analysis is a partial regression technique which separates the direct effects from the indirect effects through other related characters by partitioning the correlation coefficient into direct and indirect effects on yield. It is most efficient method to establish relationships among the variables that affect grain yield as it allows determination of the relative magnitude of each effect. And such information is used to sustain the high yield levels of wheat for further projections (Sharma *et al*. 2018) [15].

Therefore, the objective of this study was to assess the association among yield and yield contributing traits and identify traits those have the most direct and indirect effects on grain yield.

Materials and Methods

The experimental materials for the present investigation consisted of 17 diverse genotypes/varieties of wheat viz., K-607, K-9434, MP-4010, HD-2864, HUW-658, K-6525, HD-3076, HD-3095, K-9107, K-802, UP-2523, RAJ-4246, PBW-984, K-9267, K-9423, PBW-533 and DBW-71and their 52 hybrids. The observations were recorded on various quantitative characters *viz.* days to 50 % flowering, days to maturity, plant height (cm), spike length (cm), spikelets per spike, productive tillers per plant, grains per spike, flag leaf area (cm^2), biological yield per plant (g), grain yield per plant (g), harvest index (%), test weight (g), gluten content (%), ash content (%) and phenol colour reaction (grading). Five randomly selected competitive plants in each row of each replication for all the characters were recorded under study except of days to 50% flowering and days to maturity which were recorded on plot basis. Analysis of variance to test the significance for each character was carried out as per methodology given by Panse and Sukhatme (1967) [11]. Correlation coefficient and path coefficient was worked out as method suggested by Al-Jibouri *et al.* (1958) [2] and Dewey and Lu (1959) [4].

Results and Discussion

The analysis of variance (table-1) revealed that the treatments were highly significant for all the characters except ash content is significant. Correlation coefficient analysis measure at phenotypic level (table-2), grain yield per plant exhibited highly significant and positive correlation with harvest index (0.8045), biological yield per plant (0.6451), grain per spike (0.4100), days to 50 % flowering (0.3775), spikelets per spike (0.3058) and spike length (0.2318), while with gluten content (0.1683) and productive tillers per plant (0.1463) revealed positive significant and plant height (-0.1480) expressed negatively significant.

At genotypic level (table-3), grain yield per plant showed high and positive correlation values with harvest index (0.8087), biological yield per plant (0.6698), grain per spike (0.4547), days to 50 % flowering (0.4963), spikelets per spike (0.3961), spike length (0.3976), gluten content (0.2397), productive tillers per plant (0.2631), ash content (0.3296) and expressed negatively significant with plant height (-0.1494). Thus, it can be inferred that by improving any one of these characters either alone or in combination will result in improving of yield in wheat. These results are in general agreement with the finding of Singh *et al*. (2012) [16], Kumar *et al.* (2014) [7], Singh *et al.* (2015) [17], Wahidy *et al*. (2016) [20], Kumar *et al.* (2016) [8], Sabit *et al.* (2017) [14], Imran *et al*. (2017) [16], Rajput (2018) [13] and Sharma *et al.* (2018) [15]. Selection for these traits could definitely be yielded towards productivity as they appeared correlated response with grain yield per plant. The genotypic correlation values were also in general higher than the phenotypic correlation values indicating the masking effects of environment on these characters.

The above inter-association amongst the attribute indicated that harvest index had positive significant correlation with grain yield per plant and hence direct selection for such trait will be effective in improving the grain yield. The strong positive association among the traits indicated that simultaneous selection for these characters would result in improvement of high yielding varieties.

A character contributing to grain yield may contribute directly or indirectly. The estimates of direct and indirect effect are presented in table-.4 at phenotypic level. In the present investigation, maximum positive direct effect was revealed for harvest index (0.7670) displayed high order of direct effect on grain yield per plant followed by biological yield per plant (0.6022), test weight (0.0286), flag leaf area (0.0208), productive tillers per plant (0.0119) and ash content (0.0099). However, direct effect of gluten content (-0.0221) followed by grains per spike (-0.0188), days to maturity (-0.0110), spikelets per spike (-0.0109), days to 50 % flowering (-0.0095), spike length (-0.0090) and plant height (-0.0030) on grain yield was negative. Days to 50% flowering having high order of indirect effect on grain yield per plant via harvest index (0.2863) and biological yield per plant (0.1074); days to maturity via biological yield per plant (0.0938); plant height via biological yield per plant (0.0135); flag leaf area via harvest index (0.1322); productive tillers per plant via biological yield per plant (0.1694); spike length via harvest index (0.1830) and biological yield per plant (0.0708); spikelets per spike via harvest index (0.1779) and biological yield per plant (0.1440); grains per spike via harvest index (0.2403) and biological yield per plant (0.1927); biological yield per plant via harvest index (0.0616); harvest index via biological yield per plant (0.0484); test weight via harvest index (0.0372); gluten content via biological yield per plant (0.0801) and harvest index (0.1047); ash content via biological yield per plant (0.0523) and harvest index (0.0618).

A close examination of table-5 revealed that at genotypic level, harvest index (0.7652) displayed high order of direct effect on grain yield per plant followed by biological yield per plant (0.05727), productive tillers per plant (0.0650), test weight (0.0378), days to 50 % flowering (0.0373), flag leaf area (0.0288), grains per spike (0.0226), plant height (0.0171) and days to maturity (0.0149). However, direct effect of spike length (-0.0659) followed by gluten content (-0.0412), spikelets per spike (-0.0309) and ash content (-0.0070) on grain yield was negative. Days to 50% flowering having high order of indirect effect on grain yield per plant via harvest index (0.3832) and biological yield per plant (0.1257); days to maturity via biological yield per plant (0.1091); plant height via biological yield per plant (0.0140); flag leaf area via harvest index (0.1603); productive tillers per plant via biological yield per plant (0.2793); spike length via days to 50 % flowering (0.0140), grains per spike (0.0136), harvest index (0.3211) and biological yield per plant (0.1066); spikelets per spike via days to 50 % flowering (0.0114), harvest index (0.2467) and biological yield per plant (0.1657); grains per spike via harvest index (0.2736) and biological yield per plant (0.2043); biological yield per plant via productive tillers per plant (0.0317) and harvest index (0.0861); harvest index via days to 50 % flowering (0.0187) and biological yield per plant (0.0645); test weight via harvest index (0.0445); gluten content via flag leaf area (0.0105), productive tillers plant (0.0149), biological yield per plant (0.0910) and harvest index (0.1629); ash content via days to 50 % flowering (0.0171), biological yield per plant (0.1377) and harvest index (0.1668). The direct and indirect effect of remaining characters was much low to be considered for any consequences.

Table 1: Analysis of variance for different characters in bread wheat (*Triticum aestivum* L.)

Source of variation	DF	Days to 50% Flowering	Days to maturity	Plant height (cm)	Flag Leaf Area (cm²)	Productive Tillers/ Plant	Spike Length (cm)	Spikelets/ Spike	Grains/ Spike	Biological Yield/ Plant (gm)	Grain Yield/Plant (gm)	Harvest Index (%)	1000-grain weight (gm)	Gluten Content (%)	Ash Content (%)
Replication	2	1.057	1.454	0.536	0.994	1.026	0.281	1.298	0.299	1.538	0.423	3.158	1.265	0.054	0.040
Treatments	68	9.349**	11.038**	496.615**	20.330**	0.786**	0.474**	3.012**	36.521**	93.698**	63.914**	85.636**	18.359**	0.466**	0.038*
Error	136	1.665	1.262	1.409	1.933	0.315	0.222	0.503	1.724	1.467	1.255	3.200	0.839	0.090	0.025
Total	206	12.071	13.754	51.606	23.257	2.127	0.977	4.813	38.544	96.703	65.592	91.994	20.463	0.61	0.103

*,** Significant at 5% and 1% probability level respectively

Table 2: Estimates of phenotypic correlation coefficients among different characters in bread wheat (*Triticum aestivum* L.)

Character	Days to 50% Flowering	Days to Maturity	Plant Height (cm)	Flag Leaf Area (cm²)	Productive Tillers/ Plant	Spike Length (cm)	Spikelets/ Spike	Grains/ Spike	Biological Yield/ Plant (gm)	Harvest Index (%)	1000-grain weight (gm)	Gluten Content (%)	Ash Content (%)	Correlation with Grain Yield / Plant
Days to 50% Flowering	1.0000	0.0994	-0.1956**	-0.0737	0.0351	0.1897**	0.1790**	0.0790	0.1784*	0.3733**	-0.0618	-0.0022	0.1841**	0.3775**
Days to Maturity		1.0000	0.3359**	0.0637	-0.0111	0.2103**	0.1746*	0.1820**	0.1558*	0.0418	0.0911	0.1935**	0.1200	0.0423
Plant Height (cm)			1.0000	0.0164	-0.0341	0.0462	0.0057	-0.0820	0.0225	-0.2033**	- 0.2170**	-0.1525*	0.1047	-0.1480*
Flag Leaf Area (cm²)				1.0000	-0.0315	-0.0203	0.1909**	0.1908**	0.2072**	0.1724*	0.0842	0.2788**	0.0253	0.0188
Productive Tillers/ Plant					1.0000	0.0941	0.0352	-0.0189	0.2813**	-0.0418	-0.0080	0.0848	0.0729	0.1463*
Spike Length (cm)						1.0000	0.1290	0.2969**	0.1175	0.2386**	-0.0119	0.1065	0.0291	0.2318**
Spikelets/ Spike							1.0000	0.2675**	0.2392**	0.2320**	0.0382	0.1045	0.1375*	0.3058**
Grains/ Spike								1.0000	0.3199**	0.3133**	0.0984	0.1556*	0.0910	0.4100**
Biological Yield/ Plant (gm)									1.0000	0.0804	-0.0867	0.1330	0.0869	0.6451**
Harvest Index (%)										1.0000	0.0485	0.1365*	0.0806	0.8045**
1000-grain weight (gm)											1.0000	0.2130**	-0.1085	0.0075
Gluten Content (%)												1.0000	-0.0613	0.1683*
Ash Content (%)													1.0000	0.1168
Grain Yield /Plant														1.0000

*,** Significant at 5% and 1% probability level respectively

Table 3: Estimates of genotypic correlation coefficients among different characters in bread wheat (*Triticum aestivum* L.)

Character	Days to 50% Flowering	Days to Maturity	Plant Height (cm)	Flag Leaf Area (cm²)	Productive Tillers/ Plant	Spike Length (cm)	Spikelets/ Spike	Grains/ Spike	Biological Yield/ Plant (gm)	Harvest Index (%)	1000- grain weight (gm)	Gluten Content (%)	Ash Content (%)	Correlation with Grain Yield / Plant
Days to 50% Flowering	1.0000	0.0724	-0.2540	-0.0946	-0.0890	0.3752	0.3053	0.1070	0.2194	0.5007	-0.0681	0.0112	0.4580	0.4963
Days to Maturity		1.0000	0.3971	0.0507	0.0431	0.4907	0.2598	0.2183	0.1906	-0.0515	0.0782	0.2731	0.4980	0.0511
Plant Height (cm)			1.0000	0.0240	-0.0597	0.0852	0.0113	-0.0922	0.0245	-0.2129	-0.2352	-0.1976	0.2957	-0.1494
Flag Leaf Area (cm²)				1.0000	-0.1191	0.0759	0.2792	0.2592	-0.2368	0.2095	0.0765	0.3654	0.1633	0.0224
Productive Tillers/ Plant					1.0000	0.1733	0.1246	-0.0049	0.4877	-0.0554	-0.1074	0.2298	0.3992	0.2631
Spike Length (cm)						1.0000	0.2283	0.5989	0.1862	0.4196	0.0221	0.1505	0.2141	0.3976
Spikelets/ Spike							1.0000	0.3772	0.2894	0.3224	0.0225	0.1898	0.5080	0.3961
Grains/ Spike								1.0000	0.3568	0.3575	0.1099	0.2453	0.2202	0.4547
Biological Yield/ Plant (gm)									1.0000	0.1125	-0.1037	0.1589	0.2404	0.6698
Harvest Index (%)										1.0000	0.0582	0.2128	0.2180	0.8087
1000-grain weight (gm)											1.0000	0.2699	-0.1715	0.0032
Gluten Content (%)												1.0000	-0.0784	0.2397

Ash Content (%)													1.0000	0.3296
Grain Yield /Plant														1.0000

*,** Significant at 5% and 1% probability level respectively

Table 4: Estimates of direct and indirect effect of different characters on grain yield in bread wheat (*Triticum aestivum* L.) –phenotypic

Character	Days to 50% Flowering	Days to Maturity	Plant Height (cm)	Flag Leaf Area (cm²)	Productive Tillers/ Plant	Spike Length (cm)	Spikelets/ Spike	Grains/ Spike	Biological Yield/ Plant (gm)	Harvest Index (%)	1000- grain weight (gm)	Gluten Content (%)	Ash Content (%)	Correlation with Grain Yield / Plant
Days to 50% Flowering	-0.0095	-0.0009	0.0019	0.0007	-0.0003	-0.0018	-0.0017	-0.0008	-0.0017	-0.0035	0.0006	0.0000	-0.0018	0.3775
Days to Maturity	-0.0011	-0.0110	-0.0037	-0.0007	0.0001	-0.0023	-0.0019	-0.0020	-0.0017	0.0005	-0.0010	-0.0021	-0.0013	0.0423
Plant Height (cm)	0.0006	-0.0010	-0.0030	0.0000	0.0001	-0.0001	0.0000	0.0002	-0.0001	0.0006	0.0006	0.0005	-0.0003	-0.1480
Flag Leaf Area (cm²)	-0.0015	0.0013	0.0003	0.0208	-0.0007	-0.0004	0.0040	0.0040	-0.0043	0.0036	0.0017	0.0058	0.0005	0.0188
Productive Tillers/ Plant	0.0004	-0.0001	-0.0004	-0.0004	0.0119	0.0011	0.0004	-0.0002	0.0034	-0.0005	-0.0001	0.0010	0.0009	0.1463
Spike Length (cm)	-0.0017	-0.0019	-0.0004	0.0002	-0.0008	-0.0090	-0.0012	-0.0027	-0.0011	-0.0022	0.0001	-0.0010	-0.0003	0.2318
Spikelets/ Spike	-0.0019	-0.0019	-0.0001	-0.0021	-0.0004	-0.0014	-0.0109	-0.0029	-0.0026	-0.0025	-0.0004	-0.0011	-0.0015	0.3058
Grains/ Spike	-0.0015	-0.0034	0.0015	-0.0036	0.0004	-0.0056	-0.0050	-0.0188	-0.0060	-0.0059	-0.0019	-0.0029	-0.0017	0.4100
Biological Yield/ Plant(gm)	0.1074	0.0938	0.0135	-0.1248	0.1694	0.0708	0.1440	0.1927	0.6022	0.0484	-0.0522	0.0801	0.0523	0.6451
Harvest Index (%)	0.2863	-0.0321	-0.1559	0.1322	-0.0320	0.1830	0.1779	0.2403	0.0616	0.7670	0.0372	0.1047	0.0618	0.8045
1000-grain weight (gm)	-0.0018	0.0026	-0.0062	0.0024	-0.0002	-0.0003	0.0011	0.0028	-0.0025	0.0014	0.0286	0.0061	-0.0031	0.0075
Gluten Content (%)	0.0000	-0.0043	0.0034	-0.0062	-0.0019	-0.0024	-0.0023	-0.0034	-0.0029	-0.0030	-0.0047	-0.0221	0.0014	0.1683
Ash Content (%)	0.0018	0.0012	0.0010	0.0002	0.0007	0.0003	0.0014	0.0009	0.0009	0.0008	-0.0011	-0.0006	0.0099	0.1168

• Bold figure indicate direct effect • Residual effects = 0.1070

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

Character	Days to 50% Flowering	Days to Maturity	Plant Height (cm)	Flag Leaf Area (cm²)	Productive Tillers/ Plant	Spike Length (cm)	Spikelets/ Spike	Grains/ Spike	Biological Yield/ Plant (gm)	Harvest Index (%)	1000-grain weight (gm)	Gluten Content (%)	Ash Content (%)	Correlation with Grain Yield / Plant
Days to 50% Flowering	0.0373	0.0027	-0.0095	-0.0035	-0.0033	0.0140	0.0114	0.0040	0.0082	0.0187	-0.0025	0.0004	0.0171	0.4963
Days to Maturity	0.0011	0.0149	0.0059	0.0008	0.0006	0.0073	0.0039	0.0032	0.0028	-0.0008	0.0012	0.0041	0.0074	0.0511
Plant Height (cm)	-0.0043	0.0068	0.0171	0.0004	-0.0010	0.0015	0.0002	-0.0016	0.0004	-0.0036	-0.0040	-0.0034	0.0051	-0.1494
Flag Leaf Area (cm²)	-0.0027	0.0015	0.0007	0.0288	-0.0034	0.0022	0.0081	0.0075	-0.0068	0.0060	0.0022	0.0105	0.0047	0.0224
Productive Tillers/ Plant	-0.0058	0.0028	-0.0039	-0.0077	0.0650	0.0113	0.0081	-0.0003	0.0317	-0.0036	-0.0070	0.0149	0.0259	0.2631
Spike Length (cm)	-0.0247	-0.0323	-0.0056	-0.0050	-0.0114	-0.0659	-0.0151	-0.0395	-0.0123	-0.0277	-0.0015	-0.0099	-0.0141	0.3976
Spikelets/ Spike	-0.0094	-0.0080	-0.0003	-0.0086	-0.0039	-0.0071	-0.0309	-0.0117	-0.0089	-0.0100	-0.0007	-0.0059	-0.0157	0.3961
Grains/ Spike	0.0024	0.0049	-0.0021	0.0059	-0.0001	0.0136	0.0085	0.0226	0.0081	0.0081	0.0025	0.0056	0.0050	0.4547
Biological Yield/ Plant(gm)	0.1257	0.1091	0.0140	-0.1356	0.2793	0.1066	0.1657	0.2043	0.5727	0.0645	-0.0594	0.0910	0.1377	0.6698
Harvest Index (%)	0.3832	-0.0394	-0.1629	0.1603	-0.0424	0.3211	0.2467	0.2736	0.0861	0.7652	0.0445	0.1629	0.1668	0.8087
1000-grain weight (gm)	-0.0026	0.0030	-0.0089	0.0029	-0.0041	0.0008	0.0008	0.0042	-0.0039	0.0022	0.0378	0.0102	-0.0065	0.0032
Gluten Content (%)	-0.0005	-0.0112	0.0081	-0.0151	-0.0095	-0.0062	-0.0078	-0.0101	-0.0065	-0.0088	-0.0111	-0.0412	0.0032	0.2397
Ash Content (%)	-0.0032	-0.0035	-0.0021	-0.0012	-0.0028	-0.0015	-0.0036	-0.0016	-0.0017	-0.0015	0.0012	0.0006	-0.0070	0.3296

• Bold figure indicate direct effect • Residual effects = 0.0574

Similar findings were earlier reported by Tripathi *et al.* (2011), Singh *et al.* (2012) [16], Kumar *et al*. (2014) [7], Sabit *et al*. (2017) [14] and Imran *et al.* (2017) [16]. Residual effect at both levels was (p=0.1070, g=0.0574) indicating that some other factors which were not been considered in the study, need to be included in the analysis to explain total variation in yield. The study of character association and path coefficient analysis indicated that biological yield per plant and harvest index had positive direct effect coupled with positive significant correlation with grain yield per plant and hence direct selection can be made based on this traits for improving grain yield in this crop.

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