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Genetic parameters of variability and path analysis for morpho-physiological and seed vigour character in bread wheat (*Triticum aestivum* L.)

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Abstract
An experiment was conducted to determine the genetic variability, heritability, genetic advance and direct and indirect effect for yield and its component traits in 40 wheat genotypes under irrigated condition. Phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) for all the characters under studied. Plant drooping height exhibited highest GCV and PCV estimates followed by number of tillers per meter, flag leaf area, seed density and harvest index. Plant drooping height, number of tillers per meter, flag leaf area, harvest index, flag leaf length and seed density exhibited high genetic advance as per cent of mean along with high heritability estimates. Path analysis showed that thousands grain weight had highest positive direct as well as indirect contribution toward grain yield via grain weight per spike followed by flag leaf area followed by harvest index, flag leaf area and biological yield

Keywords: PCV, GCV, heritability, genetic advance, path analysis, morpho-physiological

Introduction
Wheat (*Triticum aestivum* L. em. Thell) belongs to family Poaceae, the largest family within the monocotyledonous plants. It is allohexaploid (2n = 6x = 42) with three genetically related genomes A, B, and D. Wheat is the most important and ancient crop of the world, providing main source of calories to humankind since the beginning of agriculture about ~10,000 years ago. Due to its wide adaptation and multiple uses, it is used as staple food for above 40 per cent human population across the globe. In India wheat is cultivated on 30.72mha, with a production 97.44 mt and productivity 31.72q/ha. Haryana with 11.14 mt production, 2.54 m ha area and 4.39 t/ha productivity ranks third in the country (Annonymous, 2017) [3]. Grain yield is an important trait as it measures the economic productivity in wheat. Grain yield is the end product of interaction of many factors known as yield contributing components and is a complex trait. Selection based on grain yield is usually not very successful but the one based on its component characters could be more effective. For effective selection, information on nature and magnitude of variation in population, knowledge of correlation among yield contributing traits, their contributions towards grain yield and the extent of environment influence on the expression of these characters are necessary (Yagdi, 2009) [15].

It is a reputable fact that greater variability among the genotypes leads to better chance for further improvement in the crop. Therefore, selection on the basis of traits with higher heritability makes the progress easier of traits with low heritability. Since the correlation coefficients generally show linear relationships among independent variables that may not sufficiently describe the association when a clear cause-effect relationship is required between the variables. Therefore, the direct and indirect effects between yield and yield components should be known in breeding programs (Albayrak *et al*; 2003) [2]. Path coefficients analysis partitioned the correlation coefficient into direct and indirect effects on yield. It is a reliable statistical technique which provides means not only to quantify the inter relationship of different yield component but also indicate whether the influence is directly reflected in the yield or takes some other path way for ultimate effects. Therefore, this technique provides a critical examination of specific factors producing a given correlation and can be successfully employed in formulating a selection strategy. The present study therefore was conducted to estimate magnitude of phenotypic and genotypic variability, heritability, genetic advance and magnitude of direct and indirect effect by path analysis with the aim to utilize the genetic information gained in developing superior wheat genotypes and varieties.

Materials and Methods

A field experiment was conducted under irrigated condition at CCSHAU, Hisar, India during winter (*Rabi*) season 2013-2014 in a randomized block design with three replications. Hisar is located in global geographical position between 29.09°N and 75.43°E in western Haryana. The experimental materials comprised of genetically diverse 40 wheat genotypes whose description is given in table 1. Out of forty genotypes, 10 genotypes were recommended for timely sown irrigated condition, 5 were recommended for late sown irrigated condition, 3 varieties for early sown conditions out of which two for rainfed conditions and one for restricted irrigation conditions and 22 advance breeding lines. Observations for all the traits were recorded on five randomly selected plants for each genotype in each replication. The data were recorded for Observations for all the traits were recorded by taking five plants per plot. The data were recorded for days to 50% heading (DH), days to anthesis (DA), plant height (PH), flag leaf length (FL), flag leaf width (FB), flag leaf area (FLA), number of tillers per meter (T), spike length (SL), main spike weight (SW), spikelets per spike (SPS), grains per spike (GPS), grains weight per spike (GW), grain length (GL), grain breadth (GB), grain growth rate (GGR) at 14, 21 and 28 days after anthesis, biological yield (BY), grain yield (GY), thousand grains weight (TGW), harvest index (HI), standard germination test (GM), seedling length (SLg), seedling dry weight (SD), vigour index-I (V-I), vigour index-II (V-II), seed density (Sd), plant straight height (SH) at 30 days, plant drooping height (Dr.H) at 30 days, field emergence index (FE) and seedling establishment (FS). Analysis of the observations recorded on different characters was carried out as per the standard procedure.

Table 1: List of genotypes along with their pedigree

S. No.	Genotypes	Pedigree
1	WH 542	JUPATECO/BLUEJA/URES
2	WH 711	ALD ‘S’/HAU//HD2285/3/HFW-17
3	WH 1021	NYOT95(GW296)/SONAK
4	WH 1025	C591/PBW231
5	WH 1080	PRL/2*PASTOR
6	WH 1081	PBW65/2*PASTOR
7	WH 1105	MILAN/S87230//BABAX
8	WH 1120	PRL/2*PASTOR
9	WH 1124	MUNIA/CHTO//AMSEL
10	WH 1126	WBLL1*2/VIVITSI
11	WH 1129	CS/TH.CS//3*PVN/3/MIRLO/BUC/4/MILAN/5/TILHI
12	WH 1130	PRL/2*PASTOR/4/CHOIX/STAR/3/HE1*CN079
13	WH 1138	PBW65*2/PASTOR
14	WH 1142	CHEN/Ae.sq (TAUS)//FCT/3/2*WEAVER
15	WH 1154	WH337/HD2255//RAJ3077
16	WH 1163	HPW42/WH542
17	WH 1164	RL6043/4*NAC//2*PASTOR
18	WH 1166	HD29/*WEAVER/3/VEE/PJN//2*WEAVER/3/VEE/PJN//2*TUI/4/MILAN
19	WH 1167	WEAVEAR/VIVISI/3/C80.1/3*BATAVIA//2*WBLLI
20	WH II68	ATTILA*2//CHIL/BUC*2/3/KUKUNA
21	WH 1169	KLDR/PEWITI/MILAN/DUCULA
22	WH 1170	LERKE/5/KAUZ/3/MYNA/VUL//BUC/FLK/4/MILLAN/6PROGRESOF2007
23	WH 1171	MILAN//PRL/2*PASTOR/4/CROC_1/AE.SQ(213)//PGO/3/BAV92
24	WH 1172	KLDR/PEWIT//MILAN/DUCULA
25	WH 1174	FILIN/IRENA/5/CNDOR/R143/ENIE/MEXI_2/3Ae.Sq/4/
26	WH 1175	FILIN/2*PASTOR//BERKUT/3/PASTOR/2*SITTA
27	WH 1177	HP1744/PBW443
28	WH 1178	CS//TH.86/3*PVN/3/MIRLO/BUC/4/MILAN/5/TILHI
29	WH 1179	OASIS/SKAUZ//4*BCN/3/3*PASTOR
30	HD 2687	CPAN2009/HD2329
31	HD 2851	CPAN3004/WR426//HW2007
32	HD 2967	ALD/CUC//URES/HD2160/HD2278
33	PBW 343	ND/VG9144//KAL//BB/3//YCO ’S’/4/VEE#5 ‘S’
34	PBW 550	WH594/RAJ3856//W485
35	PBW 590	WH594/RAJ3814//W485
36	PBW 373	ND/VG9144//KAL//BB/3//YCO ’S’/4/VEE#5 ‘S’
37	DBW 17	CMH79A.95/3*CN079//RAJ3777
38	DPW 621- 50	KAUZ//ALTAR84/AOS/3/MILAN/KAUZ/4/HUITES
39	RAJ 3765	HD 2402/VL639
40	UP 2338	UP368/VL421//UP262

Results and Discussion

Variability parameters

The result of mean, range, genotypic coefficient of variation (GCV), Phenotypic Coefficient of Variation (PCV), heritability (broad sense), and expected genetic advance have been presented in table 2. This revealed sufficient range of variation among genotypes for each character. Phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) for all the characters under studied. The higher PCV and GCV values for all the characters could be evidence for the existence of a wide range of variation for such characters. In general, the PCV values for all the characters were closer than the corresponding GCV values showing little environment effect on the expression of these characters. Plant drooping height exhibited highest GCV (17.32) and PCV (17.61) estimates followed by number of tillers per meter, flag leaf area, seed density and harvest index indicating that greater amount of variability prevailed among the genotypes for these characters. Ashfaq *et al.* (2016) [4], Kumar and Kerkhi (2015) [12] reported similar results. Low GCV and PCV were obtained for germination per cent 2.08 and 2.66 respectively, followed by field emergence, days to anthesis, seedling length and days to 50% heading. The remaining characters exhibited intermediate GCV and PCV estimates.

Table 2: Mean, range, phenotypic and genotypic coefficient of variation, heritability and genetic advance as per cent of mean for physio-morphological and seed quality traits in wheat

S. No.	Characters	Mean ± S.E (m)	Range	GCV	PVC	Heritability (%)	Genetic advance as % mean of
1	Days to 50% Heading	95.36 ± 0.54	86.67 - 108.00	4.46	4.57	95.48	8.98
2	Days to Anthesis	102.96 ± 0.55	96.00 - 114.00	3.95	4.05	94.76	7.91
3	Plant height (cm)	108.89 ± 1.07	85.8 - 131.73	7.95	8.13	95.62	16.02
4	Flag leaf length (cm)	26.94± 0.53	19.97 - 33.57	12.16	12.63	92.71	24.11
5	Flag leaf breadth (cm)	1.89 ± 0.03	1.50 - 2.27	6.92	7.69	81.06	12.83
6	Flag leaf area (cm2)	38.22 ± 1.11	25.97 - 50.63	14.50	15.35	90.08	28.19
7	Number of tillers per meter	123.72±1.35	92.33 - 172.00	14.61	14.73	98.34	29.84
8	Spike length (cm)	11.79 ± 0.12	10.37 - 14.97	9.01	9.19	96.03	18.18
9	Spike weight (g)	3.19 ± 0.06	2.60 - 3.70	7.65	8.25	86.11	14.63
10	Spikelets per spike	18.90 ± 0.33	16.60 - 22.20	6.56	7.24	82.12	12.25
11	Grains per spike	54.18 ± 0.94	44.80 - 67.03	7.66	8.23	86.64	14.69
12	Grains weight/spike (g)	2.18 ± 0.05	1.83 - 2.57	7.90	8.80	80.48	14.59
13	Grain length (mm)	6.75 ± 0.06	6.17 - 7.93	4.69	4.94	90.08	9.17
14	Grain breadth (mm)	3.27 ± 0.06	2.90 - 3.90	5.32	6.19	73.87	9.42
15	1000-grain weight (g)	44.20 ± 0.99	36.33 - 51.70	7.80	8.71	80.27	14.40
16	Biological yield (g)	3402.1 ± 114.3	2916.70 - 4333.30	10.56	12.06	76.68	19.04
17	Grain yield (g)	939.4 ± 26.0	801.70 - 1150.0	8.37	9.65	75.24	14.96
18	Harvest index (%)	27.96 ± 0.78	20.73 - 33.87	12.89	13.76	87.77	24.87
19	Grain growth rate at 14 days (g/gr/day x 10-4)	6.83 ± 0.10	5.57 - 7.77	7.76	8.16	90.57	15.22
20	Grain growth rate at 21 days (g/gr/day x 10-4)	12.77 ± 0.18	10.80 - 15.07	9.53	9.83	94.06	19.04
21	Grain growth rate at 28 days (g/gr/day x 10-4)	16.32 ± 0.16	13.20 - 21.27	10.80	10.94	97.46	21.95
22	Germination (%)	96.13 ± 0.92	91.00 - 99.67	2.08	2.66	61.08	3.35
23	Seedling length (cm)	21.48 ± 0.22	19.77 - 23.13	4.42	4.77	85.85	8.44
24	Seedling dry weight (g)	124.11 ± 1.09	102.33 - 159.23	9.09	9.22	97.27	18.47
25	Vigour index-I	2065.12 ± 27.99	1856.03- 2267.20	5.64	6.11	85.23	10.72
26	Vigour index-II	11936.82 ±155.00	9687.00-15124.43	9.79	10.04	94.98	19.65
27	Seed density (g/cc)	1.06 ± 0.03	0.87 - 1.57	14.06	14.83	89.82	27.44
28	Straight plant height (cm)	24.03 ± 0.35	18.57 - 30.93	12.81	13.05	96.35	25.89
29	Plant drooping height (cm)	15.62 ± 0.29	10.90 - 20.57	17.32	17.61	96.75	35.09
30	Field emergence index	9.46 ±0.10	8.53 - 10.13	3.52	3.97	78.52	6.42
31	Seedling establishment (%)	76.23 ± 1.17	64.00 - 84.00	6.62	7.14	86.14	12.66

Heritability and genetic advance

Heritability estimates were high for all most of the characters under study. The high heritability and genetic advance are attributed due to additive gene action with least environment influence which would result in improvement of these traits merely by selection. Plant drooping height (35.09), number of tillers per meter (29.84), flag leaf area (28.19), harvest index (24.87), flag leaf length (24.11) and seed density (27.44) exhibited high genetic advance as per cent of mean along with high heritability estimates (87.77-98.34) indicating the presence of additive genes effect. Similar results were found by Kumar *et al.* (2012) [11] and Farshadfar *et al.* (2013) [7]. Ashfaq *et al.* (2016) [4] also noticed highly significant differences in wheat genotypes for flag leaf area. Similarly, Jatoi *et al.* (2012) [9] also noticed significant differences in wheat varieties and high heritability estimates for flag leaf area. Broad-sense heritability estimates were high while genetic advance were moderate for grain yield. Days to anthesis (7.91), seedling length (8.44), days to 50% heading (8.98) and grain length (9.17) have low genetic advance as per cent of mean along with high heritability estimates (85.85-95.48). Similar results obtained by Ahmad *et al*. (2016) [1] for plant height.

Path coefficient analysis

Since correlation studies alone are not sufficient to make picture of association analysis very clear, hence the assessment of real contribution of an individual character towards seed yield per plant becomes essential. Path coefficient provides a clear and more realistic picture of a complex situation that exists at correlation level. It measures the direct as well as indirect effect of one variable on the dependent variable through the other traits. Direct and indirect effect of various traits on grain yield is presented in Table 3 and Table 4.

Table 3: Direct (diagonal) and indirect effects of component traits on grain yield of wheat

	DH	DA	PH	FL	FB	FLA	T	SL	SW	SPS	GPS	GW	GL	GB	TGW	BY	HI	GGR14	GGR21	GGR28	GY
DH	0.053	-0.215	0.039	-0.009	-0.044	0.069	0.000	-0.043	0.010	-0.039	-0.046	0.267	0.008	0.005	-0.171	0.045	0.030	0.016	-0.024	0.027	0.115
DA	0.052	-0.222	0.030	-0.018	-0.015	0.035	0.000	-0.040	0.009	-0.035	-0.033	0.262	0.008	0.005	-0.156	0.049	0.041	0.003	-0.007	0.020	0.128
PH	0.008	-0.027	0.247	0.049	-0.015	-0.083	0.000	-0.043	-0.024	-0.050	-0.028	0.139	-0.009	-0.001	-0.068	0.387	-0.448	0.022	-0.015	-0.001	-0.013
FL	0.001	-0.011	-0.033	0.373	-0.031	0.843	-0.005	-0.007	-0.016	-0.022	-0.029	-0.341	0.002	-0.003	0.200	-0.018	0.747	-0.003	0.052	-0.066	0.903
FB	0.009	-0.012	0.013	-0.043	-0.267	0.560	0.000	-0.064	-0.011	-0.030	-0.034	0.078	0.013	-0.003	-0.088	-0.133	0.185	0.026	-0.037	-0.027	0.091
FLA	0.004	-0.008	-0.021	-0.326	-0.155	0.964	-0.004	-0.038	-0.019	-0.034	-0.038	-0.261	0.008	-0.004	0.143	-0.092	0.712	0.008	0.025	-0.066	0.778
T	0.003	-0.020	0.006	-0.332	-0.012	0.727	-0.005	0.004	-0.006	-0.022	-0.018	-0.248	0.002	-0.001	0.142	0.007	0.760	-0.004	0.044	-0.062	0.947
SL	0.012	-0.044	0.053	-0.013	-0.085	0.185	0.000	-0.199	0.019	-0.084	-0.030	0.417	-0.002	0.002	-0.305	0.200	-0.315	0.024	-0.027	0.051	0.083
SW	-0.006	0.024	0.070	-0.069	-0.034	0.214	0.000	0.045	-0.084	-0.004	-0.039	-0.854	0.002	-0.001	0.768	0.139	0.023	-0.022	0.028	-0.049	0.195
SPS	0.014	-0.052	0.083	-0.055	-0.053	0.218	-0.001	-0.110	-0.002	-0.151	-0.158	0.531	0.007	0.005	-0.499	0.175	-0.211	0.035	-0.038	0.022	0.012
GPS	0.010	-0.029	0.028	-0.042	-0.036	0.145	0.000	-0.024	-0.013	-0.095	-0.251	0.395	0.006	0.005	-0.395	-0.046	0.069	0.048	-0.006	0.011	0.047
GW	-0.010	0.040	-0.023	-0.087	0.014	0.172	-0.001	0.057	-0.049	0.055	0.068	-1.462	-0.015	-0.007	1.289	-0.056	0.286	-0.052	0.059	-0.078	0.214
GL	-0.008	0.035	0.043	0.014	0.069	-0.150	0.000	-0.009	0.003	0.020	0.029	-0.418	-0.052	-0.001	0.405	-0.067	0.112	-0.026	-0.007	0.029	0.004
GB	-0.013	0.053	0.009	-0.055	-0.046	0.202	0.000	0.019	-0.004	0.041	0.071	-0.548	-0.003	-0.019	0.423	-0.076	0.124	-0.009	0.025	-0.070	0.015
TGW	-0.007	0.026	-0.013	-0.055	0.018	0.103	-0.001	0.045	-0.048	0.056	0.074	-1.405	-0.016	-0.006	1.341	-0.017	0.195	-0.067	0.036	-0.066	0.162
BY	0.003	-0.012	0.102	0.007	0.038	-0.095	0.000	-0.043	-0.013	-0.028	0.012	0.087	0.004	0.002	-0.024	0.936	-1.027	0.009	-0.031	0.023	-0.021
HI	0.001	-0.007	-0.084	-0.211	-0.037	0.519	-0.003	0.047	-0.002	0.024	-0.013	-0.317	-0.004	-0.002	0.197	-0.727	1.323	-0.011	0.037	-0.046	0.638
GGR14	-0.006	0.005	-0.041	-0.009	0.052	-0.054	0.000	0.035	-0.014	0.039	0.090	-0.562	-0.010	-0.001	0.666	-0.063	0.110	-0.135	0.021	0.004	0.060
GGR21	-0.007	0.008	-0.019	-0.102	0.052	0.125	-0.001	0.028	-0.013	0.030	0.008	-0.456	0.002	-0.003	0.253	-0.153	0.258	-0.015	0.190	-0.070	0.143
GGR28	-0.008	0.023	0.002	-0.128	-0.038	0.332	-0.002	0.053	-0.022	0.017	0.015	-0.602	0.008	-0.007	0.463	-0.116	0.318	0.003	0.070	-0.190	0.246

Table 4: Direct (diagonal) and indirect effect of seed quality parameters on grain yield per plant of wheat

	BY	GM	SLg	SD	V-I	V-II	Sd	SH	Dr.H	FE	FS	GY
BY	0.936	0.134	0.760	2.041	0.091	-3.019	0.021	0.003	-0.019	0.000	0.014	-0.021
GM	0.286	0.439	-2.544	3.763	5.271	-6.983	0.069	0.004	0.030	-0.007	0.003	-0.042
SLg	-0.117	0.183	-6.103	0.084	7.106	-1.437	0.033	-0.028	0.068	-0.002	0.059	-0.262
SD	0.141	0.122	-0.038	13.572	0.806	-14.732	-0.020	0.000	0.015	-0.004	0.083	0.115
V-I	0.011	0.307	-5.747	1.449	7.547	-3.705	0.052	-0.020	0.065	-0.004	0.047	-0.217
V-II	0.188	0.204	-0.583	13.295	1.859	-15.039	-0.004	0.001	0.020	-0.005	0.077	0.097
Sd	0.068	0.104	-0.686	-0.934	1.344	0.209	0.291	0.002	-0.011	-0.002	-0.011	-0.183
SH	0.048	0.026	2.575	0.057	-2.350	-0.268	0.007	0.065	-0.149	-0.002	0.018	-0.208
Dr.H	0.076	-0.057	1.799	-0.888	-2.125	1.322	0.014	0.042	-0.230	0.001	0.027	-0.019
FE	-0.001	0.299	-1.336	5.121	3.210	-7.432	0.061	0.010	0.035	-0.010	0.037	-0.217
FS	0.065	0.006	-1.800	5.614	1.782	-5.802	-0.016	0.006	-0.031	-0.002	0.200	-0.122

Thousands grain weight had highest positive direct (1.341) as well as indirect contribution toward grain yield via grain weight per spike (1.289) followed by flag leaf area (0.102) followed by harvest index (1.323), flag leaf area (0.964) and biological yield (0.936). This means that a slight increase in one of the above traits may directly contribute to seed yield. Similar result found for biological yield and thousand grain weight by Mollasadeghi *et al*., (2013) [14], Dabi *et al*, 2016 [5] and Mecha *et al* (2017) [13]. Days to 50% (0.053) heading and plant height (0.247) had positive direct effect on grain yield which confirms the findings of Degewione *et al*. (2013) [6], Fallahi *et al*. (2013) [8]. Number of tillers per meter had positive indirect contribution toward grain yield via harvest index (0.760) and flag leaf area (0.727). The highest positive indirect effect on grain yield were observed with grains weight per spike (-1.462) through 1000 grain weight, flag leaf length, flag leaf area, number of tillers per meter, spike weight, grain length, grain breadth, harvest index as well as through grain growth rate at 14, 21 and 28days.

Table 4 indicate that seedling dry weight exhibited highest positive direct effect (13.572) and a negative indirect effect via vigour index -II (-14.732) on grain yield. Germination% (0.439) and vigour index-I (7.547) had positive direct effect on grain yield. The negative direct effect of vigour index-II (-15.039) was nullified by its positive indirect effect through seed dry weight (13.295). Similar results found by Kumar *et al*. (2017) [10]. Field emergence exhibited indirect effect via seedling dry weight (5.121) and vigour index-I (3.210) on grain yield.

Conclusion

The high heritability values coupled with high genetic advance were recorded for plant drooping height, number of tillers per meter, flag leaf area, harvest index, flag leaf length and seed density, indicating that these characters are governed by additive gene effects and direct selection for these traits would be more effective for desired genetic improvement. The path analysis revealed that 1000 grain weight, harvest index, flag leaf area and biological yield found to be more important as these traits had high direct contribution and also exhibited substantially indirect contribution to the gross correlation of other traits with grain yield. Seedling dry weight, vigour index-I and germination percentage exhibited high direct effect, hence each of these traits must be given preference in selecting the superior types.

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