

## Correlation and Path Coefficient Analysis of Protein Content and Yield Related Traits in Recombinant Inbred Lines (RILs) Population of Bread Wheat (*Triticum aestivum* L. Em. Thell)

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Received 25 August 2017; Accepted 28 September 2017; Published on 17 October 2017

**Abstract** A total of 103 Recombinant Inbred Lines (RILs) of wheat derived from the cross between HUW-510 and WH 730 (heat tolerant), were evaluated for variation in agronomic and protein content. The RILs along with the parents were grown in two conditions i.e. timely sown (20<sup>th</sup> Nov) and late sown (24<sup>th</sup> Dec). The analysis of variance revealed that RILs have ample variation for yield and yield contributing traits. The grain yield showed significant and positive correlation with biological yield and 1000 grain weight in both experiments. Biological yield, harvest index (HI) and 1000 grain weight exhibited high direct and indi-

rect effects in normal sown experiment. However, for late sown experiment beside biological yield and harvest index, peduncle length also found to be important. It may be inferred that number of biological yield, harvest index and 1000 grain weight must be used as selection criteria in development of high yielding varieties.

**Keywords** Wheat, Recombinant Inbred Lines (RILs), Protein content, Correlation, Path coefficient.

### Introduction

Wheat is the most important cereal crop of the world. It is the cheapest source of carbohydrate and proteins and a staple food of about one third population of the world. In India wheat is cultivated in around 30.72 mha with a production of 97.44 m tonnes [1].

Wheat production is limited by a wide array of abiotic and biotic stress factors including drought, cold, heat, salinity, imbalances in mineral nutrition, fungal and others, often acting in combinations under field conditions. Genetic variability in natural plant populations holds the potential to deal with multiple biotic and abiotic stresses. Further, it holds the potential for improved efficiency and hence their use for breeding, which eventually may result in enhanced food production. For the effective use of genetic di-

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**Table 1.** Pedigree of parents and their ancestors of the WH-730 × HUW-510 RIL population.

Genotypes	Pedigree
Parents	
WH-730	CPAN2092/Improved Lok-1
Ancestors	
Lok-1	S308/S331
S308 (Sonalika)	II54388/AN/3/YT54/N10B/LR64
Parents	
HUW-510	HD2278/HUW234/DL230-16
Ancestors	
HUW-234	HUW12*2/CPAN1666/HUW12
HUW-12	NP876/CIAN066
HD-2278	HD2119/247

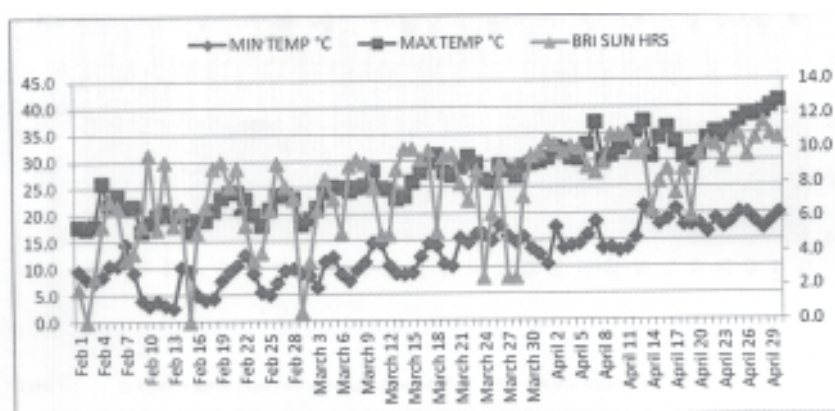
versity in plant breeding, knowledge of its extent and distribution plays a crucial role [2]. On depletion of genetic variability, plants are unable to cope with unfavorable environmental conditions or pathogens and pests. Considering the significance of diversity, its analysis in crops is a prerequisite for crop breeding programs, as it serves to provide information about genetic variation.

Wheat is sensitive to high temperature at the time of reproductive development. Genotypes differ in their responses to environmental factors, in general and to temperature and photoperiod in particular [3]. Genetic potentialities and environmental factors, including cultural practices determine yield, however, final grain yield is mainly dependent on potential grain growth of any cultivar. Grain yield, a main economic trait, is the sum total of the component characters. Thus the selection based on grain yield is usually not very successful but the one based on its component characters could be very effective. Proteins are the most important components of wheat grains governing end-use quality.

Since information on association among yield and its components is of prime importance in this direction, an attempt was made in this study to determine the relationship between grain yield and physio-morphological characters and also, to assess the extent and nature of direct and indirect effect of these character on yield to formulate an efficient selection program for grain yield improvement in wheat.

## Materials and Methods

A field experiment was conducted under irrigated condition at CCSHAU, Hisar, India during winter (*rabi*) season of 2013-14. The average annual rainfall was



**Fig. 1.** Min, max and sunshine hours during heading period.

**Table 2.** ANOVA for yield related traits and protein content in bread wheat under timely sown (TS) experiment of *rabi* season, 2013-14. \* -Significant at 5%, \*\* -Significant at 1%.

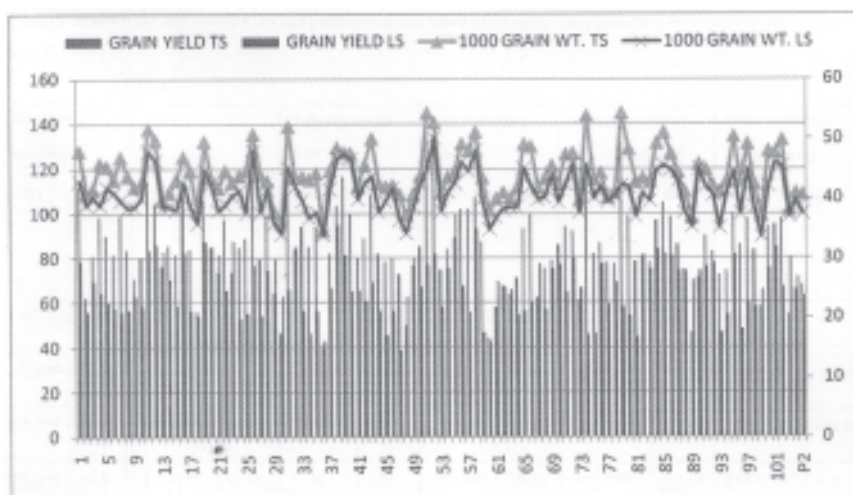
Traits Source	Df	Days to 50% flowering		Plant height (cm)		Peduncle length (cm)		Flag leaf area (cm <sup>2</sup> )		Biological yield 50 cm row length (g)	
		(MS)	F (cal)	(MS)	F (cal)	(MS)	F (cal)	(MS)	F (cal)	(MS)	F (cal)
Replication	2	8.35	2.99	1.90	0.70	2.11	2.59	1.13	0.50	16.19	1.839
Genotypes	104	197.37**	70.79	721.65**	244.22	137.52**	156.82	218.69**	97.19	7316.02**	777.73
RILs	102	195.77**	71.92	670.81**	243.50	130.31**	163.74	216.81**	99.45	6864.94**	472.74
Parents	1	140.17**	50.24	266.67**	97.68	1.402	1.71	517.08**	229.81	7072.67**	802.80
RILs vs Parents	1	418.47**	149.99	6406.31**	196.64	1014.26	0.30	111.54**	49.57	53629.53**	562.74
Error	208	2.79		58.74		10.58		2.25		498.82	
CV (%)		1.77		6.61		7.66		3.99		8.13	

**Table 2.** Continued.

Traits Source	Df	Grain yield/50cm row length (g)		Harvest index (%)		1000 grain weight (g)		Protein content (%)	
		(MS)	F (cal)	(MS)	F (cal)	(MS)	F (cal)	(MS)	(cal)
Replication	2	4.35	0.57	4.17	1.93	1.14	4.97	0.12	
Genotypes	104	1137.99*	136.34	49.03**	22.50	53.03**	230.17	8.22**	
RILs	102	1,047.47**	134.53	48.01**	21.78	53.29**	130.14	7.49**	
Parents	1	6.00	0.78	64.03**	29.51	0.167	0.75	32.854**	
RILs vs Parents	1	11503.02**	277.29	166.15**	49.63	211.45**	333.30	53.05**	
Error	208	97.80		2.74		1.53		0.63	
CV (%)		11.60		5.34		2.80		7.58	

455 mm with 27 rainy days (a day with minimum of 2.5 mm rainfall or more). This location typically experi-

ences moderate drought during the pre and post-anthesis periods. The soil at the location was clay loam



**Fig. 2.** Grain yield and 1000 grain yield of timely and late sown environments.

**Table 3.** ANOVA for yield related traits and protein content in bread wheat under late sown (LS) experiment of *rabi* season, 2013-14. ^\* -Significant at 5%, \*\* -Significant at 1%.

Days to 50% flowering		Plant height (cm)		Peduncle length (cm)		Flag leaf area (cm <sup>2</sup> )		Biological yield/50 cm row length (g)	
(MS)	F (cal)	(MS)	F (cal)	(MS)	F (cal)	(MS)	F (cal)	(MS)	F (cal)
34.84	8.81	1.95	1.18	0.51	0.83	0.63	0.38	8.47	1.64
155.56**	39.35	627.59**	348.25	122.61**	189.90	124.55**	73.72	6221.61**	1,136.46
156.73**	39.99	575.14**	342.55	118.59**	193.78	123.39**	73.21	5,879.18**	1,131.99
54.00**	13.67	0.54	0.33	9.13**	14.97	366.60**	216.92	9,126.00**	1761.78
137.22**	34.74	6604.54**	708.39	646.13**	4.46	0.62	0.37	38.25**	548.00
3.95		53.93		6.81		1.69		345.63	
2.38		7.41		6.10		3.79		8.37	

**Table 3.** Continued.

Grain yield/50 cm row length (g)		Harvest index (%)		1000 grain weight (g)		Protein content (%)	
(MS)	F (cal)	(MS)	F (cal)	(MS)	F (cal)	(MS)	F (cal)
4.52	1.31	0.38	1.01	0.00	0.00	0.00	0.32
555.49**	149.90	59.44**	149.65	39.40**	119.77	7.60**	21,477.0
442.62**	152.37	54.93**	145.07	39.29**	120.80	7.04**	21,110.0
4,320.17**	1255.86	228.17**	600.45	7.94**	24.06	13.02**	651.00
8303.55**	1225.5	350.73**	56.66	82.02**	89.94	59.30**	50.5
42.73		3.55		0.82		0.52	
9.86		6.31		2.23		7.18	

with a pH 7.1–8. A total of 103 RIL descended from a cross between HUW-510/WH-730 (heat tolerant genotype) of bread wheat genotypes along with parents were sown in randomized block design with 3 replications at the wheat research area of Dept. Genetics and Plant Breeding, CCS, HAU, Hisar, during *rabi* season of 2013 on two dates of sowing i.e. timely (1<sup>st</sup> week of Nov) and late (1<sup>st</sup> week of Dec). All the recommended cultural practices were adopted to raise a good crop. Data were recorded on five randomly selected plants in each replication on characters like days to 50% heading, plant height (cm), peduncle length (cm), flag leaf area (cm<sup>2</sup>), harvest index (%), 1000 grain weight (g) and grain protein content (%). Biological yield and grain yield which were measured on the basis of 1/2 m row length. The pedigree of parents and their ancestors of the RIL population are presented in Table 1.

Genotypic and phenotypic correlation coefficients between two characters were determined by using the variance and covariance components and

path coefficients as suggested earlier.

## Results and Discussion

Analysis of variance for RILs and two parents evaluated in two environments, timely sown (TS) and late sown (LS) indicated significant variation due to genotypes for all the traits under study (Tables 2 and 3). All the traits expressed significant interaction with environments, indicating that all traits respond to high temperature in different ways in different RILs. This variability gives sufficient scope for further selection of the traits under consideration. The RILs developed from HUW-510/WH-730 (heat tolerant genotype) was phenotyped for yield and its component traits.

Seasonal fluctuations in temperature have potential impacts on the phases of development and grain yield of crops. Wheat, being a winter cereal, requires particular environmental conditions for better emergence, growth and flowering and is more ven-

**Table 4.** *Per se* performance of top 10% RILs for various yield related traits and protein content of the HUU-510 × WH-730 RIL population of bread wheat evaluated in the timely sown (TS) experiment of *rabi* season, 2013-14.

RIL (Acc. No.)	Days to 50% flowering		Plant height (cm)		Peduncle length (cm)		Flag leaf area (cm <sup>2</sup> )		Biological yield/1/2m row length (g)		Grain yield/ 1/2m row length (g)		HI (%)		1000 grain weight (g)		Protein content (%)	
	Mean	No.)	Mean	No.)	Mean	No.)	Mean	No.)	Mean	No.)	Mean	No.)	Mean	No.)	Mean	No.)	Mean	No.)
53	121.00	100	144.90	20	58.60	29	60.37	52	389.33	51	137.00	8	39.93	51	54.33	36	14.88	
29	120.00	6	143.47	80	57.60	54	59.67	11	382.67	52	134.67	22	38.20	79	54.30	9	14.26	
82	115.33	94	142.00	97	57.47	53	58.80	51	382.33	79	131.33	39	37.37	74	53.83	105	13.48	
54	114.67	23	137.20	5	56.77	82	58.67	79	379.00	74	120.33	25	37.17	52	52.70	67	13.39	
47	114.33	19	136.67	9	55.40	17	55.80	23	363.67	26	118.33	43	36.80	31	52.00	34	12.73	
6	111.00	52	136.03	51	55.07	81	52.70	1	359.00	39	116.33	28	36.67	11	51.60	10	12.63	
7	110.33	93	135.63	64	52.50	94	51.57	26	352.67	11	114.33	7	36.43	58	51.03	20	12.57	
18	110.33	45	134.63	17	52.47	105	51.17	16	345.67	1	112.00	98	36.13	85	51.00	39	12.55	
91	107.00	64	132.57	66	51.60	85	48.70	74	343.67	16	111.33	81	36.10	26	50.73	38	12.54	
45	106.00	47	132.00	23	50.80	86	48.67	12	336.67	31	109.00	96	36.09	95	50.37	14	12.48	

erable if exposed to high temperatures during reproductive stages [4]. Vegetative stages (December–Early February) of wheat experienced favorable moisture conditions combined with low temperatures, while the reproductive stage (Mid February–March) experienced the moisture stress condition with high temperatures. Among the 103 RILs, RIL No. 51 (137 g) and 52 (134.67 g) in TS and RIL No. 55 (99.33 g) and 58

(93 g) in LS condition showed the highest grain yield/1/2m length, condition under the prevailing environmental conditions of the region (Tables 4 and 5). It can be said that the RILs No. 55 and 58 are better adapted to late-season drought and high temperature stress than other genotypes.

Lines 51 and 52 took 88 and 90 days to heading

**Table 5.** *Per se* performance of top 10% RILs for various yield related traits and protein content of the HUU-510 × WH-730 RIL population of bread wheat evaluated in the late sown (LS) experiment of *rabi* season, 2013-14.

RIL (Acc. No.)	Days to 50% flowering		Plant height (cm)		Peduncle length (cm)		Flag leaf area (cm <sup>2</sup> )		Biological yield/1/2m row length (g)		Grain yield/ 1/2m row length (g)		HI (%)		1000 grain weight (g)		Protein content (%)	
	Mean	No.)	Mean	No.)	Mean	No.)	Mean	No.)	Mean	No.)	Mean	No.)	Mean	No.)	Mean	No.)	Mean	No.)
82	106.00	94	139.17	20	52.60	82	48.43	23	319.33	55	99.33	51	45.83	52	50.13	36	13.97	
6	103.00	82	124.77	80	51.50	37	46.03	38	316.00	58	93.00	1	40.97	58	48.07	9	13.84	
29	102.67	6	122.08	5	50.57	11	45.80	12	311.00	23	87.33	78	39.07	11	47.83	60	13.48	
54	101.67	19	122.07	9	49.70	46	44.50	55	310.33	19	87.00	61	38.37	39	47.40	67	13.01	
60	99.00	100	121.80	55	49.33	12	43.77	11	305.33	12	85.67	30	37.83	40	46.67	105	12.50	
91	97.00	45	120.90	22	48.70	17	43.76	69	205.00	20	85.00	89	37.80	38	46.63	53	12.49	
47	93.33	93	120.80	66	48.63	32	43.63	32	292.67	32	85.00	21	37.03	12	46.40	30	12.37	
49	95.00	56	118.17	97	46.27	67	43.30	26	292.00	101	84.67	72	36.17	56	46.10	17	12.08	
89	95.00	52	116.63	50	44.60	26	43.07	105	285.33	11	83.33	18	36.07	101	45.90	20	11.96	
94	95.00	97	116.10	65	44.57	66	43.00	86	284.67	84	83.67	103	36.03	72	45.80	22	11.86	
77	94.33	64	115.93	1	44.27	78	42.83	100	284.33	13	82.67	2	35.77	74	45.60	14	11.78	
75	91.33	17	113.27	93	44.26	103	42.67	70	282.67	21	81.33	22	35.63	85	45.43	34	11.75	

**Table 6.** Mean performance of the lines, the ten highest and the ten lowest for each character.

	NS			LS		
	High	Low	Difference	High	Low	Difference
Days to 50% flowering	113.167	83.733	29.434	99.367	74.033	25.334
Plant height (cm)	137.510	84.030	53.48	122.503	72.593	46.91
Peduncle length (cm)	54.827	31.710	23.117	48.647	25.880	22.767
Flag leaf area (cm <sup>2</sup> )	54.527	23.437	31.09	45.407	24.423	20.984
Biological yield/1/2 m row length (g)	365.367	184.533	180.834	302.200	154.533	147.667
Grain yield/1/2 m row length (g)	120.467	51.400	69.067	88.533	44.433	44.100
HI (%)	37.270	23.563	13.707	38.517	23.303	15.214
1000 grain weight (g)	52.190	37.297	14.893	47.320	34.893	12.427
Protein content (%)	13.086	7.881	5.205	12.683	7.552	5.131

whereas line 55 and 58 took 81 and 73 days to heading. Under normal environmental conditions, early heading and late maturity permits a long grain-filling period, which leads to higher grain yields in cereals. However, high-temperature stress alters the pattern of plant development [5]. The data further showed significant differences in number of days to heading in timely and late sown conditions. The maximum days to heading (121) was recorded in November/December whereas wheat planted in December, took maximum 106 days to heading presumably due to cold weather effect during early crop growth stages. In all RILs, the time to heading was reduced with delays in sowing. In timely sown crop, the time to heading cor-

responds with favorable lower temperature in months of February (average max temp: 20.8°C and average minimum temperature: 7.6°C), while the late sown crop in December suffered from heat stress during grain formation stage in March (average max temp: 26.3°C and average minimum temperature: 12.2°C) leading to shrivelled grain development and reduction in grain yield (Fig. 1). Heading and maturity are important traits that are related to the adaptation of wheat cultivars under prevalent field conditions in particular areas. Vulnerability of species and cultivars to high temperatures may vary with the stage of plant development; however, all cultivars experience heat stress at reproductive stage to some extent [6].

**Table 7.** Genotypic and phenotypic correlation coefficients between yield related traits and protein content in the HUW-510 × WH-730 RIL population of bread wheat evaluated under timely sown (TS) experiment of *rabi* season, 2013-14.

Traits	Days to 50% flowering	Plant height (cm)	Peduncle length (cm)	Flag leaf area (cm <sup>2</sup> )	Biological yield/	Grain yield/	Harvest index (%)	1000 grain weight (g)	Protein content (%)
					row length (g)	row length (g)			
Days to 50% flowering	1	-0.13*	-0.43**	0.31**	-0.16**	-0.27**	-0.23**	-0.28**	-0.14*
Plant height (cm)	-0.12*	1	0.65**	0.04	0.49**	0.36**	-0.02	0.37**	-0.12*
Peduncle length (cm)	-0.42**	0.64**	1	-0.03	0.39**	0.33**	0.03	0.35**	0.03
Flag leaf area (cm <sup>2</sup> )	0.30**	0.04	-0.02	1	0.16**	0.09	-0.08	0.09	0.000
Biological yield/50 cm row length (g)	-0.15**	0.49**	0.38**	0.15**	1	0.81**	0.02	0.79**	-0.03
Grain yield/50 cm row length (g)	-0.26**	0.36**	0.32**	0.08	0.80**	1	0.59**	0.93**	-0.08
Harvest index (%)	-0.21**	-0.02	0.03	-0.07	0.01	0.59**	1	0.50**	-0.11*
1000 grain weight (g)	-0.28**	0.36**	0.34**	0.08	0.78**	0.92**	0.47**	1	-0.13*
Protein content (%)	-0.13*	-0.11*	0.03	0.00	-0.03	-0.08	-0.10	-0.13*	1

**Table 8.** Genotypic and phenotypic correlation coefficients between yield related traits and protein content in the HUW-510 × WH-730 RIL population of bread wheat evaluated under late sown (LS) experiment of *rabi* season, 2013-14.

Traits	Days to 50% flowering	Plant height (cm)	Peduncle length (cm)	Flag leaf area (cm <sup>2</sup> )	Biological yield/50 cm row length (g)	Grain yield/50 cm row length (g)	Harvest index (%)	1000 grain weight (g)	Protein content (%)
Days to 50% flowering	1	-0.03	-0.24**	0.18**	-0.10	-0.09	-0.00	-0.29**	-0.08
Plant height (cm)	0.03	1	0.64**	0.06	0.19**	0.05	-0.21**	0.29**	-0.25**
Peduncle length (cm)	-0.23**	0.63**	1	0.05	0.20**	0.08	-0.18**	0.33**	-0.07
Flag leaf area (cm <sup>2</sup> )	0.17**	0.05	0.04	1	0.24**	0.13*	-0.14*	0.23**	-0.06
Biological yield/50 cm row length (g)	-0.09	0.19**	0.20**	0.24**	1	0.76**	-0.35**	0.57**	-0.06
Grain yield/50 cm row length (g)	-0.08	0.05	0.08	0.12*	0.75**	1	0.34**	0.50**	-0.15**
Harvest index (%)	-0.00	-0.21**	-0.18**	-0.14*	-0.34**	0.35**	1	-0.09	-0.11*
1000 grain weight (g)	-0.08	0.28**	0.33**	0.22**	0.56**	0.49**	-0.09	1	-0.23**
Protein content (%)	-0.08	-0.25**	-0.07	-0.06	-0.06	-0.14*	-0.10	0.22**	1

Thousand-grain weight is a genetic character and influenced by the environment. The grain weight was higher in TS wheat 54.33–39.73 as compare to LS 50.13–36.43 for Dec. The average 1000 grain weight for RILs was 44.4 and 40.9 in TS and LS conditions, respectively (Fig. 2). Parents viz. HUW 510 and WH 730 had 40.8 and 38.7 g 1000 grain weight in TS and LS conditions, respectively. Many workers have also reported a decrease in wheat grain weight due to late sowing [7]. This is because the delayed sowing shortens the duration of each development phase which ultimately reduces grain filling period resulting in lower grain weight. The green photosynthetic area which is

responsible for carbohydrate formation, grain filling and final grain yield reduced by forced maturity caused by terminal heat stress.

RIL No. 36 and 9 having protein (%) of 14.88, 14.26 in timely sown environment and 13.96, 13.84 in late sown environment retained its position among top 10 performing RILs in both environments.

There were significant differences between the 10 best lines selected for high and low values of the traits in TS and LS conditions. There were significant differences between the lines selected for high and

**Table 9.** Path coefficient analysis of yield related traits and protein content in the HUW-510 × WH-730 RIL population of bread wheat evaluated under timely sown (TS) experiment of *rabi* season, 2013-14. Residual effect=0.094.

Traits	Days to 50% flowering	Plant height (cm)	Peduncle length (cm)	Flag leaf area (cm <sup>2</sup> )	Biological yield/1/2 m row length (g)	Harvest index (%)	1000 grain weight (g)	Protein content (%)
Days to 50% flowering	<b>-0.003</b>	0.000	0.001	-0.001	0.000	0.001	0.001	0.000
Plant height (cm)	0.004	<b>-0.028</b>	-0.018	-0.001	-0.014	0.001	-0.010	0.003
Peduncle length (cm)	-0.005	0.007	<b>0.011</b>	-0.000	0.004	0.000	0.004	0.000
Flag leaf area (cm <sup>2</sup> )	0.001	0.000	-0.000	<b>0.004</b>	0.000	-0.000	0.000	0.000
Biological yield/1/2m row length (g)	-0.115	0.359	0.279	0.115	<b>0.728</b>	0.017	0.575	-0.023
Harvest index (%)	-0.122	-0.013	0.018	-0.040	0.012	<b>0.526</b>	0.263	-0.060
1000 grain weight (g)	-0.029	0.037	0.035	0.009	0.080	0.050	<b>0.101</b>	-0.013
Protein content (%)	-0.001	-0.001	0.000	0.000	-0.000	-0.001	-0.001	<b>0.009</b>
Grain yield/1/2m row length (g)	-0.269	0.361	0.327	0.085	0.8112	0.594	0.932	-0.084

**Table 10.** Path coefficient analysis of yield related traits and protein content in the HUW-510 × WH-730 RIL population of bread wheat evaluated under late sown (LS) experiment of *rabi* season, 2013-14. Residual effect=0.120.

Traits	Days to 50% flowering	Plant height (cm)	Peduncle length (cm)	Flag leaf area (cm <sup>2</sup> )	Biological yield/1/2 m row length (g)	Harvest index (%)	1000 grain weight (g)	Protein content (%)
Days to 50% flowering	<b>0.014</b>	0.001	-0.003	0.003	-0.001	0.000	-0.004	-0.001
Plant height (cm)	-0.000	<b>-0.010</b>	-0.0063	-0.001	-0.002	0.002	-0.003	0.003
Peduncle length (cm)	-0.005	0.014	<b>0.021</b>	0.001	0.004	-0.004	0.007	-0.001
Flag leaf area (cm <sup>2</sup> )	-0.003	-0.001	-0.001	<b>-0.018</b>	-0.004	0.003	-0.004	0.001
Biological yield/1/2m row length (g)	-0.099	0.187	0.198	0.242	<b>1.001</b>	-0.347	0.569	-0.057
Harvest index (%)	-0.001	-0.143	-0.123	-0.098	-0.237	<b>0.683</b>	-0.064	-0.072
1000 grain weight (g)	0.003	-0.003	-0.003	-0.002	-0.005	0.001	<b>-0.009</b>	0.002
Protein content (%)	0.002	0.005	0.001	0.001	0.001	0.002	0.004	<b>-0.020</b>
Grain yield/1/2m row length (g)	-0.091	0.051	0.084	0.128	0.757	0.341	0.497	-0.146

low values of the traits under study (Table 6). More variation for the traits were found in TS condition as compare to LS suggested that genotypes were more influenced by environment.

Mutual relationship between grain yield and its contributing characters revealed that the genotypic correlation coefficient were higher than the corresponding phenotypic correlation coefficient in most cases indicating strong inherent relationship between the traits, but suppressing the effect of the environment, which modified the phenotypic expression of these characters by reducing phenotypic coefficient values. A strong and positive association of grain yield with biological yield (0.80\*\*, 0.75\*\*), 1000 grain weight (0.92\*\* 0.49\*\*), harvest index (0.59\*\*, 0.35\*\*) and plant height (0.36\*\*, 0.05) was observed consistently across the environments (Tables 7 and 8). So, grain yield can be improved by exercising selection on any of these traits. Days to 50% flowering (-0.26\*\*) showed negative significant correlation with grain yield in timely sown experiment but not in late sown experiment. In TS environment delay in heading will expose the plants to the heat stress Alvaro et al. [8] showed that high grain yield in durum wheat was associated with an extended period of the pre-heading stage. No significant association observed in late sown experiment. Plant height exhibited positive association with 1000 grain weight (0.36\*\*). Similar results were recorded by Choudhary et al. [9]. The genetic cause of association between two traits may result from pleiotropy, linked genes or epistasis. Since,

RIL population was descended from F2, population. Therefore, most probable genetic cause for association between traits in this population is linkage disequilibrium rather than pleiotropy.

The improvement of both yield and protein characters has been hampered due to strong negative association as reported earlier [10]. In the present study, protein content in the RILs in general was not associated with grain yield or it had a very weak negative association (-0.08, -0.14\*). Thus it appears that protein content and grain yield can be improved simultaneously in this population. The correlation between traits is a population specific traits, that may depend on genetic structure of a specific population.

The correlation coefficient indicates only linear relationship existing between pair of characters. But, a dependent character is an interaction of product of many component characters and change in any one component will disturb whole network. The path coefficient analysis takes into account the cause and effect relationship between the variables which is unique in partitioning the associations into direct and indirect effects through other in dependent variables. The path analysis revealed that in both the environments i.e. TS and LS, biological yield (0.728, 1.001), harvest index (0.526, 0.683) and peduncle length (0.011, 0.021) were 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 (Tables 9 and 10).

This established that due weightage should be given to these traits for improvement of grain yield in wheat. Plant height showed negative direct contribution with grain yield (-0.028) hence, dwarf varieties are preferred, as they could withstand in lodging conditions [11]. Positive indirect effect was observed for 1000 grain weight on grain yield via biological yield (0.080). In the present study protein content showed very weak negative direct effect on grain yield (-0.020). It means yield loss may not occur in this population, during the selection of a variety for high protein content. The indirect contribution of various traits was not substantial towards the association of protein content with grain yield.

The study of genotype  $\times$  environment interactions forms an important aspect of all major breeding programs. These interaction often create manifold difficulties in interpreting results from the experiments carried out in different agro-climate situations, thereby these are an obstacle in depicting successful strategies in breeding programs aiming at further genetic improvement in crop plants. For grain yield, RIL No. 58 and 11 retaining their position among top performing RILs over the environment, were found desirable based on this screening for their *per se* performance. On the other hand there were some RILs (TS: 51, 52, 79, 74, 26, 39, 11, 1, 16, 31 and LS: 55, 58, 23, 19, 12, 20, 32, 101, 11, 84, 13, 21) that performed better in one of the two environments. It is recommended that above mentioned RILs performing better for a yield and related trait may be used as a potential donor parent for genetic improvement of respective trait in wheat breeding and ultimately affecting the genetic improvement of morpho-physiological traits and protein content.

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