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Effect of Late Sowing on Bread Wheat Resilience to Terminal Heat stress based on Morphological and Quality Traits

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ABSTRACT: Crop improvement programmes require precise knowledge of germplasm variability and genetic relationships among breeding material. To study the effect of late sowing on variability and association among twenty three morphological and quality traits, the experiment was carried out with sixty advance breeding lines along with four standard checks of wheat during *Rabi* 2020-21 at the research area of Wheat and Barley section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar. The study revealed highly significant differences among the advance lines for yield and its contributing traits. The magnitude of phenotypic coefficient of variation (PCV) was slightly higher than their respective genotypic coefficient of variation (GCV) for all the characters, indicating the least influence of environment on the characters studied. The estimates of PCV, GCV, heritability and genetic advance were observed to be high for total soluble sugars, while grain weight per spike, crude protein, sedimentation value, wet gluten, dry gluten and total gluten had moderate GCV, PCV along with high heritability and genetic advance, suggesting the possibility of improving these traits through selection. Grain yield per plot was found to have significant and positive correlation with days to heading, number of effective tillers per metre, spike length, number of spikelets per spike, flag leaf length, peduncle length, main spike weight, grain weight per spike, number of grains per spike, 1000 grain weight, biological yield per plot, harvest index and hectolitre weight, depicting the prospect of improving these yield contributing traits concurrently. Whereas, grain yield showed a negative significant correlation with crude protein and sedimentation value. The path coefficient analysis showed that almost all the traits contributed to grain yield per plot *via* biological yield per plot and harvest index, indicating that indirect selection through both these traits would lead to crop improvement. A remarkable magnitude of genetic variability was found that can be used for selection of heat tolerant lines.

Keywords: Late sown, Genetic variability, Morphological and Quality traits.

INTRODUCTION

Wheat [*Triticum aestivum* (L) em. Thell] is one of the most widely grown monocot cereal crop, accounting for approximately 30 per cent of global grain production and 50 per cent of the global grain trade. It is a disomic allohexaploid with three homoeologous genomes (AABBDD) that originated in the Levant region to the East and the Ethiopian Highlands. Over the last fifty years, India has achieved self-sufficiency and has risen to become the world's second-largest wheat producer and a significant exporter. To meet the demands of an ever-increasing population by 2050, wheat production will need to increase by 60 per cent with an annual growth rate of 2 per cent (Agcaoili and Rosegrant 1995).

But production is limited by ongoing and upcoming challenges, among which, increased temperature stress is becoming more of a concern. Heat stress presently affects 40 per cent of the wheat growing area in the world's arid, semi-arid, tropical and sub-tropical regions (Ashraf and Harris 2005), occupying over 36 million ha (Reynolds *et al*., 2001), the majority of which is in India (Joshi *et al*., 2007).

Terminal heat stress halts the crop's anatomy, morphology, biochemistry, physiology and ultimately reduces the grain yield. As a result, improving genetically governed high temperature tolerance in wheat by combining multiple approaches has become a major wheat breeding goal. The expansion of genetic variability in the wheat gene pool is critical for breeding programmes aiming at increasing heat tolerance during the reproductive and grain filling stages, as crop improvement success is primarily influenced by the magnitude of genetic variability and the degree to which desired traits are heritable. Grain yield is a dynamic trait controlled by various morpho-physiological factors (Reynolds *et al*., 1994). Therefore, it is necessary to separate the total variation into its heritable and non-heritable components with the help of genetic parameters. Genotypic coefficient of variation, phenotypic coefficient of variation, heritability and genetic advance are all valuable tools for determining the variability and transmissibility of the linked traits. Moreover, the selection criteria for segregating generation is based on correlation and path analysis, that assesses the degree of relationship as well as the direct and indirect association between two or more traits. This study aimed to examine genetic variability and association analysis among traits to develop selection criteria for producing thermotolerant cultivars by morphological and biochemical evaluation of wheat genotypes under late sown conditions.

MATERIALS AND METHODS

The experimental material comprised of sixty advance lines of wheat along with four standard checks *viz.*, WH 1021, WH 1124, DBW 90 and HD 3059 that were evaluated under late sown conditions at the research area of the Wheat and Barley Section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar during *Rabi* 2020-21. The seeds of all the lines were sown with a hand plough in a Randomized Block Design (RBD) with three replications. The field was divided into blocks of uniform fertility. Treatments were assigned at random to each block with a plot size of 6.48 square metres. Each plot had 6 rows, each of 6 m length and 18 cm row to row spacing. Recommended package of practices for late sown condition was followed, so that genotypes may express their full genetic potential. Observations were recorded for fifteen morphological traits *viz.*, days to heading, days to maturity, plant height, number of spikelets per spike, spike length, peduncle length, flag leaf length, main spike weight, number of grains per spike, grain weight per spike, 1000 grain weight, number of effective tillers per metre, grain yield per plot, biological yield per plot, harvest index from five plants chosen at random from each entry of the three replications. Eight quality traits *viz.*, grain appearance score, hectolitre weight, sedimentation value, wet gluten, dry gluten, total gluten, crude protein, and total soluble sugars were assessed for each replication and the average was taken for statistical analysis. Analysis of variance of the observations for different traits to test the variations among the advance breeding lines was carried out as per the standard procedure suggested by Fisher (1925) and described by Panse and Sukhatme (1967). Coefficients of correlation were determined by using the variance and covariance components as suggested by Al-jibouri *et al*. (1958). Path coefficient analysis was done by using phenotypic correlation values of yield and its components as described by Wright (1921) and illustrated by Dewey and Lu (1959).

RESULTS AND DISCUSSION

A. Variability Parameters

The crop improvement *via* selection is largely influenced by the presence of genetic variability in the germplasm and its exploitation. The analysis of variance, as presented in Table 1, showed that the mean sum of squares due to genotypes were highly significant ($p < 0.01$) for all the studied traits indicating considerable magnitude of genetic variability, that can be used for selection of heat tolerant lines for further crop improvement. Baye *et al*. (2020); Neeru *et al.* (2017); Kumar *et al.* (2018) reported significant differences among genotypes for grain yield and its component traits in bread wheat. The genetic parameters *viz.*, mean, range, genotypic coefficient of variation, phenotypic coefficient of variation, heritability, and genetic advance as per cent of mean are presented in Table 2, with which impact of environment can be measured. The frequency heat map as shown in the Figure 1depicts variability for the studied traits. For each of the traits, the intensity of blue colour showed the frequency of genotypes in that specific range, as for days to heading, maximum number of genotypes fall in the range 80-90 and a few in the range of 70-80.

B. Phenotypic and Genotypic Coefficient of Variation

The magnitude of PCV values were higher than the GCV values indicating little influence of environment on the phenotypic expression of all the studied traits. Similar conclusions were also cited by Monpara (2011); Kumar *et al.* (2014); Parihar *et al.* (2018); Ramanuj *et al.* (2018) for morphological traits and Aashu *et al.* (2022) for quality traits. The phenotypic coefficient of variation ranged from 2.26 (Days to heading) to 31.74 (TSS%), while the genotypic coefficient of variation ranged from 2.53 (Grain appearance score) to 32.62 (TSS%). The PCV and GCV estimates were observed to be high for total soluble sugars (32.62, 31.74) followed by wet gluten (18.46, 18.26), total gluten (17.53, 17.31), dry gluten (17.06,15.86), grain weight per spike (14.99,12.68), sedimentation value (13.76, 13.16) and crude protein (11.88, 11.50) depicting the scope of improvement of these traits through selection among the advance lines. The results were in accordance with Aashu *et al.* (2022) for total soluble sugars and Nukasani *et al.* (2013) for grain yield. Lower PCV and GCV values were observed for days to heading (2.56, 2.26), days to maturity (2.68, 2.38) and plant height (6.00, 4.53), which were in accordance with Neeru *et al*. (2017). Monpara (2011); Babar *et al*. (2022), indicating lesser variability among genotypes for the respective traits.

C. Heritability and Genetic Advance

The GCV alone would not be an accurate measure of the heritable variations present, so it is taken into account with heritability estimates to obtain a more accurate picture of the amount of the advance to be anticipated from the selections. Heritability ranged from 51.55 per cent to 97.81 per cent. The maximum heritability was shown by days to heading (77.85 %), grain weight per spike (71.56 %), 1000 grain weight (60.87 %), days to maturity (79.32 %), harvest index (61.37 %), hectolitre weight (81.54 %), grain appearance score (95.46 %), sedimentation value (91.54 %), wet gluten (97.81 %), dry gluten (86.47 %), total gluten (97.51 %), crude protein (93.68 %) and total soluble sugars (94.63 %), while it being moderate for plant height (57.01 %), spike length (53.41 %), number of spikelets per spike (51.55 %), peduncle length (53.74 %), number of effective tillers per metre(54.67 %), flag leaf length (54.58 %), main spike weight (59.04 %), number of grains per spike (58.06 %), biological yield per plot (56.22 %) and grain yield per plot (58.00 %) suggesting that selection should be delayed to more advance generation for these characters.

Table 1: Analysis of variance for various morphological and quality traits in advance lines of wheat under late sown conditions.

Source of Variation	d.f.	Mean sum of squares							
		DH	PH	NET/m	SL	NS/S	FLL	PL	MSW
Replication	**2**	1.313	17.12	8.859	0.167	1.266	4.069	0.193	0.245
Treatment	**63**	11.611**	67.965**	151.219**	1.466**	5.614**	9.192**	14.55**	0.285**
Error	**126**	1.006	13.654	58.336	0.33	1.509	3.554	5.757	0.098

Source of Variation	d.f.	Mean sum of squares							
		GW/S	NG/S	TGW	DM	BY/P	HI	GY/P	CP
Replication	**2**	0.056	3.943	0.465	6.297	193605.609	3.061	36436.875	0.035
Treatment	**63**	0.34**	71.649**	27.026**	26.613**	1459449.281**	8.843**	219852.824**	5.334**
Error	**126**	0.04	13.906	8.794	2.128	300776.186	1.534	42748.36	0.117

Source of Variation	d.f.	Mean sum of squares						
		SV	HW	GAS	WG	DG	TG	TSS
Replication	**2**	25.797	1.315	0.186	2.246	0.071	2.938	0.013
Treatment	**63**	101.847**	10.501**	0.492**	103.622**	8.147**	161.49**	0.595**
Error	**126**	3.046	0.737	0.008	0.769	0.404	1.361	0.011

** Significant at 1% level of significance

DH: Days to heading, **PH**: Plant height (cm), **NET/m**: Number of effective tillers per metre, **SL**: Spike length (cm), **NS/S**: Number of spikelets per spike, **FLL**: Flag leaf length (cm), **PL**: Peduncle length (cm), **MSW**: Main spike weight (g), **GW/S**: Grain weight per spike (g), **NG/S**: Number of grains per spike, **TGW**: 1000 grain weight (g), **DM**: Days to maturity, **BY/P**: Biological yield per plot (g), **GY/P**: Grain Yield per plot (g), **HI**: Harvest Index (%), **CP**: Crude Protein (%), **SV**: Sedimentation Value (ml), **HW**: Hectolitre weight (Kg/hl), **GAS**: Grain Appearance Score (max. 10), **WG**: Wet Gluten (%), **DG**: Dry Gluten (%), **TG**: Total Gluten (%), **TSS**: Total Soluble Sugars (%)

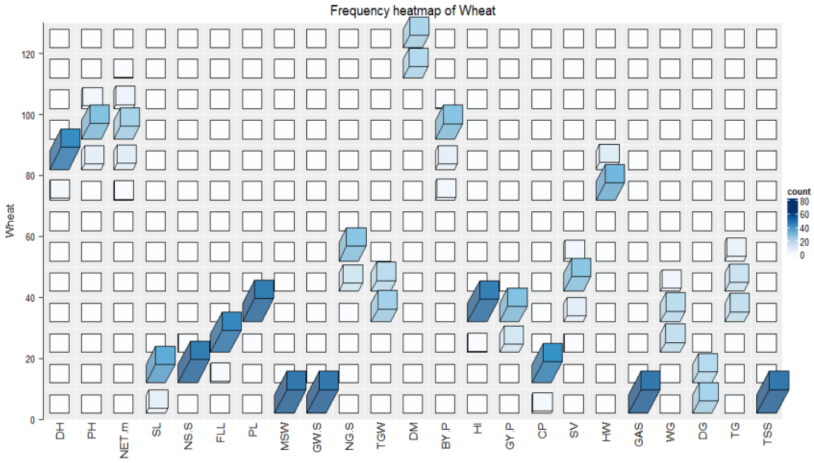
Table 2: Mean, GCV, PCV, heritability and genetic advance for various morphological and quality traits in bread wheat under late sown conditions.

Traits	Mean ± SE(m)	Range		Heritability	GCV	PCV	GA (5 % of mean)
		Minimum	Maximum				
DH	83 ± 0.58	78	88	77.85	2.26	2.56	4.11
PH (cm)	93.96 ± 2.13	84	103	57.01	4.53	6.00	7.04
NET/m	94 ± 4.43	72	112	54.67	5.90	10.02	7.16
SL (cm)	10.46 ± 0.33	8.6	12.5	53.41	5.88	8.05	8.86
NS/S	17 ± 0.66	15	21	51.55	6.75	9.79	9.59
FLL (cm)	23.11 ± 1.09	19	27	54.58	5.93	10.09	7.19
PL (cm)	36.69 ± 1.39	29	40	53.74	4.67	8.03	5.58
MSW (g)	3.01 ± 0.18	2.27	3.78	59.04	8.31	13.31	10.70
GW/S (g)	2.50 ± 0.12	1.47	2.98	71.56	12.68	14.99	22.09
NG/S	51 ± 2.14	38	60	58.06	8.61	11.30	13.51
TGW (g)	39.19 ± 1.71	31.41	44.38	60.87	6.29	9.84	8.28
DM	120 ± 0.84	114	126	79.32	2.38	2.68	4.37
BY/P (g)	9203.39 ± 316.64	7533.33	10066.67	56.22	6.75	9.01	10.43
HI (%)	33.69 ± 0.72	26.24	36.19	61.37	4.63	5.92	7.48
GY/P (g)	3119.07 ± 119.38	2406.11	3513.35	58.00	7.79	10.23	12.22
CP (%)	11.47 ± 0.20	9.34	16.03	93.68	11.50	11.88	22.92
SV (ml)	43.61 ± 1.01	29.00	57.00	91.54	13.16	13.76	25.94
HW (kg/hl)	78.91 ± 0.49	71.72	82.62	81.54	2.29	2.53	4.25
GAS	5.45 ± 0.05	4.4	6.3	95.46	7.37	7.54	14.83
WG (%)	32.07 ± 0.51	22.70	42.79	97.81	18.26	18.46	37.20
DG (%)	10.13 ± 0.55	7.28	14.10	86.47	15.86	17.06	30.39
TG (%)	42.2 ± 0.86	30.30	55.84	97.51	17.31	17.53	35.22
TSS (%)	1.39 ± 0.06	0.96	2.97	94.63	31.74	32.62	63.59

DH: Days to heading, **PH**: Plant height (cm), **NET/m**: Number of effective tillers per metre, **SL**: Spike length (cm), **NS/S**: Number of spikelets per spike, **FLL**: Flag leaf length (cm), **PL**: Peduncle length (cm), **MSW**: Main spike weight (g), **GW/S**: Grain weight per spike (g), **NG/S**: Number of grains per spike, **TGW**: 1000 grain weight (g), **DM**: Days to maturity, **BY/P**: Biological yield per plot (g), **GY/P**: Grain Yield per plot (g), **HI**: Harvest Index (%), **CP**: Crude Protein (%), **SV**: Sedimentation Value (ml), **HW**: Hectolitre weight (Kg/hl), **GAS**: Grain Appearance Score (max. 10), **WG**: Wet Gluten (%), **DG**: Dry Gluten (%), **TG**: Total Gluten (%), **TSS**: Total Soluble Sugars (%)

Similar findings were observed by Singh *et al.* (2013) for days to maturity and 1000 grain weight, Suresh *et al*. (2018) for days to heading and harvest index, Upadhyay *et al*. (2019) for grain weight per spike, Saini *et al.* (2020) for harvest index, Kumar *et al.* (2021); Aashu *et al.* (2022) for quality traits. The genetic advance as per cent of mean varied from 4.11 per cent to 63.59 per cent, exhibiting all the three categories.

High heritability in conjunction with high genetic advance observed for grain weight per spike (22.09), crude protein (22.92), sedimentation value (25.94), wet gluten (37.20), dry gluten (30.39), total gluten (35.22) and total soluble sugars (63.59), indicated predominant effects of additive gene action. Such results are in concurrence with the results of Upadhyay *et al*. (2019) for grain weight per spike and Aashu *et al.* (2022) for total soluble sugars, wet gluten, total gluten and sedimentation value Low genetic advance as per cent of mean for number of spikelets per spike (9.59), spike length (8.86), 1000 grain weight (8.28), harvest index (7.48), flag leaf length (7.19), number of effective tillers per metre (7.16), plant height(7.04), peduncle length (5.58), days to maturity (4.37), hectolitre weight (4.25) and days to heading (4.11) depicted the need of slight changes in improvement for these traits in subsequent generations.



DH: Days to heading, **PH**: Plant height (cm), **NET/m**: Number of effective tillers per metre, **SL**: Spike length (cm), **NS/S**: Number of spikelets per spike, **FLL**: Flag leaf length (cm), **PL**: Peduncle length (cm), **MSW**: Main spike weight (g), **GW/S**: Grain weight per spike (g), **NG/S**: Number of grains per spike, **TGW**: 1000 grain weight (g), **DM**: Days to maturity, **BY/P**: Biological yield per plot (g), **GY/P**: Grain Yield per plot (g), **HI**: Harvest Index (%), **CP**: Crude Protein (%), **SV**: Sedimentation Value (ml), **HW**: Hectolitre weight (Kg/hl), **GAS**: Grain Appearance Score (max. 10), **WG**: Wet Gluten (%), **DG**: Dry Gluten (%), **TG**: Total Gluten (%), **TSS**: Total Soluble Sugars (%)

Fig. 1. Frequency heat map depicting variability for the various morphological and quality traits of wheat under late sown conditions.

D. Correlation Coefficient Analysis

As it is not practical to include different component traits in a selection procedure, understanding the relationship between various traits and grain yield becomes important. The phenotypic correlation coefficients estimated to find out the degree of association among different morphological and quality traits are depicted in Table 3(a) and 3(b) respectively. The highest degree of association with grain yield per plot was shown by biological yield per plot (0.853**) followed by flag leaf length (0.665**), grain weight per spike (0.652**), peduncle length (0.564**), number of effective tillers per metre (0.513**), number of spikelets per spike (0.510**), harvest index (0.500**), 1000 grain weight (0.499**), main spike weight (0.451**), spike length (0.408**), number of grains per spike (0.385**), days to heading (0.203**). These results agree with findings of Wani *et al.* (2011) for tillers per square meter, spike length, number of grains per spike and harvest index, Ali (2012) for biological yield and harvest index, Nukasani *et al*. (2013) for number of tillers per metre and grain weight per spike, Bhutto *et al.* (2016) for number of tillers per metre and number of grains per spike, Mecha *et al.* (2017) for hectolitre weight. The biological yield per plot also exhibited a positive significant association with flag leaf length (0.629**), grain weight per spike (0.556**), peduncle length (0.485**), number of effective tillers per metre (0.445**), main spike weight (0.391**), 1000 grain weight (0.390**), spike length (0.374**), number of grains per spike (0.372**), number of spikelets per spike (0.355**) and days to heading (0.190*). However, it showed a negative significant association with days to maturity (-0.228**).

Among morphological traits, the grain yield per plot exhibited a positive and significant association with all the traits except plant height and days to maturity, while it exhibited a positive significant correlation with hectolitre weight (0.160**) and showed a negative significant correlation with crude protein (-0.195**) and sedimentation value (-0.230**) among quality traits. Rharrabti *et al*. (2001); Amiri *et al.* (2018); Aashu *et al*. (2022) reported similar results for quality traits. These negative associations may be due to linkage or pleiotropy that can be improved by recombination through biparental mating and diallel selective mating.

Table 3(a): Phenotypic correlation coefficients among grain yield and its component traits in bread wheat under late sown conditions.

	DH	PH	NET/m	SL	NS/S	FLL	PL	MSW	GW/S	NG/S	TGW	DM	BY/P	HI	GY/P
DH															
PH	0.019														
NET/m	-0.098	-0.002													
SL	0.105	0.106	0.331**												
NS/S	0.248**	0.191**	0.358**	0.457**											
FLL	0.059	0.058	0.518**	0.412**	0.511**										
PL	-0.034	0.009	0.445**	0.379**	0.287**	0.573**									
MSW	0.245**	0.092	0.320**	0.351**	0.414**	0.432**	0.414**								
GW/S	0.144*	0.136	0.394**	0.325**	0.455**	0.581**	0.439**	0.448**							
NG/S	0.085	-0.004	0.064	0.228**	0.266**	0.412**	0.236**	0.267**	0.506**						
TGW	0.119	0.049	0.339**	0.315**	0.292**	0.346**	0.305**	0.281**	0.356**	-0.005					
DM	0.423**	0.224**	-0.095	0.062	0.213**	-0.176*	-0.137	0.09	-0.083	-0.113	0.083				
BY/P	0.190**	-0.001	0.445**	0.374**	0.355**	0.629**	0.485**	0.391**	0.556**	0.372**	0.390**	-0.228**			
HI	0.092	0.087	0.224**	0.12	0.378**	0.137	0.191**	0.098	0.190**	0.048	0.263**	0.237**	-0.045		
GY/P	**0.203****	**0.06**	**0.513****	**0.408****	**0.510****	**0.665****	**0.564****	**0.451****	**0.652****	**0.385****	**0.499****	**-0.104**	**0.853****	**0.500****	

DH: Days to heading, **PH**: Plant height (cm), **NET/m**: Number of effective tillers per metre, **SL**: Spike length (cm), **NS/S**: Number of spikelets per spike, **FLL**: Flag leaf length (cm), **PL**: Peduncle length (cm), **MSW**: Main spike weight (g), **GW/S**: Grain weight per spike (g), **NG/S**: Number of grains per spike, **TGW**: 1000 grain weight (g), **DM**: Days to maturity, **BY/P**: Biological yield per plot (g), **GY/P**: Grain Yield per plot (g), **HI**: Harvest Index (%), **CP**: Crude Protein (%), **SV**: Sedimentation Value (ml), **HW**: Hectolitre weight (Kg/hl), **GAS**: Grain Appearance Score (max. 10), **WG**: Wet Gluten (%), **DG**: Dry Gluten (%), **TG**: Total Gluten (%), **TSS**: Total Soluble Sugars (%)

Table 3(b): Phenotypic correlation coefficients among grain yield and eight quality traits in bread wheat under late sown conditions.

	CP	SV	HW	GAS	WG	TG	DG	TSS	GY/P
CP									
SV	-0.072								
HW	-0.175*	-0.006							
GAS	-0.237**	0.225**	0.175*						
WG	-0.132	0.191**	-0.014	0.289**					
TG	-0.039	0.1	-0.012	0.254**	0.816**				
DG	-0.114	0.176*	-0.014	0.290**	0.991**	0.887**			
TSS	-0.043	-0.05	0.03	0.182*	0.139	0.13	0.142		
GY/P	**-0.195****	**-0.230****	**0.160***	**-0.126**	**-0.088**	**-0.066**	**-0.086**	**-0.096**	

DH: Days to heading, **PH**: Plant height (cm), **NET/m**: Number of effective tillers per metre, **SL**: Spike length (cm), **NS/S**: Number of spikelets per spike, **FLL**: Flag leaf length (cm), **PL**: Peduncle length (cm), **MSW**: Main spike weight (g), **GW/S**: Grain weight per spike (g), **NG/S**: Number of grains per spike, **TGW**: 1000 grain weight (g), **DM**: Days to maturity, **BY/P**: Biological yield per plot (g), **GY/P**: Grain Yield per plot (g), **HI**: Harvest Index (%), **CP**: Crude Protein (%), **SV**: Sedimentation Value (ml), **HW**: Hectolitre weight (Kg/hl), **GAS**: Grain Appearance Score (max. 10), **WG**: Wet Gluten (%), **DG**: Dry Gluten (%), **TG**: Total Gluten (%), **TSS**: Total Soluble Sugars (%)

Table 4(a): Path coefficient analysis based on phenotypic correlation showing direct (diagonal) and indirect (off-diagonal) effects of morphological traits on grain yield per plot under late sown conditions.

	DH	PH	NET/m	SL	NS/S	FLL	PL	MSW	GW/S	NG/S	TGW	DM	BY/P	HI	r with GY/P
DH	**0.02491**	0.00022	-0.00025	0.00064	-0.00309	0.00329	-0.00143	0.01069	0.01393	0.00151	0.0058	-0.01986	0.12709	0.0396	**0.203****
PH	0.00047	**0.01165**	0.0001	0.00054	-0.00238	0.00328	0.00039	0.00401	0.01314	-0.00007	0.00239	-0.01053	-0.00007	0.03731	**0.06**
NET/m	-0.00245	-0.00002	**0.12259**	0.002	-0.00446	0.02906	0.01842	0.01397	0.03804	0.00114	0.01647	0.00447	0.17711	0.09622	**0.513****
SL	0.00262	0.00123	0.00086	**0.00604**	-0.00569	0.02311	0.01569	0.01531	0.03137	0.00405	0.01532	-0.00291	0.24986	0.05142	**0.408****
NS/S	0.00619	0.00223	0.00093	0.00276	**0.01246**	0.02867	0.01187	0.01807	0.03186	0.00471	0.01417	-0.01001	0.22394	0.16198	**0.510****
FLL	0.00146	0.00068	0.00134	0.00249	-0.00637	**0.05609**	0.02372	0.01885	0.05607	0.0073	0.01682	0.00827	0.41967	0.05894	**0.665****
PL	-0.00086	0.00011	0.00115	0.00229	-0.00358	0.03217	**0.04136**	0.01805	0.04238	0.00419	0.0148	0.00642	0.32374	0.08173	**0.564****
MSW	0.00611	0.00107	0.00083	0.00212	-0.00516	0.02424	0.01712	**0.04361**	0.04324	0.00473	0.01366	-0.00422	0.26126	0.04205	**0.451****
GW/S	0.0036	0.00159	0.00102	0.00196	-0.00567	0.0326	0.01817	0.01955	**0.09646**	0.00897	0.0173	0.0039	0.3713	0.08134	**0.652****
NG/S	0.00212	-0.00004	0.00017	0.00138	-0.00331	0.02309	0.00977	0.01164	0.0488	**0.11773**	-0.00023	0.00532	0.1481	0.02042	**0.385****
TGW	0.00297	0.00057	0.00088	0.0019	-0.00363	0.01942	0.0126	0.01226	0.03435	-0.00008	**0.14858**	-0.0039	0.19006	0.08301	**0.499****
DM	0.01053	0.00261	-0.00025	0.00037	-0.00266	-0.00987	-0.00565	0.00392	-0.008	-0.00201	0.00403	**-0.04698**	-0.15207	0.10154	**-0.104**
BY/P	0.00474	0.0001	0.00115	0.00216	-0.00442	0.03526	0.02005	0.01707	0.05364	0.00659	0.01892	0.0107	**0.66764**	0.01935	**0.853****
HI	0.0023	0.00101	0.00058	0.00072	-0.00471	0.00771	0.00788	0.00428	0.01829	0.00084	0.0128	-0.01112	0.03012	**0.42889**	**0.500****

Residual factor 0.03390

DH: Days to heading, **PH**: Plant height (cm), **NET/m**: Number of effective tillers per metre, **SL**: Spike length (cm), **NS/S**: Number of spikelets per spike, **FLL**: Flag leaf length (cm), **PL**: Peduncle length (cm), **MSW**: Main spike weight (g), **GW/S**: Grain weight per spike (g), **NG/S**: Number of grains per spike, **TGW**: 1000 grain weight (g), **DM**: Days to maturity, **BY/P**: Biological yield per plot (g), **GY/P**: Grain Yield per plot (g), **HI**: Harvest Index (%), **CP**: Crude Protein (%), **SV**: Sedimentation Value (ml), **HW**: Hectolitre weight (Kg/hl), **GAS**: Grain Appearance Score (max. 10), **WG**: Wet Gluten (%), **DG**: Dry Gluten (%), **TG**: Total Gluten (%), **TSS**: Total Soluble Sugars (%)

Table 4(b): Path coefficient analysis based on phenotypic correlation showing direct (diagonal) and indirect (off-diagonal) effects of quality traits on grain yield per plot under late sown conditions.

	CP	SV	HW	GAS	WG	TG	DG	TSS	r with GY/P
CP	**-0.22715**	0.0153	-0.02538	0.03194	-0.01334	-0.00335	0.02237	0.004	**-0.195****
SV	0.01631	**-0.21306**	-0.00086	-0.03026	0.01933	0.00857	-0.0344	0.00468	**-0.230****
HW	0.03986	0.00127	**0.14463**	-0.0235	-0.00143	-0.00101	0.00275	-0.0028	**0.160***
GAS	0.05394	-0.04794	0.02527	**-0.13451**	0.02926	0.02177	-0.05676	-0.01698	**-0.126**
WG	0.02988	-0.04063	-0.00205	-0.03882	**0.10137**	0.06993	-0.19372	-0.01299	**-0.088**
TG	0.00888	-0.02131	-0.0017	-0.03418	0.08275	**0.08567**	-0.17337	-0.0122	**-0.066**
DG	0.02599	-0.03749	-0.00203	-0.03905	0.10045	0.07597	**-0.19551**	-0.01324	**-0.086**
TSS	0.00971	0.01067	0.00432	-0.02443	0.01408	0.01118	-0.02769	**-0.09348**	**-0.096**

Residual factor 0.8554

DH: Days to heading, **PH**: Plant height (cm), **NET/m**: Number of effective tillers per metre, **SL**: Spike length (cm), **NS/S**: Number of spikelets per spike, **FLL**: Flag leaf length (cm), **PL**: Peduncle length (cm), **MSW**: Main spike weight (g), **GW/S**: Grain weight per spike (g), **NG/S**: Number of grains per spike, **TGW**: 1000 grain weight (g), **DM**: Days to maturity, **BY/P**: Biological yield per plot (g), **GY/P**: Grain Yield per plot (g), **HI**: Harvest Index (%), **CP**: Crude Protein (%), **SV**: Sedimentation Value (ml), **HW**: Hectolitre weight (Kg/hl), **GAS**: Grain Appearance Score (max. 10), **WG**: Wet Gluten (%), **DG**: Dry Gluten (%), **TG**: Total Gluten (%), **TSS**: Total Soluble Sugars (%)

E. Path Coefficient Analysis

The path coefficients present a clearer and more accurate picture of complex scenario present at the correlation level as it ascertains the true contribution of individual traits to grain yield. The path coefficient analysis depicted in Table 4(a) and 4(b) respectively, showed that biological yield per plot (0.6676), harvest index (0.4289), 1000 grain weight (0.1485), number of effective tillers per metre (0.1226), number of grains per spike (0.1177), hectolitre weight (0.1446) and wet gluten (0.1014) are more important as they had a high positive and direct effect on grain yield per plot, depicting true relationship with it. Similar associations were cited by Mollasadeghi *et al*. (2011); Ali (2012) for harvest index, Ozukum *et al*. (2019); Baye *et al.* (2020) for biological yield and harvest index. Almost all the traits *viz.*,flag leaf length (0.4197), grain weight per spike (0.3713), peduncle length (0.3237), main spike weight (0.2613), spike length (0.2499), number of spikelets per spike (0.2239), 1000 grain weight (0.1900), number of effective tillers per metre (0.1771), number of grains per spike (0.1481), days to heading (0.1270) and harvest index (0.0301) contributed towards grain yield per plot *via* biological yield per plot and harvest index, indicating indirect selection through both these traits would be rewarding in cop improvement. Among quality traits, hectolitre weight (0.1446), wet gluten (0.1014) and total gluten (0.0856) had a positive direct effect on grain yield per plot, while, crude protein (-0.2271) exhibited a significant negative direct effect on grain yield per plot. The results were in accordance with Mecha *et al*. (2017) for hectolitre weight.

CONCLUSIONS

It can be concluded from the above mentioned findings and details that the genotypes used in the study exhibited considerable variability for various traits giving opportunities of the genetic gain through selection or hybridization. High PCV, GCV, heritability and genetic advance were observed for total soluble sugars, while moderate GCV, PCV along with high heritability and genetic advance were observed for grain weight per spike, crude protein, sedimentation value, wet gluten, dry gluten and total gluten, suggesting the possibility of improving these traits through selection. The traits governing yield *i.e.*, biological yield per plot, number of effective tillers per meter, 1000 grain weight, flag leaf length, peduncle length, number of grains per spike, grain weight per spike and hectolitre weight under stress were identified, on the basis of association analysis. Hence, it would be rewarding to lay stress on these characters for improvement. The genetic control of variation in the grain yield per plot in bread wheat is governed by a number of interrelated processes, many of which have been better understood as a result of the current study. Thus, the findings of the present study would offer some guidance for choosing parents, predicting the potential benefits of genetic recombination, and developing a model plant type for selection in segregating generations.

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