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ASSESSMENT OF MORPHO-PHYSIOLOGICAL TRAITS AND THEIR CAUSAL RELATIONSHIPS IN BARLEY GENOTYPES UNDER DIFFERENT SOWING CONDITIONS

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SUMMARY

The current study aimed at identification and incorporation of key traits in developing high yielding barley varieties through assessment of various morpho-physiological characters and their relative direct and indirect contribution towards grain yield. The experiment was carried out with 44 barley germplasm lines at the Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar during 2021-22 under timely sown and heat stress conditions. The association study under both the environments revealed significant positive correlation of grain yield with biological yield per plant, days to maturity, harvest index, number of grains per spike, spike length, number of effective tillers per plant and 1000-grain weight at genotypic level. Similarly, under both environments, all the studied physiological traits *viz*., canopy temperature depression at anthesis and 15 days after anthesis, normalized difference vegetation index at anthesis and at 15 day after anthesis; and SPAD chlorophyll content at anthesis and at 15 days after anthesis also possessed positive significant relationship with grain yield per plant. The perusal of path coefficient analysis revealed that biological yield per plant, harvest index, spike length, 1000-grain weight, days to heading, peduncle length and number of grains per spike along with all the physiological traits under study had positive direct effect on grain yield per plant under timely as well as heat stress conditions. Consequently, it is suggested that these parameters can be considered as key component traits while setting the selection criterion for barley improvement for timely sown and heat stress conditions.

Key words: Barley, correlation coefficient, heat stress, path analysis

Barley (*Hordeum vulgare* L.) is one of the major cereal grain, ranking fourth in global cereal production after rice, wheat, and maize (Swati *et al.,* 2019). It belongs to the genus *Hordeum* in the grass family *Poaceae*. Barley exists in two phenotypic forms *i.e.* six-rowed and two-rowed barley and can also be classified as hulled or hulless based on the presence of a tightly adhered hull on the its grain. Barley can thrive in various agro-climatic conditions that allow its cultivation on marginal and stress-prone environments. Barley has gained importance owing to its increased utilization in various health tonics, multigrain blends, malting and brewing industries (Kaur *et al*., 2018). Barley contains low gluten content as well as possessed high fiber and beta-glucan, aiding in weight management and cholesterol reduction (Abebaw, 2021). In India, barley occupied an area and production of 0.62 million hectare and 1.69 million tonnes grain, respectively with productivity of 27.33 q/ha. Barley was cultivated on 15,300 hectares with a production of 53,300 tons in Haryana state that ranked second in average productivity (34.86 q/ha) after Punjab (36.54 q/ha) during 2022-23 (ICAR-IIWBR, 2023).

The extent of genetic variability in the experimental breeding material, as well as the degree to which valuable traits are inherited, determines the success of any targeted breeding program. Initiation of any crop improvement programme always requires the variability assessment of traits under consideration. Grain yield is a complex trait that is affected by many environmental factors and is heavily reliant on the interrelationships between the various yield components. In order to identify the key components, it is vital to understand the genotypic and phenotypic association among yield traits, as well as their relationship with yield. The study of character association facilitates the breeders in deciding selection criterion for yield enhancement (Hebbache *et al.*, 2023). The degree to which two or more variables vary together is measured

by correlation. The average degree of the link between yield and its attributing characters may be determined using correlation analysis, which can be utilized to evaluate the relative worth of each contributing character to improve plant yield. Similarly, the effect of component traits on yield can be split into direct and indirect effects using path coefficient analysis (Vasko *et al.,* 2023). This information can be used to incorporate useful traits in optimal combinations for maximizing the yield potential.

Therefore, the present study was designed and conducted with 44 barley germplasm lines to assess the various morpho-physiological characters and their relative direct and indirect contribution towards grain yield aimed to identification and incorporation of key traits in developing high yielding barley varieties for timely sown and heat stress conditions.

MATERIALS AND METHODS

The experiment was carried out during the *rabi* season of 2021-22 at the Barley Research Area of the Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar. The experimental material consisted of 44 barley germplasm lines representing both 2-row (23) and 6-row (21) types including four check varieties (Table 1). The check varieties included were DWRB 123 and BH 946 that were used to compare the performance of genotypes under timely sown; and DWRB 91 and DWRUB 64 were used for heat stress (late sown) comparison. The experiment was laid in Randomized Block Design (RBD) with three replications. Each germplasm line was planted in paired rows of 2.5 m length spaced at 23 cm apart. The experimental material was grown under timely sown (20th November, 2021) and heat stress (20th December, 2021) conditions. The late sown material was expected to encounter terminal heat stress during grain filling. The package of practices recommended for both environments were followed to raise the crop.

The quantitative data was recorded for twelve morphological traits *viz*., days to heading, days to maturity, grain filling duration, number of effective tillers per plant, plant height (cm), peduncle length (cm), spike length (cm), number of grains per spike, 1000-grain weight (g), biological yield per plant (g), grain yield per plant (g), and harvest index (%). In addition, the observation on three physiological parameters namely canopy temperature depression at anthesis (CTD 1) and 15 days after anthesis (CTD 2), normalized difference vegetation index at anthesis (NDVI 1) and 15 days after anthesis (NDVI 2), and SPAD chlorophyll content at anthesis (SPAD 1) and 15 days after anthesis (SPAD 2), measured as per the method used by Schlichting *et al*. (2015).

The recorded data was subjected to statistical analysis using OPSTAT software available on *http://14.139.232.166/opstat/default.asp* (Sheoran *et al.,* 1998). The estimates of genotypic correlation coefficients were calculated as suggested by Al-Jibouri *et al.* (1958). These estimates were used to work out path coefficient analysis as elaborated by Dewey and Lu, 1959).

TABLE 1
Barley genotypes used in the study

S. No.	Genotypes	RT	S. No.	Genotypes	RT	S. No.	Genotypes	RT
1.	BH 1029	6	16.	IBON-HI-2021-27	2	31.	7th GSBON-2020-90	6
2.	BH 1034	2	17.	IBON-HI-2021-31	2	32.	IBON-HI-2020-6	6
3.	BH 1035	2	18.	IBON-HI-2021-33	2	33.	IBON-HI-2020-51	6
4.	BH 1036	2	19.	IBON-HI-2021-38	2	34.	7th GSBON-2020-140	6
5.	BH 1038	6	20.	IBON-HI-2021-52	2	35.	IBON-HI-2020-55	2
6.	BH 1039	6	21.	IBON-HI-2021-56	2	36.	7th GSBON-2020-101	2
7.	BH 1018	2	22.	IBON-HI-2021-81	6	37.	IBYT-HI-2020-6	6
8.	BH 1025	2	23.	IBON-HI-2021-85	6	38.	7th GSBYT-2020-20	6
9.	BH 1026	2	24.	IBON-HI-2021-99	6	39.	IBYT-HI-2020-11	6
10.	BH 1027	2	25.	IBON-HI-2021-102	6	40.	IBON-HI-2020-155	6
11.	IBYT-HI-2021-3	2	26.	RD 3002	6	41.	DWRB 123 (c)	2
12.	IBYT-HI-2021-9	2	27.	DWRB 197	2	42.	BH 946 (c)	6
13.	IBYT-HI-2021-15	6	28.	DWRB 209	2	43.	DWRB 91 (c)	2
14.	IBYT-HI-2021-17	2	29.	BCLA 11-6	6	44.	DWRUB 64 (c)	6
15.	IBYT-HI-2021-18	6	30.	IBON-HI-2020-71	2			

RT: Row Type.

RESULTS AND DISCUSSION

Association Studies (Timely sown)

The estimates of genotypic correlation coefficients for all the analysed characters under timely sown condition are present in Table 2. The results hereby revealed positive significant association of grain yield per plant with biological yield per plant, days to maturity, harvest index, number of grains per spike, days to heading, spike length, number of effective tillers per plant and 1000-grain weight at genotypic level. However, it had negative significant correlation with grain filling duration and plant height. Some researchers also reported significant positive correlation of grain yield with biological yield per plant, harvest index, days to maturity, 1000-grain weight (Devi *et al*., 2019), number of grains per spike (Aklilu *et al*., 2020), days to heading (Kumar *et al*., 2013), number of effective tillers per plant (Al-Tabbal and Al-Fraihat, 2012), spike length at phenotypic level (Kumari and Vishwakarma, 2022). Kumar *et al*. (2018) also found significant negative correlation grain yield with plant height.

Significant positive association was also observed for days to heading with days to maturity, harvest index and biological yield per plant; days to maturity with biological yield, spike length and number of grains per spike; grain filling duration with peduncle length; number of effective tillers per plant with harvest index and 1000-grains weight; plant height with peduncle length; peduncle length with 1000-grain weight; spike length with harvest index, 1000-grain weight; number of grains per spike with biological yield and harvest index.

Some findings were in consonance with these results *i.e*. significant positive association of days to heading with days to maturity and biological yield (Aklilu *et al*., 2020), days to maturity with spike length, number of grains per spike (Ahmadi *et al*., 2016; Devi *et al*., 2019), with biological yield (Devi *et al*., 2019, Aklilu *et al*., 2020), number of effective tillers per plant with 1000-grain weight (Hailu *et al*., 2016), with harvest index (Kumar and Sehrawat, 2021), plant height with peduncle length (Kumar and Sehrawat, 2021), peduncle length with 1000-grain weight (Ahmadi *et al*., 2016), spike length with 1000-grain weight (Aklilu *et al*., 2020), with harvest index (Hailu *et al*., 2016), number of grains per spike with biological yield (Aklilu *et al*., 2020), with harvest index (Kumar *et al*., 2018).

Similarly, significant negative relation was also found for days to heading with spike length, 1000-grain weight, peduncle length and grain filing duration; grain filling duration with harvest index; number of effective tillers per plant with number of grains per spike; plant height with harvest index; peduncle length with biological yield, harvest index and number of grains per spike; number of grains per spike with 1000-grains weight, spike length; biological yield per plant with harvest index; 1000-grain weight with harvest index. These results were also corroborated for days to heading with grain filling duration (Al-Tabbal and Al-Fraihat, 2012), with spike length and 1000-grain weight (Hailu *et al*., 2016), grain filling duration with harvest index (Al-Tabbal and Al-Fraihat, 2012), number of effective tillers per plant with number of grains per spike (Aklilu *et al*., 2020, Kumar and Sehrawat, 2021), plant height with harvest index (Kumar *et al*., 2018), spike length with number of grains per spike (Hailu *et al*., 2016), number of grains per spike with 1000-grain eight (Aklilu *et al*., 2020), biological yield with peduncle length (Kumar and Sehrawat, 2021), with harvest index (Kumar *et al*. (2018) and peduncle length with harvest index (Kumar and Sehrawat, 2021).

Among physiological traits under timely sown, grain yield per plant possessed positive significant relationship with canopy temperature depression at anthesis and 15 days after anthesis, normalized difference vegetation index at anthesis and at 15 day after anthesis; SPAD chlorophyll content at anthesis and at 15 days after anthesis. Kumar *et al*. (2018a) studied 30 barley genotypes and reported that physiological traits could be used to screen the genotypes. Likewise, significant positive correlation was recorded for SPAD chlorophyll content at anthesis with SPAD chlorophyll content at 15 days after anthesis, canopy temperature depression 15 days after anthesis and canopy temperature depression at anthesis; SPAD chlorophyll content at 15 days after anthesis with canopy temperature depression at anthesis and 15 days after anthesis; normalized difference vegetation index at 15 day after anthesis with canopy temperature depression at anthesis and at 15 days after anthesis; canopy temperature depression at anthesis with canopy temperature depression at 15 days after anthesis. The significant positive relationship between SPAD 1 and SPAD 2, and CTD 1 and CTD 2 along with negative significant association for NDVI 1 with CTD 1 and CTD 2 were also highlighted by Kumar *et al*. (2018a) in barley.

Further, recorded negative significant

TABLE 2
Genotypic correlation coefficients among different traits in barley under timely sown condition

Traits	DH	DM	GFD	ETP	PH	PL	SL	GPS	TGW	BY	HI	GYP	SPAD 1	SPAD 2	NDVI 1	NDVI 2	CTD 1	CTD 2
DH	1.000																	
DM	0.493**	1.000																
GFD	-0.766**	-0.113	1.000															
ETP	0.039	0.002	-0.112	1.000														
PH	0.059	0.117	-0.039	-0.075	1.000													
PL	-0.359**	-0.126	0.374**	0.062	0.476**	1.000												
SL	-0.255**	0.390**	0.162	0.045	-0.119	0.062	1.000											
GPS	0.166	0.308**	0.056	-0.515**	0.169	-0.305**	-0.314**	1.000										
TGW	-0.318**	-0.073	0.16	0.209*	-0.05	0.204*	0.212*	-0.241**	1.000									
BY	0.263**	0.624**	-0.052	-0.02	0.079	-0.432**	0.101	0.442**	0.072	1.000								
HI	0.464**	-0.058	-0.336**	0.256**	-0.483**	-0.347**	0.184*	0.212*	-0.237**	-0.148**	1.000							
GYP	0.360**	0.545**	-0.131**	0.065*	-0.088**	-0.505	0.162**	0.460**	0.004*	0.926**	0.512**	1.000						
SPAD 1	-0.106	-0.279**	-0.132	0.208*	-0.12	0.122	0.258**	0.042	0.419**	-0.04	0.158	0.347**	1.000					
SPAD 2	0.208*	0.401**	-0.001	0.051	-0.051	0.380**	0.443**	0.133	0.345**	0.064	0.505**	0.389**	0.397**	1.000				
NDVI 1	-0.053	-0.138	0.084	-0.005	-0.169	-0.12	0.086	-0.363**	0.032	0.088	0.231**	0.384**	-0.406**	0.04	1.000			
NDVI 2	0.421**	0.769**	-0.005	0.318**	0.177*	0.079	0.432**	0.136	-0.268**	0.550**	0.029	0.478**	-0.159	-0.034	0.034	1.000		
CTD 1	0.072	-0.109	-0.238**	-0.119	0.242**	0.047	0.198*	0.193*	0.084	0.055	-0.052	0.728**	0.208*	0.201*	-0.319**	0.425**	1.000	
CTD 2	0.033	-0.137	-0.216*	-0.154	0.268**	0.087	0.177*	0.180*	0.079	0.015	-0.073	0.678**	0.211*	0.220*	-0.313**	0.408**	0.999**	1.000

DH: Days to heading, DM: Days to maturity, GFD: Grain filling duration, ETP: Number of effective tillers per plant, PH: Plant height, PL: Peduncle length, SL: Spike length, GPS: Number of grains per spike, TGW: 1000-grain weight, BY: Biological yield per plant, HI: Harvest index, GYP: Grain yield per plant, SPAD 1: Chlorophyll content (SPAD) at anthesis, SPAD 2: Chlorophyll content (SPAD) at 15days after anthesis, NDVI 1: Normalized difference vegetation index at anthesis, NDVI 2: Normalized difference vegetation index at 15 days after anthesis, CTD 1: Canopy temperature depression at anthesis, CTD 2:Canopytemperaturedepressionat15days after anthesis, **&* Significantat1% and 5% level, respectively.

TABLE 3
Genotypic correlation coefficients among different traits in barley under heat stress condition

Traits	DH	DM	GFD	ETP	PH	PL	SL	GPS	TGW	BY	HI	GYP	SPAD 1	SPAD 2	NDVI 1	NDVI 2	CTD 1	CTD 2
DH	1,000																	
DM	0.667**	1.000																
GFD	-0.556**	-0.016	1.000															
ETP	0.16	0.172*	-0.189*	1.000														
PH	-0.260**	-0.049	0.081	-0.209*	1.000													
PL	-0.481**	-0.231**	0.296**	-0.255**	-0.047	1.000												
SL	-0.163	0.136	0.083	0.128	0.611**	0.447**	1.000											
GPS	0.131	0.159	0.067	-0.269**	0.768**	0.189**	-0.059	1.000										
TGW	-0.235**	-0.09	0.093	0.023	-0.272**	0.163	0.015	-0.230**	1.000									
BY	-0.001	0.273**	-0.006	-0.006	0.642**	-0.257**	0.132	0.190*	0.428**	1.000								
HI	-0.095	0.047	0.237**	0.174*	-0.332**	0.297**	0.051	0.295**	0.480**	-0.508**	1.000							
GYP	-0.06**	0.349**	-0.025**	0.227**	0.447**	0.226**	0.171**	0.503**	0.046*	0.572**	0.160**	1.000						
SPAD 1	0.041	0.139	0.082	0.330**	0.490**	-0.104	0.273**	0.315**	0.13	-0.021	0.357**	0.343**	1.000					
SPAD 2	-0.047	-0.198*	-0.163	0.473**	-0.015	0.143	0.578**	-0.159	0.006	0.101	0.137	0.629**	0.210*	1.000				
NDVI 1	0.251**	0.288**	0.101	-0.086	-0.251**	-0.271**	0.094	0.365**	-0.185*	0.719**	-0.436**	0.403**	0.377**	0.510**	1.000			
NDVI 2	0.568**	0.737**	-0.129	0.154	-0.048	-0.214*	0.102	0.268**	-0.366**	0.210*	0.153	0.412**	0.129	0.098	0.556**	1.000		
CTD 1	0.335**	0.219*	-0.176*	0.232**	-0.11	-0.111	0.153	0.259**	0.001	0.124	0.373**	0.361**	0.102	0.301**	-0.093	0.151	1.000	
CTD 2	0.341**	0.201*	-0.183*	0.180*	-0.205*	-0.139	0.074	0.270**	-0.02	0.108	0.367**	0.360**	0.117	0.295**	-0.09	0.118	0.999**	1.000

DH: Days to heading, DM: Days to maturity, GFD: Grain filling duration, ETP: Number of effective tillers per plant, PH: Plant height, PL: Peduncle length, SL: Spike length, GPS: Number of grains per spike, TGW: 1000-grain weight, BY: Biological yield per plant, HI: Harvest index, GYP: Grain yield per plant, SPAD 1: Chlorophyll content (SPAD) at anthesis, SPAD 2: Chlorophyll content (SPAD) at 15days after anthesis, NDVI 1: Normalized difference vegetation index at anthesis, NDVI 2: Normalized difference vegetation index at 15 days after anthesis, CTD 1: Canopy temperature depression at anthesis, CTD 2:Canopytemperaturedepressionat15days after anthesis, **&* Significantat1% and 5% level, respectively.

correlation for SPAD chlorophyll content at anthesis with normalized difference vegetation index at anthesis; normalized difference vegetation index at anthesis with canopy temperature depression at anthesis and 15 days after anthesis.

Association Studies (Heat Stress)

A perusal of correlation analysis under heat stress condition (Table 3) revealed that grain yield per plant had significant and positive association with biological yield per plant, number of grains per spike, plant height, days to maturity, number of effective tillers per plant, peduncle length, spike length, harvest index and 1000-grain weight while it had negative significant association with days to heading and grain filling duration. The significant positive correlation of grain yield had also been reported with number of grains per spike, plant height, number of effective tillers per plant and 1000-grain weight under late sown/heat stress condition (Vinesh *et al*., 2018), biological yield per plant and harvest index (Al-Tabbal and Al-Fraihat, 2012; Kumar *et al*., 2018; Devi *et al*., 2019), days to maturity and peduncle length (Ahmadi *et al*., 2016), spike length at phenotypic level (Kumari and Vishwakarma, 2022). Similar observation of significant negative association between grain yield and days to heading had also been reported by Kumar *et al*. (2018), Vinesh *et al*. (2018) and Devi *et al*. (2019).

The significant positive relationship also existed for the traits *viz*. harvest index with 1000 grains weight, number of grains per spike, peduncle length, grain filling duration and number of effective tillers per plant; biological yield per plant with plant height, 1000-grain weight, days to maturity and number of grains per spike; number of grains per spike with plant height and peduncle length; spike length with plant height and peduncle length; peduncle length with grain filling duration; number of effective tillers per plant with days to maturity; days to maturity with days to heading. These results were also confirmed for days to heading with days to maturity (Devi *et al*., 2019), days to maturity with number of effective tillers per plant and biological yield, grain filling duration and number of effective tillers per plant with harvest index (Al-Tabbal and Al-Fraihat, 2012), plant height with spike length, number of grains per spike (Vinesh *et al*., 2018), with biological yield (Devi *et al*., 2019), peduncle length with number of grains per spike (Ahmadi *et al*., 2016), number of grains per spike with biological yield and harvest index (Aklilu *et al*., 2020), 1000-grain weight with biological yield (Al-Tabbal and Al-Fraihat, 2012), with harvest index (Devi *et al*., 2019).

The traits that showed significant negative association includes harvest index with biological yield and plant height; biological yield per plant with peduncle length; peduncle length with days to heading and number of effective tillers per plant; number of effective tillers per plant with grain filling duration; grain filling duration with days to heading, days to maturity with peduncle length; days to heading with 1000-grain weight and plant height; plant height with number of effective tillers per plant and 1000-grain weight; and number of grains per spike with number of effective tillers per plant and 1000-grain weight. These findings were also reported for days to heading with grain filling duration, plant height, 1000-grain weight (Al-Tabbal and Al-Fraihat, 2012), plant height with 1000-grain weight and harvest index (Devi *et al*., 2019, Aklilu *et al*., 2020), number of grains per spike with number of effective tillers per plant and 1000-grain weight (Aklilu *et al*., 2020), biological yield with harvest index (Al-Tabbal and Al-Fraihat, 2012).

Grain yield per plant showed positive and significant association with physiological traits namely, SPAD chlorophyll content at 15 days after anthesis, normalized difference vegetation index at 15 days after anthesis, normalized difference vegetation index at anthesis, canopy temperature at anthesis, canopy temperature depression at 15 days after anthesis and SPAD chlorophyll content at anthesis under heat stress environment. The physiological characters that exhibited significant and positive correlation includes SPAD chlorophyll content at anthesis with normalized difference vegetation index at anthesis and SPAD chlorophyll content at anthesis; SPAD chlorophyll content at 15 days after anthesis with normalized difference vegetation index at anthesis, canopy temperature depression at anthesis and canopy temperature at 15 days after anthesis; normalized difference vegetation index at anthesis with normalized difference vegetation index at 15 days after anthesis; canopy temperature at 15 days after anthesis with canopy temperature depression at anthesis at genotypic level. Kumar *et al*. (2018a) also concluded the positive and significant relation of SPAD1 with SPAD 2, NDVI 1 with NDVI 2 and CTD 1 with CTD 2 while studying barley genotypes under stress condition. In addition, Vinesh *et al*. (2018) also observed significant and positive correlation SPAD with spike length under late sown *i.e*. heat stress environment.

TABLE 4
Direct (diagonal) and indirect effects of different traits on grain yield in barley under timely sown condition

Traits	DH	DM	GFD	ETP	PH	PL	SL	GPS	TGW	BY	HI	SPAD 1	SPAD 2	NDVI 1	NDVI 2	CTD 1	CTD 2
DH	0.085	0.042	-0.065	0.003	0.005	-0.031	-0.022	0.014	-0.027	0.022	0.039	-0.009	0.018	-0.005	0.036	0.006	0.003
DM	-0.081	-0.165	0.019	0.000	-0.019	0.021	-0.064	-0.051	0.012	-0.103	0.010	0.046	-0.066	0.023	-0.127	0.018	0.023
GFD	0.003	0.000	-0.004	0.000	0.000	-0.002	-0.001	0.000	-0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.001	0.001
ETP	0.000	0.000	0.001	0.011	0.001	-0.001	0.000	0.006	-0.002	0.000	-0.003	-0.002	-0.001	0.000	-0.003	0.001	0.002
PH	0.001	0.002	-0.001	-0.002	0.020	0.010	-0.002	0.003	-0.001	0.002	-0.010	-0.002	-0.001	-0.003	0.004	0.005	0.005
PL	-0.030	-0.011	0.031	0.005	0.040	0.084	0.005	-0.026	0.017	-0.036	-0.029	0.010	0.032	-0.010	0.007	0.004	0.007
SL	-0.044	0.067	0.028	0.008	-0.020	0.011	0.171	-0.054	0.036	0.017	0.031	0.044	0.076	0.015	0.074	0.034	0.030
GPS	0.015	0.028	0.005	-0.047	0.016	-0.028	-0.029	0.092	-0.022	0.041	0.020	0.004	0.012	-0.033	0.013	0.018	0.017
TGW	-0.044	-0.010	0.022	0.029	-0.007	0.028	0.030	-0.034	0.140	0.010	-0.033	0.059	0.048	0.005	-0.037	0.012	0.011
BY	0.238	0.565	-0.047	-0.018	0.072	-0.392	0.091	0.400	0.066	0.906	0.134	-0.036	0.058	0.079	0.498	0.050	0.013
HI	0.204	-0.025	-0.148	0.112	-0.212	-0.152	0.081	0.093	-0.104	0.065	0.439	0.069	0.222	0.101	0.013	-0.023	-0.032
SPAD 1	0.018	0.046	0.022	-0.035	0.020	-0.020	-0.043	-0.007	-0.070	0.007	-0.026	0.167	-0.066	0.068	0.026	-0.035	-0.035
SPAD 2	-0.018	-0.034	0.000	-0.004	0.004	-0.033	-0.038	-0.011	-0.030	-0.005	-0.043	-0.034	0.086	-0.003	0.003	-0.017	-0.019
NDVI 1	0.007	0.017	-0.010	0.001	0.021	0.015	-0.011	0.045	-0.004	-0.011	-0.029	0.050	-0.005	0.124	-0.004	0.040	0.039
NDVI 2	0.003	0.005	0.000	0.002	0.001	0.000	0.003	0.001	-0.002	0.003	0.000	-0.001	0.000	0.000	0.006	0.003	0.002
CTD 1	0.019	-0.029	-0.063	-0.031	0.064	0.012	0.052	0.051	0.022	0.015	-0.014	0.055	0.053	-0.084	0.112	0.264	0.256
CTD 2	-0.011	0.047	0.075	0.053	-0.093	-0.030	-0.061	-0.062	-0.027	-0.005	0.025	-0.073	-0.076	0.108	-0.141	0.329	0.346
r_g (GYP)	0.360**	0.5450**	-0.131**	0.088**	-0.088**	-0.505	0.162**	0.460**	0.004**	0.926**	0.512**	0.3470**	0.389**	0.384**	0.478**	0.728**	0.678**

Residual effect=0.00173

DH: Days to heading, DM: Days to maturity, GFD: Grain filling duration, ETP: Number of effective tillers per plant, PH: Plant height, PL: Peduncle length, SL: Spike length, GPS: Number of grains per spike, TGW: 1000-grain weight, BY: Biological yield per plant, HI: Harvest index, GYP: Grain yield per plant, SPAD 1: Chlorophyll content (SPAD) at anthesis, SPAD 2: Chlorophyll content (SPAD) at 15days after anthesis, NDVI 1: Normalized difference vegetation index at anthesis, NDVI 2: Normalized difference vegetation index at 15 days after anthesis, CTD 1: Canopy temperature depression at anthesis, CTD 2:Canopytemperaturedepressionat15days after anthesis.

Path Analysis

Path coefficient analysis partitions the correlation coefficients between the independent and dependent variable, into direct and indirect effects, depicting the true path through which the independent variable affects the dependent one. In the present study, genotypic correlation coefficients were used for path coefficient analysis. Path analysis was done for morphological and physiological characters under both the environments; the results have been depicted in Table 4 and 5 for timely sown and heat stress condition, respectively.

Timely sown

The value of direct and indirect effects ranged from -0.004 to 0.906 and 0.001 to 0.565, respectively, under timely sown condition. The magnitude of residual factor was 0.00173. A perusal of path coefficient analysis (Table 4) revealed that biological yield per plant (0.906) had highest positive direct effect on grain yield, followed by harvest index (0.439), canopy temperature depression at 15 day after anthesis (0.346), canopy temperature depression at anthesis (0.264), spike length (0.171), SPAD chlorophyll content at anthesis (0.167), 1000-grain weight (0.140), normalized difference vegetation index at anthesis (0.124), number of grains per spike (0.092), SPAD chlorophyll content at 15 days after anthesis (0.086), days to heading (0.085), peduncle length (0.084), plant height (0.020) and number of effective tillers per plant (0.011), while traits like days to maturity (-0.165) and grain filling duration (-0.004) had negative direct effect on grain yield per plant under timely sown condition. The positive direct effect of number of effective tillers per plant, plant height, number of grains per spike, 1000-grain weight, harvest index and biological yield (Kumar *et al*., 2018; Devi *et al*., 2019), days to heading and spike length (Kumari and Vishwakarma, 2022), peduncle length (Kumar and Sehrawat, 2021) were also found in barley under timely sown condition. The negative direct effect of days to maturity towards grain yield was also confirmed by (Aklilu *et al*., 2020, Kumar and Sehrawat, 2021).

Biological yield and harvest index showed significant positive correlation with grain yield, showed direct positive effect and also contributed toward grain yield through days to heading and SPAD chlorophyll content at 15 days after anthesis. The traits *i.e.* 1000-grain weight, number of grains per spike and spike length exhibited significant and positive correlation with

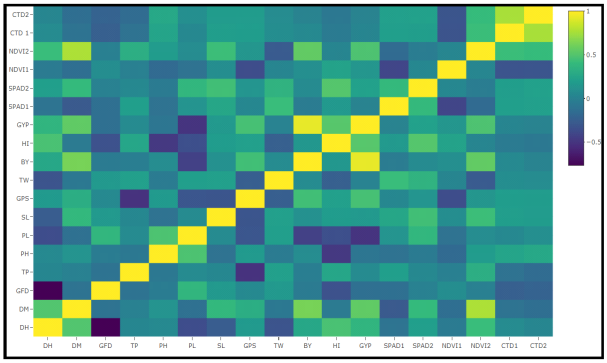

Fig. 1. Graphical representation of genotypic correlation under timely sown condition.

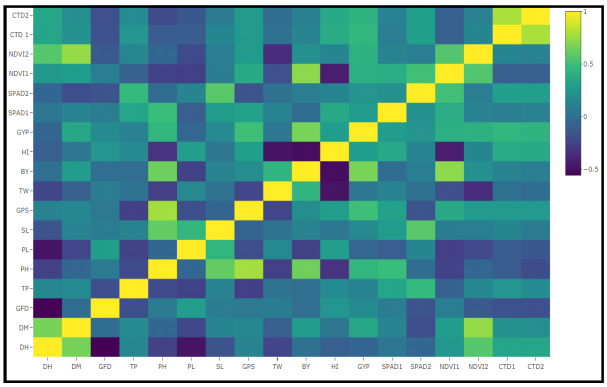

Fig. 2. Graphical representation of genotypic correlation under heat stress condition.

grain yield, showed direct positive effect as well as contributed toward grain yield *via* biological yield, SPAD chlorophyll content at 15 days after anthesis and grain filling duration. Plant height and number of effective tillers per plant showed direct positive effect on grain yield and also contributed indirectly *via* number of grains per spike and canopy temperature depression at 15 day after anthesis. Grain filling duration and days to maturity had negative direct effect on grain yield but these traits also contributed to grain yield *via* days to heading and canopy temperature depression at 15 day after anthesis. Days to heading and canopy temperature at 15 days after anthesis had positive direct effect as well as contributed to grain yield *via* days to maturity and harvest index. SPAD chlorophyll content at anthesis, SPAD chlorophyll content at 15 days after anthesis, NDVI at anthesis, NDVI at 15 days after anthesis and canopy temperature at anthesis significantly associated with grain yield, showed positive direct effect as well as contributed to grain yield *via* plant height.

Heat stress

The studied morphological and physiological traits under heat stress condition (Table 5) ranged for

TABLE 5
Direct (diagonal) and indirect effects of different traits on grain yield in barley under heat stress condition

Traits	DH	DM	GFD	ETP	PH	PL	SL	GPS	TGW	BY	HI	SPAD1	SPAD2	NDVI 1	NDVI 2	CTD 1	CTD 2
DH	0.110	0.074	-0.061	0.018	-0.029	-0.053	-0.018	0.014	-0.026	0.000	-0.010	0.004	-0.005	0.028	0.063	0.037	0.038
DM	-0.154	-0.231	0.004	-0.040	0.011	0.053	-0.031	-0.037	0.021	-0.063	-0.011	-0.032	0.046	-0.067	-0.170	-0.050	-0.046
GFD	0.038	0.001	-0.069	0.013	-0.006	-0.020	-0.006	-0.005	-0.006	0.000	-0.016	-0.006	0.011	-0.007	0.009	0.012	0.013
ETP	-0.009	-0.009	0.010	-0.055	0.011	0.014	-0.007	0.015	-0.001	0.000	-0.010	-0.018	-0.026	0.005	-0.008	-0.013	-0.010
PH	0.031	0.006	-0.010	0.025	-0.119	0.006	-0.073	-0.091	0.032	-0.076	0.040	-0.058	0.002	0.030	0.006	0.013	0.024
PL	0.091	0.044	-0.056	0.048	0.009	0.890	-0.084	0.036	-0.031	0.048	-0.056	0.020	-0.027	0.051	0.040	0.021	0.026
SL	-0.038	0.032	0.020	0.030	0.144	0.105	0.236	-0.014	0.004	0.031	0.012	0.064	0.136	0.022	0.024	0.036	0.018
GPS	0.006	0.007	0.003	-0.012	0.036	-0.009	-0.003	0.046	-0.011	0.009	0.014	0.015	-0.007	0.017	0.012	0.012	0.013
TGW	-0.028	-0.011	0.011	0.003	-0.032	0.019	0.002	-0.027	0.117	0.050	-0.056	0.015	0.001	-0.022	-0.043	0.000	-0.002
BY	-0.001	0.318	-0.007	-0.007	0.746	-0.298	0.153	0.221	0.497	0.962	-0.590	-0.024	0.117	0.836	0.244	0.144	0.125
HI	-0.106	0.053	0.266	0.194	-0.372	0.333	0.057	0.330	-0.538	-0.569	0.889	0.399	0.153	-0.488	0.172	0.417	0.411
SPAD1	-0.003	-0.012	-0.007	-0.028	-0.042	0.009	-0.023	-0.027	-0.011	0.002	-0.030	0.085	-0.018	-0.032	-0.011	-0.009	-0.010
SPAD2	0.010	0.040	0.033	-0.096	0.003	-0.029	-0.118	0.032	-0.001	-0.021	-0.028	-0.043	0.204	-0.104	-0.020	-0.061	-0.060
NDVI 1	0.032	0.037	0.013	-0.011	-0.032	-0.035	0.012	0.047	-0.024	0.092	-0.056	0.048	0.065	0.128	0.071	-0.012	-0.012
NDVI 2	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.001	-0.001	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.000
CTD1	0.346	0.225	-0.181	0.239	-0.114	-0.114	0.158	0.267	0.001	0.128	0.385	0.105	0.311	-0.096	0.156	0.090	0.070
CTD2	-0.386	-0.227	0.207	-0.203	0.232	0.157	-0.084	-0.305	0.023	-0.122	-0.415	-0.132	-0.334	0.102	-0.133	0.010	0.013
r_g (GYP)	-0.060**	0.349**	-0.025**	0.227**	0.447**	0.226**	0.171**	0.503**	0.046**	0.572**	0.160**	0.343**	0.629**	0.403**	0.412**	0.361**	0.360**

Residual effect=0.00135

DH: Days to heading, DM: Days to maturity, GFD: Grain filling duration, ETP: Number of effective tillers per plant, PH: Plant height, PL: Peduncle length, SL: Spike length, GPS: Number of grains per spike, TGW: 1000-grain weight, BY: Biological yield per plant, HI: Harvest index, GYP: Grain yield per plant, SPAD 1: Chlorophyll content (SPAD) at anthesis, SPAD 2: Chlorophyll content (SPAD) at 15days after anthesis, NDVI 1: Normalized difference vegetation index at anthesis, NDVI 2: Normalized difference vegetation index at 15 days after anthesis, CTD 1: Canopy temperature depression at anthesis, CTD2:Canopytemperaturedepressionat15days after anthesis.

direct and indirect effects from -0.231 to 0.960 and -0.590 to 0.962, respectively, with residual factor of 0.00135. The results of path analysis showed positive direct effect of biological yield (0.962), harvest index (0.889), spike length (0.236), SPAD chlorophyll content at 15 days after anthesis (0.204), normalized difference vegetation index at anthesis (0.128), 1000-grain weight (0.117), days to heading (0.110), peduncle length (0.890), canopy temperature depression at anthesis (0.090), SPAD chlorophyll content at anthesis (0.085), number of grains per spike (0.046), canopy temperature depression at 15 day after anthesis (0.013) and normalized difference vegetation index at 15 day after anthesis (0.002) on grain yield per plant under late sown, whereas, days to maturity (-0.231), plant height (-0.119), grain filling duration (-0.069) and number of effective tillers per plant (-0.055) exerted negative direct effect on grain yield.

Harvest index, biological yield, number of grains per spike, spike length and peduncle length showed positive direct effect as well as contributed to grain through normalized difference vegetation index at 15 day after anthesis and days to maturity. The positive direct effect of number of grains per spike, 1000-grain weight, spike length (Vinesh *et al*., 2018), harvest index and biological yield (Kumar *et al*., 2018, Aklilu *et al*., 2020), days to heading (Hailu *et al*., 2016) and peduncle length (Kumar and Sehrawat, 2021) were also recorded in barley. The negative direct effect of days to maturity (Kumar and Sehrawat, 2021), number of effective tillers per plant (Kumar *et al*., 2013) and plant height (Aklilu *et al*., 2020) towards grain yield were also confirmed in previous studies.

Plant height showed direct negative effect to grain yield but this trait also contributed to grain yield *via* 1000-grain weight and harvest index. Similarly, number of effective tillers per plant contributed towards grain yield through peduncle length and number of grains per spike. Likewise, the traits namely grain filling duration *via* days to heading and days to maturity through peduncle length as well as SPAD 2 added to grain yield though these traits have negative direct effect. Days heading and canopy temperature depression at 15 days after anthesis showed positive direct effect and also contributed to grain yield through normalized difference vegetation index at anthesis. SPAD chlorophyll content at anthesis indirectly contributed to grain yield, showed positive direct effect as well as indirectly contribute to grain yield through peduncle length and traits like SPAD chlorophyll content at 15 days after anthesis, normalized difference vegetation index at anthesis, normalized difference vegetation index at 15 day after anthesis and canopy temperature depression at 15 day after anthesis showed positive direct effect as well as contribute indirectly to grain yield through days to maturity and days to heading.

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