



# Genetic Analysis of Morpho-Physiological Traits in Relation to Heat Tolerance in Barley (*Hordeum vulgare* L.)

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**Abstract:** The subject of the current study was to assess heat susceptibility index with the aim to identify the heat tolerant genotypes, in addition to recognize the selection criterion for heat tolerance. Forty four barley genotypes were tested in two environments as created by different sowing dates *i.e.* timely sown (non-stress) and late sown (heat stress) during 2021-22 at CCS Haryana Agricultural University, Hisar. The genotypes namely BH 1018, IBON-HI-2021-52, BH 1036, DWRUB 64, 7<sup>th</sup> GSBON-2020-101, IBON-HI-2021-102, IBON-HI-2021-85 and DWRB 123 were identified heat tolerant based on heat susceptibility index of grain yield. Further, results based on average of ranks of HSI of all traits illustrated the genotypes, BH1018, IBON-HI-2021-102, IBON-HI-2021-52, DWRB 209 and IBON-HI-2020-55 with high heat tolerance under stress condition. Correlation among HSI of different traits indicated significant positive association of grain yield per plant with days to heading and maturity, spike length, number of grains per spike, biological yield per plant, harvest index and NDVI 2, exhibiting the relevance of these traits for deciding the selection criterion for stress condition. The genotypes of cluster III portrayed better performance under stress condition for grain yield and other traits studied. The genotypes from this group could be utilized as promising breeding material intended to develop new heat tolerant barley varieties.

**Keywords:** Barley, Heat stress, HSI, Tolerance

Barley (*Hordeum vulgare* L.) is a true diploid ( $2n=14$ ) species that belongs to the genus *Hordeum* of family *Poaceae* and tribe *Triticeae*. Since ancient times, barley has been used in diverse ways as human food, livestock feed and in malt production (Kumar et al 2020) and is a hardy and versatile crop that allows its cultivated in a variety of agro-climatic zones. It is one of the globally accepted cereal crops due to its low input requirements and cost effective cultivation. Abiotic stresses remain one of the major yield reducing factors of various crop plants. Among them, high temperature, drought and salinity *etc.* are some of the factors causing undesirable effects on commercial cultivation of crops (Kumar et al 2022). Heat stress is emerging as a great threat influencing growth and development of most crop plants due to climatic disturbances as a result of global warming. The influence of high temperature on crops depends on the intensity and duration of heat, rate of temperature rise, and developmental stage of plants (Wahid et al 2007). Increase in temperature particularly at post anthesis stages shorten the grain filling period and also reduces individual grain weight (Dias and Lidon 2009, Kaur and Behl 2010). Furthermore, crop yield can be affected by high temperatures by inducing pollen sterility as well as causes seed abortion during the reproductive growth stage (Barnabas et al 2008). There is challenge for crop

researchers and need of hours to develop heat tolerant high yielding barley cultivars with good malt content for heat stress conditions. The most favorable temperature in barley for grain filling is 20°C in sub-tropical regions (Dwivedi et al 2017). It was, however, also reported that during grain filling even an increase of 1° C temperature from the optimum range causes adverse effects on grain yield (Narayanan 2018).

Under heat stress among the physiological processes, photosynthesis is the most sensitive mechanism (Wang et al 2015). The decline in the performance of genotypes under stress for various attributes could be due to inhibition of photosynthesis, as reflected by the loss of leaf chlorophyll content. The physiological responses of tolerance to abiotic stresses need to be studied in details at the genetic level before they can be exploited in the introgressive breeding. Reduction in crop productivity as a consequence of heat stress during the reproductive stage has also been reported in barley (Klink et al 2014). Vaezi et al (2010) observed grain yield loss by 39.59 and 31.39%, respectively in two-and six-row barley genotypes owing to reduction in number of spikes per square meter, grain number per spike and 1000-grain weight due to delayed sowing. In addition, average grain yield reduction in barley genotypes by 17% was also stated by Modhej et al (2015), when the crop was exposed to heat

stress after anthesis. The development of stable barley genotypes with higher economic yield under different environments is a need of breeding program intended to stress tolerance. The investigation of new sources of genetic variability and their utilization is an essential task that breeders would like to achieve for incorporation of heat tolerance in the varietal development process (Verma et al 2021). The crop production will be seriously challenged as a result of rise in temperature by 2.0-4.5 °C till the end of the century (Liu et al 2017), as reported by the Intergovernmental Panel on Climate Change (IPCC). Hence, effective exploitation of heat tolerant genetic resources in breeding programmes is imperative in context to genetic erosion and climate change scenarios (Bahrami et al 2019). Therefore, to cope up with the alarming threat of high temperature stress, detailed understanding of physiological responses and mechanisms of plants to heat tolerance and their further possible strategies for improving crop thermo tolerance is vital (Devi et al 2021). The heat susceptibility index may be used as a measure of heat tolerance in order to display yield stability under heat stress (Kavita et al 2016). Consequently, forty four genotypes of barley including six and two-row types were evaluated for heat tolerance using HSI based on grain yield of stress and non-stress environments.

### MATERIAL AND METHODS

The field trial was conducted during 2021-22 crop season at CCS Haryana Agricultural University, Hisar which is situated in subtropical region of North Western Plain Zone of India at latitude of 29°10'N, longitude of 75°46'E and altitude of 215.2 m above sea level. The experimental material consisted of 44 barley genotypes representing both 2-row (23) and 6-row (21) types including four check varieties, DWRB 123 and BH 946 (Timely sown); and DWRB 91 and DWRUB 64 (Late sown genotypes) in randomized block design replicated thrice. Each genotype was planted in paired rows of 2.5 m length spaced at 23 cm apart. The experimental material was grown under timely (non-stress) and late sown (heat stress) conditions on 20<sup>th</sup> November and 20<sup>th</sup> December, 2021, respectively. The package of practices recommended for both environments in terms of inputs were accordingly applied to raise the crop.

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 (%) alongwith 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) were studied under both stress and non-stressed environments.

Heat susceptibility index (HSI) based on grain yield and all other traits were calculated using the formula as suggested by Fischer and Maurer (1978).  $HSI = [1 - YD/YP]/D$  Where, YP = Mean of genotypes under timely sown, YD = Mean of genotypes under stress and  $D = 1 - [\text{Mean YD of all genotypes} / \text{Mean YP of all genotypes}]$ . The recorded data was subjected to statistical analysis using Microsoft Excel for calculation of HSI. R studio version 2023.12.1.402 was used for correlation coefficients and cluster analysis.

The weather parameters for 2021-22 crop season were obtained from the Agricultural Meteorology Department, CCS HAU, Hisar and are presented in Figure 1. During crop season, highest values for maximum (41.1°C) and minimum temperature (21.2°C) were recorded in standard week 15<sup>th</sup> and 16<sup>th</sup> (2022), respectively. The data disclosed that the average minimum and maximum temperature for post heading phase of the crop under timely sown condition was 11.37 and 28.50°C, whereas, under late sown condition, it was 14.64 and 34.32°C, respectively (Fig. 2). An average increase of 3.26°C and 5.82°C were observed for minimum and maximum temperature under stress as compared to non stress condition during post heading, denoting the appearance of significant heat stress under the late sown condition.

### RESULTS AND DISCUSSION

The estimates of HSI for grain yield revealed that the genotypes, BH 1018 followed by IBON-HI-2021-52, BH 1036 and DWRUB 64 exhibited minimum values of HSI, revealing the genotypes with low heat susceptibility and high yield stability under heat stress condition (Table 1). In contrast, IBON-HI-2020-155 followed by 7<sup>th</sup> GSBYT-2020-20 and BH 1029 recorded maximum HSI for grain yield and were identified as highly heat susceptible genotypes. HSI of various traits in barley were also used by Ram and Shekhawat (2017) for selection and utilization of heat tolerant genotypes in future breeding programme. For biological yield per plant, minimum HSI was shown by 7<sup>th</sup> GSBON-2020-101 followed by IBON-HI-2021-85, BH 1027 and BH 1026. Similarly, minimum HSI for harvest index was recorded for genotype BH 1018 followed by IBON-HI-2020-6, IBYT-HI-2021-17, IBON-HI-2021-81 and BH 1036. All of these genotypes showed their superiority for tolerance to high temperature than other genotypes for concerned traits. The genotypes confirmed with negative values of HSI for trait under study signifies the better performing genotype under

heat stress as compared to non-stress condition, is suitable for climate resilience (Thakur et al 2020).

Three genotypes namely IBON-HI-2021-52, BH 1034 and BH 946 showed their superiority for days to heading and maturity by exhibiting low estimates of HSI for these traits. Four genotypes were promising for grain filling duration viz., IBON-HI-2021-27, IBYT-HI-2021-3, DWRB 209 and 7<sup>th</sup> GSBON-2020-101. The HSI estimates for number of effective tillers per plant were minimum for BH 1038 followed by BH 946, DWRUB 64 and BH 1018. The heat tolerant genotypes with respect to plant height were IBON-HI-2021-81 followed by IBYT-HI-2020-6, BH 1038, IBYT-HI-2021-3 whereas, for peduncle length, IBYT-HI-2021-3 followed by BH 1018, IBYT-HI-2021-15 and BH 1027 showed tolerance to heat under stress condition. Spike length and number of grain per spike, important yield attributes for which DWRB 209, IBON-HI-2021-38 and IBON-HI-2020-55 showed low estimates of HSI. The genotype *i.e.* BH 1035 followed by BH 1026, IBYT-HI-2021-15 and IBON-HI-2021-33 exhibited minimum reduction in 1000-grain weight under heat stress among all evaluated genotypes. Bahrami et al (2020) selected heat tolerant genotypes employing selection indices based on grain yield in cultivated (*Hordeum vulgare ssp. vulgare* L.) and wild (*H. vulgare ssp. spontaneum* L.) barley

genotypes. All the physiological traits considered together and it was found that five genotypes *i.e.* BH 1025, IBON-HI-2021-102, DWRB 209, IBON-HI-2020-155 and DWRB 91 had low estimates of HSI simultaneously for four physiological characters, implies physiologically efficient entries under stress condition in context to heat tolerance. Various morpho-physiological traits were also used for heat tolerance screening by Sallam et al (2018) in barley.

All the genotypes including check varieties were first ranked on the basis of HSI of concerned studied trait and then based on average of ranks of HSI of all traits, the genotypes were further ranked, indicated as overall rank (Table 1). The genotypes viz., BH 1018, IBON-HI-2021-102, IBON-HI-2021-52, DWRB 209 and IBON-HI-2020-55 were the most tolerant to terminal heat stress among the experimental material evaluated. Due to detrimental effect of high temperature during reproductive phase, the genotypes performed differently under stress. Few genotypes could combat with the stress, while some of them were adversely affected (Fig. 3). The promising genotypes showing minimum reduction in grain yield were BH 1018 (2%) followed by IBON-HI-2021-52, BH 1036 and DWRUB 64. The reduction in grain yield, spike length, grains per spike and 1000-grain weight in

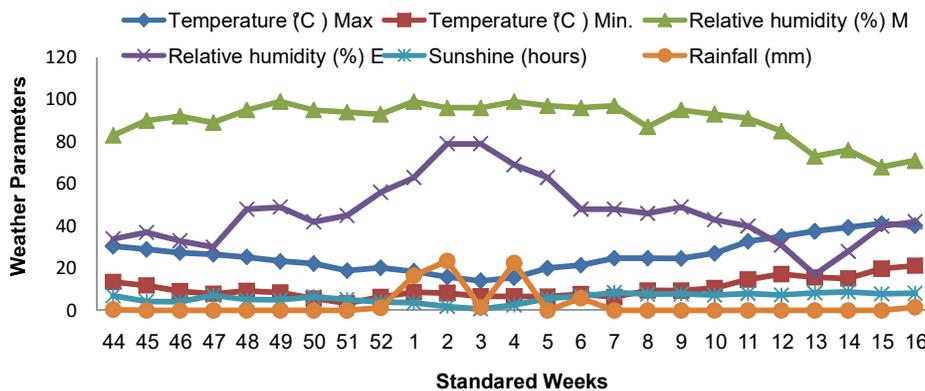


Fig. 1. Mean meteorological data during crop season 2021-2022

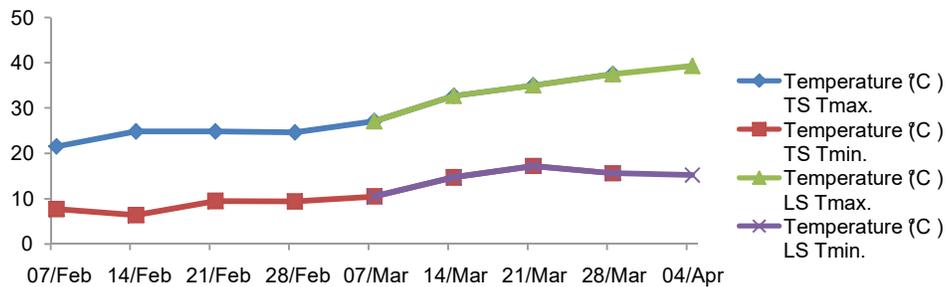


Fig. 2. Post heading maximum and minimum temperature under normal and late sown condition during 2021-22

Table 1. Heat susceptibility index (HSI) of barley genotypes for different traits

Genotypes	DH	DM	GFD	ETP	PH	PL	SL	GPS	TGW	BY	HI	GYP	SPAD1	SPAD2	NDVI1	NDVI2	CTD1	CTD2	R	OR
BH 1029	0.88	0.82	0.96	0.99	0.73	1.47	1.41	0.81	0.26	1.79	-0.15	1.71	0.22	0.64	0.36	0.44	3.74	3.49	42	44
BH 1034	0.53	0.69	1.22	0.66	0.80	1.67	0.90	0.24	0.10	0.84	-0.17	0.71	0.32	0.53	0.40	0.24	3.60	3.14	14	15
BH 1035	0.70	0.79	1.38	0.43	0.80	1.50	0.70	0.12	-0.18	1.17	-0.49	0.82	-0.34	0.35	0.05	0.48	3.72	3.44	20	20
BH 1036	0.63	0.72	1.12	0.40	1.02	2.17	0.67	0.58	0.14	1.15	-1.01	0.42	-0.32	0.07	0.27	0.25	3.72	3.48	3	10
BH 1038	0.68	0.73	1.14	-0.62	0.28	1.92	0.25	0.96	0.30	1.23	0.28	1.42	-0.11	0.41	0.16	0.34	3.64	3.29	34	13
BH 1039	0.74	0.76	1.05	0.54	0.63	1.93	-0.04	0.76	0.11	1.42	-0.66	0.98	-0.20	0.28	0.41	0.78	3.68	3.33	25	27
BH 1018	0.67	0.69	0.93	0.18	0.52	0.71	0.46	0.61	0.75	1.20	-1.57	0.09	-0.12	0.29	0.31	0.12	3.67	3.38	1	1
BH 1025	0.74	0.77	1.01	0.64	0.86	0.98	0.61	0.21	0.04	1.49	-0.87	0.94	0.21	0.06	0.31	0.19	3.48	2.63	23	6
BH 1026	0.74	0.74	0.94	1.01	0.63	1.46	0.95	0.39	-0.04	0.70	0.88	1.43	-0.50	0.59	0.20	0.61	3.56	2.89	35	16
BH 1027	0.77	0.77	1.06	0.78	0.36	0.83	0.80	0.50	0.05	0.65	0.08	0.72	0.62	0.16	0.21	0.44	3.65	3.22	16	14
IBYT -HI-2021-3	0.83	0.72	0.61	0.78	0.32	0.22	0.34	0.53	0.22	1.05	0.05	1.09	0.33	0.38	0.15	0.38	3.58	2.99	29	7
IBYT -HI-2021-9	0.62	0.78	1.55	0.66	0.95	1.59	0.43	0.17	0.50	1.70	-0.73	1.27	0.07	1.05	0.41	0.13	3.72	3.48	32	36
IBYT -HI-2021-15	0.82	0.84	1.03	0.34	0.83	0.78	0.46	0.84	0.00	1.67	-0.70	1.25	0.22	0.27	0.05	0.67	3.60	3.05	30	18
IBYT -HI-2021-17	0.85	0.87	1.21	0.90	0.95	1.38	0.97	0.86	0.96	2.08	-1.06	1.54	-0.02	0.19	0.05	0.58	3.68	3.34	38	40
IBYT -HI-2021-18	0.87	0.84	1.06	0.49	0.76	1.27	0.18	0.84	0.27	1.48	-0.72	1.02	0.09	0.34	0.27	0.50	3.73	3.52	27	35
IBON-HI-2021-27	0.87	0.75	0.53	0.23	0.55	1.47	0.79	0.30	0.54	1.94	-0.65	1.59	0.08	0.75	0.37	0.21	3.77	3.52	39	34
IBON-HI-2021-31	0.82	0.81	1.01	0.70	0.55	2.19	0.93	0.52	0.21	1.22	0.56	1.62	0.18	0.18	0.31	0.95	3.74	3.41	40	42
IBON-HI-2021-33	0.81	0.80	0.94	0.41	0.62	1.59	0.84	0.38	0.04	1.20	-0.69	0.71	0.11	0.04	0.27	0.57	3.73	3.48	14	21
IBON-HI-2021-38	0.70	0.78	1.22	0.43	0.69	1.19	0.17	0.24	1.19	1.17	-0.21	1.02	0.17	0.14	0.26	0.55	3.79	3.60	27	30
IBON-HI-2021-52	0.53	0.66	1.18	0.35	0.63	1.18	0.48	0.34	0.06	0.85	-0.79	0.23	0.06	0.17	0.26	0.47	3.75	3.51	2	3
IBON-HI-2021-56	0.74	0.81	1.31	0.68	0.64	1.09	0.94	0.48	1.19	1.36	-0.15	1.25	0.32	0.23	0.31	0.49	3.79	3.62	30	43
IBON-HI-2021-81	0.75	0.85	1.30	0.89	0.14	1.33	0.03	0.58	0.82	1.32	-1.02	0.63	0.33	0.53	0.37	0.14	3.63	3.16	12	25
IBON-HI-2021-85	0.51	0.71	1.40	0.86	0.77	1.72	0.59	0.18	1.20	0.38	0.17	0.53	0.32	0.85	0.26	0.36	3.57	3.07	7	24
IBON-HI-2021-99	0.62	0.73	1.28	0.41	1.07	1.58	1.61	0.47	0.80	1.25	-0.36	1.00	0.49	0.04	0.38	0.06	3.69	3.41	26	33
IBON-HI-2021-102	0.75	0.78	0.99	0.64	0.08	0.94	0.38	0.90	0.47	0.76	-0.31	0.51	-0.20	0.19	0.16	0.23	3.59	3.16	6	2
RD 3002	0.68	0.78	1.27	0.67	0.53	1.91	0.76	0.27	0.67	1.12	-0.69	0.61	-0.19	0.28	0.36	0.32	3.68	3.33	11	19
DWRB 197	0.63	0.75	1.41	0.38	0.51	1.12	1.01	1.03	1.12	1.16	-0.49	0.81	0.31	0.62	0.05	0.66	3.69	3.37	19	31
DWRB 209	0.70	0.64	0.63	0.52	0.87	1.72	0.11	0.03	0.62	0.73	0.05	0.77	0.08	0.16	0.26	0.12	3.65	3.32	18	4
BCLA 11-6	0.69	0.78	1.34	0.39	0.64	1.64	0.45	1.50	0.36	1.47	0.00	1.47	0.11	0.22	0.20	0.13	3.70	3.40	37	32
IBON-HI-2020-71	0.72	0.82	1.32	0.52	1.08	1.89	1.25	0.19	0.34	1.38	-0.78	0.86	0.59	0.15	0.32	0.68	3.76	3.53	21	41
7 <sup>th</sup> GSBON-2020-90	0.66	0.75	1.22	0.21	1.03	1.47	0.84	1.18	1.23	1.46	-0.23	1.30	0.39	0.73	0.37	0.26	3.66	3.31	33	39
IBON-HI-2020-6	0.59	0.72	1.34	0.59	0.63	1.97	0.54	0.29	1.34	1.35	-1.13	0.58	0.51	0.62	0.27	0.39	3.69	3.33	9	28
IBON-HI-2020-51	0.67	0.65	0.83	0.59	0.59	2.09	0.62	0.30	0.43	1.05	-0.61	0.60	0.58	0.67	0.21	0.18	3.65	3.30	10	11
7 <sup>th</sup> GSBON-2020-140	0.68	0.65	0.74	0.81	0.39	1.59	0.31	1.23	0.23	1.60	0.03	1.62	0.20	0.65	0.00	0.57	3.64	3.24	40	21
IBON-HI-2020-55	0.67	0.65	0.74	0.61	0.67	1.61	0.37	0.16	0.29	1.12	-0.61	0.67	0.07	0.67	0.21	0.06	3.70	3.40	13	5
7 <sup>th</sup> GSBON-2020-101	0.72	0.67	0.68	0.33	0.41	2.19	0.57	0.65	0.80	-0.02	0.48	0.47	0.23	0.36	0.21	0.06	3.66	3.38	5	12
IBYT-HI-2020-6	0.73	0.72	0.92	0.24	0.28	0.86	0.36	0.91	0.33	0.89	0.05	0.93	0.21	0.17	0.36	0.42	3.67	3.32	22	9
7 <sup>th</sup> GSBYT-2020-20	0.65	0.78	1.33	1.02	0.57	1.53	0.45	0.56	1.32	1.69	0.05	1.72	-0.07	0.39	0.05	0.70	3.69	3.33	43	37
IBYT-HI-2020-11	0.61	0.76	1.37	0.40	0.77	2.22	0.14	0.73	0.66	0.97	-0.27	0.76	0.17	0.26	-0.05	0.55	3.61	3.21	17	17
IBON-HI-2020-155	0.70	0.80	1.19	0.89	0.57	2.01	1.56	0.09	0.70	1.80	0.11	1.86	-0.08	0.59	0.10	0.64	3.64	3.20	44	38
DWRB 123 (c)	0.61	0.76	1.42	0.34	0.99	2.10	1.25	0.45	0.18	1.05	-0.64	0.56	0.19	0.23	-0.27	0.54	3.69	3.41	8	23
BH 946 (c)	0.56	0.67	1.27	-0.08	0.78	2.02	0.71	0.68	0.58	1.40	-0.63	0.97	0.00	0.65	0.16	0.22	3.71	3.48	24	26
DWRB 91 (c)	0.72	0.76	1.05	0.45	0.62	1.66	1.36	0.67	0.70	1.83	-0.72	1.43	-0.12	0.20	0.10	0.12	3.71	3.44	35	29
DWRUB 64 (c)	0.52	0.74	1.35	0.04	0.39	1.07	0.68	0.23	0.50	0.85	-0.52	0.43	0.06	0.34	0.26	0.30	3.76	3.57	4	8

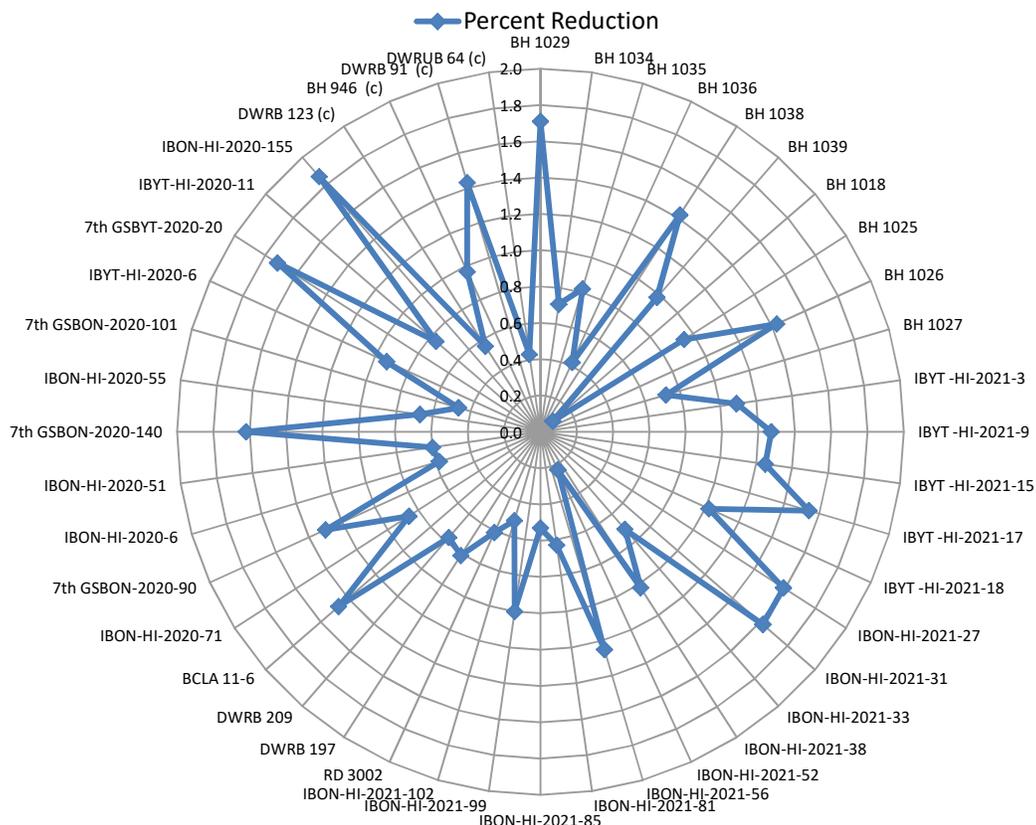
DH: Days to heading, DM: Days to maturity, GFD: Grain filling duration, ETP: Number of effective tillers per plant, PH: Plant height, PL: Peduncle length, SL: Spike length, GPS: Number of grains per spike, TGW: 1000-grain weight, BY: Biological yield per plant, HI: Harvest index, GYP: Grain yield per plant, SPAD 1: Chlorophyll content (SPAD) at anthesis, SPAD 2: Chlorophyll content (SPAD) at 15 days 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: Canopy temperature depression at 15 days after anthesis, R: Rank based on grain yield, OR: Overall rank based on average ranks of HSI of all traits

barley also cited by Pathak et al (2017) under stress condition.

Grain yield per plant exhibited significant positive association with days to heading and maturity, spike length, number of grains per spike, biological yield per plant, harvest index and NDVI 2, exhibiting the relevance of these traits for deciding the selection criterion for stress conditions (Table 2). HSI based association study for heat tolerance was also conducted by Shehrawat et al (2020). Significant positive correlations were also observed for days to heading with days to heading, number of effective tillers per plant, and biological yield; days to maturity with grain filling duration, number of effective tillers per plant, biological yield and NDVI 2; grain filling duration with plant height and 1000-grain weight; plant height with peduncle length, spike length and biological yield; biological yield with CTD 2; CTD 1 with CTD 2. The positive association enhances the progress under selection and vice-versa. Similarly, significant negative correlation was existed for days to heading with grain filling duration and peduncle length; number of effective tillers per plant with CTD 2; plant height with harvest index; biological yield with harvest index; and NDVI 1 with NDVI 2. These results corroborates for one or more traits with the findings of Devi et al (2021).

The clustering pattern recognized cluster I as largest one with 13 genotypes, followed by cluster V (9) and cluster III (8), while the cluster II and IV being smallest contained seven genotypes each (Table 3). The estimates of various stress indices were also used by Lamba et al (2023) for clustering of genotypes evaluated under stress condition. Several other genetic studies for classification of genotypes into different tolerance categories have also been conducted in barley based on HSI (Parashar et al 2019, Yadav et al 2023). The maximum intra-cluster distance for cluster I followed by cluster II and cluster III, implies the genotypes with relatively more diversity compared to genotypes belonging to other clusters. Similarly, the genotypes of cluster V showed more similarity as deciphered by minimum intra-cluster distance. The results in addition also revealed that cluster II placed most distantly from cluster III as exhibited by maximum inter-cluster distance among all cluster combinations, followed by clusters I and III. However, cluster III is most closely placed to cluster V as observed based on minimum distance among inter cluster distances.

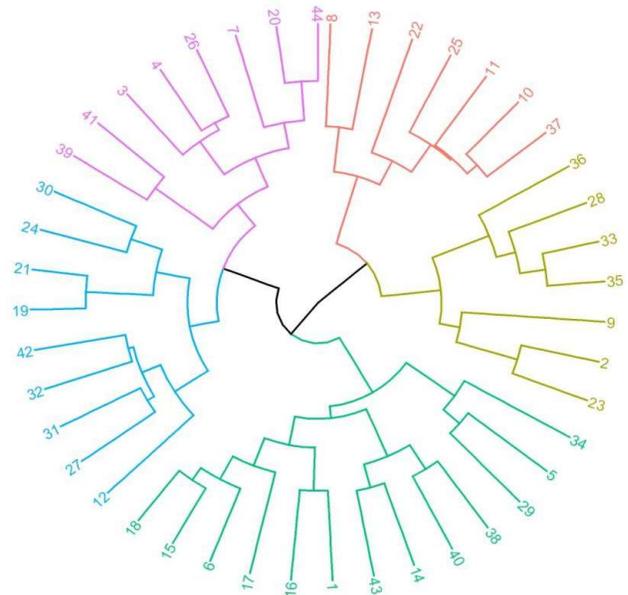
The low estimates of HSI indicates the tolerance of genotypes to terminal heat. Cluster II exhibited superiority for days to maturity, grain filling duration, number of grains



**Table 2.** Correlation among HSI of different traits in barley genotypes

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	0.564**	-0.550**	0.297*	-0.228	-0.358*	0.003	0.236	-0.278	0.305*	0.057	0.436**	0.003	-0.229	0.074	0.230	0.008	-0.038
DM		1.000	0.307**	0.310*	0.109	-0.199	0.213	0.104	-0.020	0.497**	-0.174	0.407**	-0.033	-0.248	0.043	0.466**	0.242	0.173
GFD			1.000	-0.032	0.340*	0.163	0.183	-0.119	0.325*	0.069	-0.165	-0.094	0.067	0.058	-0.071	0.187	0.206	0.195
ETP				1.000	-0.058	-0.039	0.097	-0.226	0.009	0.106	0.200	0.317	0.080	0.126	0.002	0.268	-0.258	-0.340*
PH					1.000	0.252*	0.272*	-0.262	-0.054	0.223*	-0.299*	0.063	0.078	-0.144	0.129	0.000	0.186	0.227
PL						1.000	0.100	-0.158	0.086	-0.028	0.106	-0.042	-0.086	0.139	-0.055	0.053	0.069	
SL							1.000	-0.149	0.010	0.162	0.011	0.173*	0.125	-0.052	0.019	0.131	0.241	
GPS								1.000	0.058	0.225	0.070	0.256*	0.000	-0.002	-0.213	0.136	-0.137	
TGW									1.000	0.159	-0.007	0.028	0.180	0.242	0.048	-0.199	0.085	
BY										1.000	-0.352**	0.702**	-0.099	0.147	0.066	0.162	0.289*	
HI											1.000	0.338**	0.106	-0.223	0.147	-0.272	-0.296	
GYP												1.000	-0.065	-0.099	0.348*	0.080	-0.005	
SPAD 1													1.000	0.053	-0.042	-0.109	-0.137	
SPAD 2														1.000	-0.120	-0.167	-0.179	
NDVI 1															1.000	-0.283*	0.239	
NDVI 2																1.000	0.097	
CTD 1																	1.000	-0.007
CTD 2																		1.000

See Table 1 for details



(For detail of genotypes with Sr. No., refer to Table 1)

**Fig. 4.** Dendrogram portraying clustering pattern of 44 barley genotypes

per spike, biological yield as well as for NDVI 2 (Table 4). The genotypes of cluster III were promising for days to heading, number of effective tillers per plant, harvest index, grain yield per plant, SPAD1 and 2, and NDVI 1. Similarly, cluster IV was positively associated with the traits viz., plant height, peduncle length, spike length, 1000-grain weight, and CTD. Accordingly, the promising genotypes may be sorted from different clusters for their utilization in breeding program intended to develop heat tolerant cultivars. Suresh et al (2018) observations substantiated results for deciding criterion of selection and/or identification of genotypes based on HSI. The relationship among the studied genotypes is presented in Figure 4 in the form of circular dendrogram displaying the serial number of genotypes that may be decoded by conferring Table 1.

**CONCLUSION**

HSI used was recognized as vital for identifying cultivars with high tolerance to heat stress. The genotypes, BH 1018, IBON-HI-2021-52, BH 1036, DWRUB 64, 7<sup>th</sup> GSBON-2020-101, IBON-HI-2021-102, IBON-HI-2021-85 and DWRB 123 were promising based on HSI of grain yield. However, results based on average of ranks of HSI of all traits illustrated the genotypes, BH 1018, IBON-HI-2021-102, IBON-HI-2021-52, DWRB 209 and IBON-HI-2020-55 with high heat tolerance under stress condition. Further, association study signifies the importance of days to heading and maturity, spike length,

**Table 3.** Clustering of barley genotypes based on HSI of different traits and their genetic distances

Cluster members	Number of genotypes	Clusters	Cluster distances				
			Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
BH 1029, BH 1038, BH 1039, IBYT-HI-2021-17, IBYT-HI-2021-18, IBON-HI-2021-27, IBON-HI-2021-31, IBON-HI-2021-33, BCLA 11-6, 7 <sup>th</sup> GSBON-2020-140, 7 <sup>th</sup> GSBYT-2020-20, IBON-HI-2020-155, DWRB 91	13	Cluster I	2.594	3.187	3.271	2.653	2.531
BH 1034, BH 1026, IBON-HI-2021-85, DWRB 209, IBON-HI-2020-51, IBON-HI-2020-55, 7 <sup>th</sup> GSBON-2020-101	7	Cluster II	3.187	2.346	3.312	2.896	3.028
BH 1035, BH 1036, BH 1018, IBON-HI-2021-52, RD 3002, IBYT-HI-2020-11, DWRB 123, DWRUB 64	8	Cluster III	3.271	3.312	2.311	2.692	2.331
BH 1025, BH 1027, IBYT-HI-2021-3, IBYT-HI-2021-15, IBON-HI-2021-81, IBON-HI-2021-102, IBYT-HI-2020-6	7	Cluster IV	2.653	2.896	2.692	1.955	2.667
IBYT-HI-2021-9, IBON-HI-2021-38, IBON-HI-2021-56, IBON-HI-2021-99, DWRB 197, IBON-HI-2020-71, 7 <sup>th</sup> GSBON-2020-90, IBON-HI-2020-6, BH 946	9	Cluster V	2.531	3.028	2.331	2.667	1.830

**Table 4.** Performance of clusters for HSI of barley genotypes

	DH	DM	GFD	ETP	PH	PL	SL	GPS	TGW	BY	HI	GYP	SPAD 1	SPAD 2	NDVI 1	NDVI 2	CTD 1	CTD 2
C I	0.77	0.78	1.04	0.55	0.60	1.67	0.73	0.73	0.46	1.60	-0.28	1.44	0.03	0.38	0.20	0.50	3.70	3.38
C II	0.65	0.68	0.92	0.65	0.68	1.78	0.59	0.28	0.49	0.69	0.03	0.74	0.16	0.55	0.25	0.23	3.63	3.21
C III	0.62	0.74	1.25	0.35	0.71	1.61	0.64	0.42	0.35	1.05	-0.75	0.49	-0.06	0.25	0.15	0.38	3.70	3.42
C IV	0.77	0.78	0.99	0.62	0.41	0.85	0.43	0.64	0.28	1.12	-0.39	0.87	0.25	0.25	0.23	0.35	3.60	3.08
C V	0.65	0.76	1.32	0.42	0.82	1.55	0.83	0.53	0.92	1.36	-0.52	1.01	0.32	0.47	0.28	0.38	3.72	3.46

See Table 1 for details

number of grains per spike, biological yield per plant, harvest index and NDVI 2 towards grain yield under stress condition. The genotypes of cluster III portrayed better performance under stress for grain yield and other traits studied, could be incorporated in elite barley cultivars intended to develop new heat tolerant varieties.

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