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Research Paper

Effect of sowing dates on the phenology, grain yield and stress tolerance indices of barley (*Hordeum vulgare* L.) genotypes under subtropical conditions of Punjab

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ABSTRACT

In order to assess the effect of terminal heat stress on the *in vitro* screened heat tolerant (n=9) and susceptible (n=3) genotypes of barley, a field trial was conducted during *rabi* 2019-20 and 2020-21 at Punjab Agricultural University, Ludhiana, Punjab, India. Barley genotypes were sown under timely (November 26) and late sown (December 26) conditions so that late sown crop encounters heat stress during its reproductive stages of growth. The results showed that timely sown crop took significantly higher number of days to attain physiological maturity as compared to late sown crop. For anthesis and physiological maturity, timely sown crop accumulated higher growing degree days (GDD) in comparison to late sown crop. Tolerant genotypes (*viz*., BL 1515, BL 1729, BL 1780, BL 1784, BL 1786, BL 1792, BL 1794, BL 1797 and IBYT-E24) recorded higher number of GDD for attaining physiological maturity in comparison to susceptible genotypes (*viz*., BL 1723, IBON 23 and IBYT-E15) under late sown conditions. Likewise, heat use efficiency (HUE) was also lower in susceptible genotypes as compared to tolerant genotypes particularly under late sown conditions. Results also indicated that under timely sown conditions, grain yield of tolerant genotypes was statistically at par to susceptible genotypes; but under late sown conditions, tolerant genotypes out yielded susceptible genotypes. Among the tolerant genotypes, BL1786 had the highest grain yield under late sown conditions and it was statistically similar to three other tolerant genotypes namely BL1780, BL1784 and BL1792. Tolerant genotypes recorded lower tolerance index (TOL) and stress susceptibility index (SSI) values in comparison to susceptible genotypes; however, exhibited higher values of yield stability index (YSI). Correlation studies indicated that number of days taken to physiological maturity is the most crucial phenological stage determining seed yield of barley under late sown conditions.

Key words: AGDD, barley, grain yield, phenological stages, tolerance indices

Global warming has caused an increase in average global temperature of 0.4 to 0.8°C during the past century (Ring *et al.,* 2012). Climatological extremes including heat waves have been predicted to adversely affect plant growth and development causing huge loss of crop yields (Ainsworth and Ort 2010). High temperatures have been reported to lower floret fertility and shorten the grain-filling period leading to significant reductions in seed yield (Prasad and Djanaguiraman 2014).

In the present era of global warming, heat stress is the major cause of yield reduction in cereals which are more prone to terminal heat stress during reproductive stages. Barley (*Hordeum vulgare* L.) is the fourth major cereal crop after maize, rice and wheat. As compared to maize, rice and wheat, barley shows more adaptive capabilities under heat, drought and salinity stresses (Munns *et al.*, 2006). Therefore, barley is considered an important staple food crop in regions that are susceptible to climate change.

Grain yields are reduced when sowing is delayed over the optimum time, however, the productivity of genotypes can differ (Joshi *et al*., 2016; Kumar *et al*., 2008; Bhavi *et al*., 2013) All agricultural biological processes are temperature-sensitive, and may be described in terms of three cardinal temperatures which include base, ideal and maximum temperature. However, it is crucial to understand the type of temperature reaction between these cardinal points when determining a crop's phenology, adaptability, and yield (Singh and Singh 2011). Heat use efficiency is the effectiveness of using heat to produce dry matter or grain yield. The ability to

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convert thermal energy into dry matter relies on the crop, the growth environment, and genetic factors. Several phenological models have been developed utilizing growing degree-days (GDD), photothermal units (PTU), and heliothermal units (HTU) to predict the time needed to reach distinct phenophases (Esfandiary *et al.,* 2009). The growth phases of many crops, such as sorghum and wheat can be accurately estimated using GDD and PTU (Prakash *et al*., 2017). The indices may help plant breeders in selecting genotypes with relatively consistent yields for cultivation under stress conditions in addition to genotypes with high yield under ideal conditions. In crop plants including wheat (Aziz *et al*., 2018) and common beans (Chavez-Arias *et al*., 2018), the stress tolerance indices have been utilised to evaluate high-temperature tolerance. The present study was conducted under timely and late sown conditions to validate the *in vitro* screened barley genotypes for heat stress tolerance under field conditions in relation to phenological development and productivity under semi-arid, subtropical climate of Punjab, India.

MATERIALAND METHODS

Field experiments were conducted during *rabi* 2019-20 and 2020-21 at Research Farm of Punjab Agricultural University (PAU), Ludhiana (30 54 N, 75 48 E, altitude 247 m above mean sea level). Daily meteorological data during the crop season were collected from the Department of Climate Change and Agricultural Meteorology, PAU, Ludhiana for calculating weekly mean of maximum and minimum temperature, total rain fall, relative humidity and sunshine hours (Table 1). Nine tolerant (BL 1515, BL 1729, BL 1780, BL 1784, BL 1786, BL 1792, BL 1794, BL 1797 and IBYT-E24) and three susceptible genotypes of barley (BL 1723, IBON 23 and IBYT-E15) were sown under timely (November 26) and late (December 26) conditions in a plot size of 4×٢.5 m with row to row spacing of 20 cm (replicated thrice). Field management practices as given in the Package and Practices for *rabi* crops, PAU were followed (Anonymous 2019). Crop was sown using 87.5 kg seed/ha in rows 20 cm apart. Crop was fertilized with N, P and K through urea (@137.5 kg/ha), single superphosphate (@ 187.5 kg/ha) and muriate of potash (@ 50 kg/ha). Whole of the fertilizer was applied as basal dose. Crop was sown at 4-5 cm depth on dates as per treatments.

The experiment was conducted in factorial randomized block design with two sowing dates as first factor and twelve genotypes as second factor. Data were recorded on number of days taken to attain various phenological stages *viz*., emergence, tillering, anthesis and physiological maturity. Data on grain yield were recorded from a net plot of 7 m^2 and presented as Mg/ha for each genotype. Growing degree days (GDD) were calculated as per de Beurs and Henebry (2008) and base temperature was taken as 4.5°C. Heat use efficiency (HUE) was calculated as described by Dar *et al.,* (2018). Tolerance indices *viz*., TOL, STI, SSI and YSI were calculated as per Bahrami *et al.,* (2021) as per following formulae:

Tolerance index (TOL) $= Yn - Yl$

Stress tolerance index (STI) $= \frac{(Yn \times Yl)}{Ymn^2}$

Stress susceptibility index (SSI) $= \frac{[1-(\frac{Yl}{Yn})]}{SI}$, where $SI = 1 - (\frac{Yml}{Ymn})$

Yield stability index (YSI) $= Yl/Yn$

Yn and indicate the average grain yields of each selected advanced breeding lines in timely and late sown conditions, respectively. While, Ymn and Yml represents the average grain yields of twelve selected advanced breeding lines in timely and late sown conditions, respectively.

The data were subjected to analysis of variance (ANOVA) and the correlations between yield, GDD and stress indices were computed using SPSS (version 21) programme.

RESULTS AND DISCUSSION

Phenology of barley

Date of sowing had significant effect on number of days taken to various phenological stages *viz*., emergence, tillering, anthesis and physiological maturity. Late sown crop took significantly lesser number of days to attain all phenophases except emergence and tillering, where late sown crop took significantly more days as compared to timely sown crop. The delayed emergence under late sown conditions may be attributed to low weekly mean temperature (7.7-10.7°C during 2019-20 and 9.6-11.0°C during 2020-21) prevailing during emergence at the end of December to 1st week of January as compared to normal sowing when the weekly mean temperature was higher (14.8-17.2°C during 2019-20 and 13.9-15.8°C during 2020-21). However, late sown crop took lesser number of days for attainment of anthesis stage as compared to timely sown crop. Kumar *et al*., (2013) and Chakrabarti *et al.,* (2011) also reported that higher temperature during initiation of reproductive stage resulted in early onset of anthesis in late sown wheat. At grain filling stage, late sown crop experienced higher weekly mean temperature (25.6-27.5°**C** during 2019-20 and 27.2 to 32.7°C during 2020-21) in comparison to normal sowing (20.9-27.5°**C** during 2019-20 and 24.0-27.2°C during 2020-21) during 2nd to 4th week of April and 4th week of March to 3rd week of April, respectively. Timely sown crop had longer grain filling phase in comparison to late sowing. Under timely sown conditions, number of days taken to anthesis and physiological maturity were statistically similar in nine heat tolerant and three susceptible genotypes. However, tolerant genotypes tended to maintain comparatively longer grain-filling period under late sown condition but reduction was greater in grain-filling period of susceptible genotypes. However, susceptible genotypes *viz*., BL1723, IBON-23 and IBYT-E24 took less no. of days for attaining physiological maturity as compared to tolerant genotypes under late sown conditions. High temperature and comparatively low relative humidity (%) during grain- filling stage of late sown crop enforced the crop to mature quickly (Tables 1 and 2). Reduced growth period under late sowing has also been reported by Baloch *et al*., (2012) and Ram *et al.,* (2012) in wheat and Ram *et al.,* (2010) in barley.

Growing degree days (AGDD)* and *heat use efficiency (HUE)

The late sown crop (December 26) accumulated more growing degree days (GDD) than timely sown crop (November 26)

Table 1: Mean weekly meteorological data during *rabi* 2019-20 and *rabi* 2020-21

Week	2019-20 Mean temp. (˚C)	2019-20 Mean RH (%)	2019-20 Rainfall (mm)	2019-20 Sunshine (hrs)	2020-21 Mean temp. (˚C)	2020-21 Mean RH (%)	2020-21 Rainfall (mm)	2020-21 Sunshine (hrs)
26Nov-2Dec	17.2	74.7	5.0	5.0	15.8	89.0	1.0	4.6
3Dec-9Dec	14.8	68.3	0.0	6.2	13.9	93.0	0.0	4.7
10Dec-16Dec	12.8	82.2	6.7	2.3	12.5	89.0	0.0	4.9
17Dec-23Dec	10.9	83.9	0.0	1.2	10.9	90.0	4.2	4.6
24Dec-30Dec	7.7	83.8	0.0	0.3	9.6	91.0	0.0	3.3
31Dec-6Jan	10.7	75.0	1.6	1.3	11.0	96.0	1.8	3.0
7Jan-13Jan	11.3	82.3	3.1	0.8	11.5	91.0	11.0	1.2
14Jan-20Jan	11.1	82.6	0.0	0.7	12.1	93.0	0.0	1.2
21Jan-27Jan	12.3	72.8	0.4	1.1	12.3	96.0	0.0	5.9
28Jan-3Feb	12.0	77.8	0.5	1.1	14.8	93.0	0.0	5.9
4Feb-10Feb	11.6	72.1	0.0	0.7	15.2	89.0	17.0	6.2
11Feb-17Feb	15.1	69.9	0.0	0.9	18.2	95.0	0.0	6.3
18Feb-24Feb	17.3	67.0	0.9	0.9	18.6	96.0	0.0	7.4
25Feb-2Mar	18.9	73.6	1.3	1.6	21.4	96.0	0.0	7.9
3Mar-9Mar	17.0	74.2	2.7	2.6	21.6	90.0	0.0	7.5
10Mar-16Mar	16.6	70.8	4.1	2.1	23.0	80.0	0.0	7.2
17Mar-23Mar	20.3	68.5	0.0	2.5	23.2	81.0	0.0	6.8
24Mar-30Mar	20.9	72.8	3.0	3.1	24.0	84.0	5.0	6.4
31Mar-6Apr	21.8	61.8	0.1	3.6	24.3	73.0	0.0	7.3
7Apr-13Apr	24.2	54.5	0.0	4.2	25.5	55.0	3.0	9.5
14Apr-20Apr	27.5	48.6	1.4	5.2	27.2	49.0	0.0	9.3
21Apr-27Apr	25.6	53.4	0.5	4.6	32.7	64.0	6.6	7.7
28Apr-4May	28.6	51.6	2.3	5.9	32.7	50.0	0.5	7.7

Table 2: Phenology of barley genotypes as influenced by sowing dates (pooled analysis of *rabi* 2019-20 and 2020-21)

	Number of days to											
	Emergence			Tillering			Anthesis			Phy. Maturity		
Genotypes	TS	LS	Mean	TS	LS	Mean	TS	LS	Mean	TS	LS	Mean
BL1515	6.2	10.5	8.4	29.7	44.5	37.1	91.7	76.5	84.1	153.2	128.0	140.6
BL1729	6.0	11.0	8.5	30.2	43.5	36.9	92.0	79.5	85.8	153.5	129.5	141.5
BL1780	5.7	11.0	8.4	30.5	42.5	36.5	92.7	76.2	84.5	154.5	129.7	142.1
BL1784	6.3	10.5	8.4	30.0	43.2	36.6	92.0	77.8	84.9	153.3	129.0	141.2
BL1786	6.0	10.3	8.2	29.2	43.5	36.4	91.8	76.0	83.9	154.5	128.5	141.5
BL1792	6.3	11.0	8.7	30.5	44.5	37.5	91.5	78.7	85.1	154.0	129.2	141.6
BL1794	6.2	11.5	8.9	35.5	46.5	41.0	92.0	77.0	84.5	155.5	128.5	142.0
BL1797	6.0	11.5	8.8	30.0	42.5	36.3	92.0	76.0	84.0	154.5	129.0	141.8
IBYT-E24	6.0	10.5	8.3	29.5	41.5	35.5	91.5	79.2	85.4	154.3	129.8	142.1
BL1723	6.0	10.0	8.0	30.0	43.5	36.8	92.0	76.7	84.4	153.0	125.0	139.0
IBON-23	6.0	10.0	8.0	29.5	42.5	36.0	92.0	76.3	84.2	154.0	127.0	140.5
IBYT-E15	6.0	11.0	8.5	30.0	41.5	35.8	92.0	75.5	83.8	155.0	123.2	139.1
Mean	6.1	10.7		30.4	43.3		91.9	77.1		154.1	128.0	
SEm±	D=0.13G=0.32 D×G=0.46			D=0.26G=0.64 D×G=0.91			D=0.21G=0.52 D×G=0.74			D=0.55G=1.36 D×G=1.93		
LSD (p=0.05)	D=0.38G=NS D×G=NS			D=0.75G=1.83 D×G=NS			D=0.61G=NS D×G=2.12			D=1.60G=NS D×G=NS		

*TS=Timely sown crop; LS=late sown crop; D=Date of sowing and G=Genotypes

at emergence stage; but as the crop stage progressed to tillering, the differences w.r.t. GDD between late sown and timely sown crop narrowed down (Table 3). From anthesis stage upto physiological maturity, timely sown crop accumulated higher GDD in comparison to late sown crop. For attainment of physiological maturity under late sowing, tolerant genotypes had higher GDD than that of susceptible genotypes as tolerant genotypes took higher number of days to attain physiological maturity. The higher GDD helped tolerant genotypes to gain higher grain yield in comparison to susceptible genotypes. The decrease in GDD accumulation with delay in sowing for physiological maturity may be correlated to the high temperature during the growth period of late sown crop (Dhillon *et al.*, 2017).

Table 3: Effect of sowing dates on accumulated growing degree days (GDD) for attainment of various phenophases in barley genotypes (pooled analysis of *rabi* 2019-20 and 2020-21)

	GDD (°C day hrs) for attainment of …………………											
	Emergence			Tillering			Anthesis			Phy. Maturity		
Genotypes	TS	LS	Mean	TS	LS	Mean	TS	LS	Mean	TS	LS	Mean
BL1515	69.4	118.2	93.8	263.9	348.7	306.3	795.0	608.4	701.7	1906.2	1391.9	1649.1
BL1729	67.6	123.9	95.8	266.6	341.0	303.8	800.1	642.4	721.3	1912.9	1418.1	1665.5
BL1780	63.8	123.9	93.9	268.2	335.8	302.0	808.0	602.1	705.1	1933.1	1427.1	1680.1
BL1784	71.3	118.2	94.8	265.4	339.0	302.2	800.1	621.9	711.0	1909.8	1408.3	1659.1
BL1786	67.6	116.4	92.0	260.4	341.0	300.7	797.7	600.6	699.2	1930.4	1401.7	1666.1
BL1792	71.3	123.9	97.6	268.2	348.7	308.5	790.4	635.6	713.0	1923.1	1417.5	1670.3
BL1794	69.4	129.5	99.5	294.7	361.3	328.0	800.1	613.0	706.6	1948.2	1404.1	1676.2
BL1797	67.6	129.5	98.6	265.4	335.8	300.6	800.1	600.6	700.4	1928.3	1406.8	1667.6
IBYT-E24	67.6	118.2	92.9	262.4	329.9	296.2	790.4	637.1	713.8	1926.7	1421.8	1674.3
BL1723	67.6	112.6	90.1	265.4	341.0	303.2	800.1	605.6	702.9	1902.5	1336.0	1619.3
IBON-23	67.6	112.6	90.1	262.6	335.8	299.2	800.1	602.6	701.4	1921.8	1366.7	1644.3
IBYT-E15	67.6	123.9	95.8	265.4	329.9	297.7	800.1	594.7	697.4	1944.5	1302.1	1623.3
Mean	68.2	120.9		267.4	340.7		798.5	613.7		1924	1391.8	
SEm±	D=1.48G=3.63 D×G=5.14			D=1.69G=4.15 D×G=5.88			D=2.77G=6.80 D×G=9.62			D=11.59G=28.41 D×G=40.18		
LSD (p=0.05)	D=4.24G=NS D×G=NS			D=4.84G=11.87 D×G=NS			D=7.93G=NS D×G=27.48			D=33.12G=NS D×G=NS		

*TS=Timely sown crop; LS=late sown crop; D=Date of sowing and G=Genotypes

HUE was higher for timely sown crop as compared to late sown crop. Higher HUE in timely sown crop can be correlated to their higher yield as compared to the late sown crop (Table 4). Under timely sown conditions, HUE of susceptible genotypes was comparable to tolerant genotypes. However, susceptible genotypes exhibited considerably lower HUE as compared to tolerant genotypes under late sown conditions. HUE is determined in terms of dry matter accumulation by the plant. So, higher dry matter accumulation due to higher crop growth rate under normal sowing conditions improved its heat use efficiency as compared to late sown crop. Lesser GDD and HUE for late sown crop could be attributed to shortened growth period. Khichar and Niwas (2007) observed that late sowing of wheat resulted in a reduction in the requirement of heat units for various phenological stages. Among the genotypes, tolerant genotypes exhibited advantage over the susceptible genotypes in terms of accumulated GDD and HUE under late sown conditions. Tolerant genotypes exhibited higher yield in comparison to susceptible ones as the tolerant genotypes exhibited higher GDD and HUE under late sown conditions.

Grain yield

The grain yield was significantly influenced by the sowing date and yield reduction was observed under late sown conditions in all the barley genotypes. The pooled analysis revealed that for late sowing, the percentage reduction was in the range of 9 (BL1784) to 30 % (IBYT-E24) and 41 (IBON-23) to 44% (BL1723) in tolerant and susceptible genotypes, respectively (Table 4). The forced maturation of late-sown barley and the reduction in the duration of grain filling period may be primarily responsible for the decrease in grain production with delayed sowing. Number of days taken to maturity varied by only 1-2 days among different genotypes under timely sowing conditions. However, tolerant genotypes took 2-6 days more than susceptible genotypes for maturity under late sown conditions (Table 2). This could be a result of the terminal heat stress experienced by the late sown crop during the grain filling period. Heat stress has been shown to impact the barley crop's reproductive growth and grain filling period (Sehgal *et al.,* 2018). Exposure of wheat crop to short episodes (2-5 days) of heat stress (>24°C) at anthesis stage has been reported to decrease grain weight (Prasad and Djanaguiraman 2014). The reduction in grain weight with delayed sowing time might be attributed to the shorter period from heading to maturity due to which grain filling is not proper in barley (Singh *et al.,* 2006). Timely sowing increases the availability of photosynthates and nutrients to growing reproductive structures, which enhances all yield-attributing parameters and eventually increased crop production (Sehgal *et al.,* 2018). Late sown crop completed its various growth and developmental stages in lower degree days as compared to timely sown crop, thus resulting in significant reduction in yield attributes and ultimately lower grain yields (Aslam *et al.,* 2017). The delayed sowing has been reported to cause significant decline in grain yield in barley (Singh *et al.,* 2006).

Table 4: Effect of sowing dates on yield and HUE of barley genotypes (pooled analysis of *rabi* 2019-20 and 20-21)

	Yield (Mg ha^{-1})			HUE (kg ha^{-1} °C day^{-1})		
Genotype	TS	LS	Mean	TS	LS	Mean
BL1515	4.50	3.30	3.93	2.45	2.41	2.43
BL1729	4.11	3.01	3.67	2.23	2.10	2.17
BL1780	4.70	3.69	4.12	2.54	2.62	2.58
BL1784	4.01	3.64	3.81	2.19	2.62	2.41
BL1786	4.60	3.92	4.30	2.59	2.92	2.76
BL1792	4.50	3.43	4.02	2.48	2.44	2.46
BL1794	4.11	3.21	3.79	2.11	2.43	2.27
BL1797	4.11	3.11	3.62	2.23	2.36	2.30
IBYTE24	4.30	3.02	3.76	2.33	2.30	2.32
BL1723	4.51	2.52	3.52	2.48	1.91	2.20
IBON23	4.71	2.80	3.71	2.56	2.01	2.29
IBYTE15	4.71	2.71	3.73	2.49	2.11	2.30
Mean	4.41	3.20		2.39	2.35	
SEm±	D=0.18 G=0.07 D×G=0.26			D=0.05 G=0.12 D×G=0.17		
LSD (p=0.05)	D=0.53 G=0.23 D×G= 0.72			D=NS G=NS D×G=NS		

*TS=Timely sown crop; LS=late sown crop; D=Date of sowing and G=Genotypes

Table 5: Effect of different sowing dates on tolerances indices of barley genotypes (pooled analysis of *rabi* 2019-20 and 20-21)

	Tolerances indices			
Genotype	TOL	STI	SSI	YSI
BL1515	1.20	0.767	1.07	0.733
BL1729	1.10	0.635	1.07	0.732
BL1780	1.00	0.898	0.85	0.787
BL1784	0.40	0.744	0.40	0.900
BL1786	0.70	0.927	0.61	0.848
BL1792	1.10	0.790	0.98	0.756
BL1794	0.90	0.678	0.88	0.780
BL1797	1.00	0.657	0.98	0.756
IBYTE24	1.30	0.666	1.21	0.698
BL1723	2.00	0.581	1.78	0.556
IBON23	1.90	0.680	1.62	0.596
IBYTE15	2.00	0.655	1.70	0.574

TOL-Tolerance index; STI-Stress tolerance index; SSI-Stress susceptibility index; YSI-Yield stability-index

Tolerance indices and correlation studies

Four yield-based tolerance-indices were used to screen tolerant and susceptible nature of genotypes for high-temperature stress (Table 5). Tolerant genotypes recorded lower values of TOL and SSI values in comparison to susceptible genotypes. However, the tolerant genotypes exhibited higher values of STI and YSI. Correlation studies indicated that seed yield is positively and significantly correlated with TOL but was non-significantly correlated to other indices *viz*., STI, SSI and YSI under timely sown conditions. Under late sown conditions, seed yield was significantly and negatively correlated to TOL and SSI, but was significantly and positively correlated to other two stress indices-STI and YSI (Table 6). Correlation indices were also calculated between seed yield and GDD for attainment of various phenophases. Seed yield had non-significant correlation indices with GDD to attain various phenophases under timely sown condition. Seed yield was positively and significantly correlated to GDD for attainment of physiological maturity under late sown condition; however correlation was non-significant with GDD to attain other phenophases *viz*; emergence, tillering and anthesis stages (Table 6). This indicates that no. of days taken to physiological maturity is the most important phenological stage determining seed yield in late sown barley crop. Among the tolerant genotypes, BL1786 (the genotype that had the highest seed yield under late sown conditions) exhibited the highest value of YSI along with the lowest values of two stress indices-TOL and SSI. Thus, YSI, SSI and TOL can be used for screening barley genotypes having higher seed yield under late sown conditions. Barati *et al.,*

Table 6: Correlation between yield, GDD and tolerance indices for attainment of different phenological stages in barley genotypes under timely and late sown conditions

GDD for phenological stages	YTS	YLS	Tolerance indices	YTS	YLS
GDD for emergence	-0.447^{NS}	0.157^{NS}	TOL	0.579*	-0.860**
GDD for tillering	-0.370^{NS}	0.226^{NS}	STI	0.356^{NS}	0.900**
GDD for anthesis	0.107^{NS}	0.049^{NS}	SSI	0.490^{NS}	-0.908**
GDD for phy. maturity	0.136^{NS}	0.666*	YSI	-0.490^{NS}	0.908**

** Significant at 0.01 level and * significant at 0.05 level; YTS= Yield under timely sown conditions; YLS= Yield under late sown conditions; Tolerance index (TOL); Stress tolerance index (STI); Stress susceptibility index (SSI) and Yield stability index (YSI)

(2019) used tolerance indices-SSI and STI in barley to confirm their drought tolerant nature. Bahrami *et al.*, (2021) used tolerance indices-TOL, SSI, STI and YSI to classify wheat genotypes into groups of tolerant and susceptible genotypes grown under timely and late sown conditions. Like the results of present study in barley, GDD to attain physiological maturity showed positive correlation with grain yield in wheat under late sown conditions (Dias and Lidon 2009). Grain yield was positively correlated to GDD for attainment of anthesis under timely sown conditions in wheat (Al-Karaki 2012).

CONCLUSION

For anthesis and physiological maturity stages, timely sown crop accumulated higher GDD in comparison to late sown crop. For attainment of physiological maturity under late sowing, tolerant genotypes had higher GDD than that of susceptible genotypes as the former took higher number of days to attain physiological maturity. HUE was higher for timely sown crop as compared to late sown crop. Higher HUE in timely sown crop can be correlated to their higher yield as compared to the late sown crop. Under late sown conditions, number of days taken to physiological maturity is the most crucial phenological stage determining seed yield of barley. The results also indicated that high-temperature tolerant barley genotypes could be selected for higher seed production particularly under late sowing conditions.

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