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EVALUATION FOR ADAPTIVE THERMO-TOLERANCE IN SPRING WHEAT (*TRITICUM AESTIVUM* L.) GENOTYPES UNDER NATURAL STRESS

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Abstract

Fifteen genotypes of spring wheat (*Triticum aestivum* L.) including eleven commercial cultivars, three landraces, and one Mexican variety were evaluated in an entirely different mega-environment with harsh natural stress. The plants experienced a hot and humid climate during the vegetative and reproductive stages. Three different sowing dates one-month apart were employed to all the genotypes to experience, in replications, three different regimes of harsh environmental conditions that would allow all the developmental and reproductive stages to experience high-temperature stress. It was hypothesized that all the genotypes do not have the same strategy to cope with the conditions and some must do better than others though none of them had been developed for this typical climate. Though all the genotypes were adversely affected due to delayed sowings, few showed some stability in the yield and yield components whereas others managed their green leaf status for a relatively longer duration. It has been learned that spring wheat has adaptive potential to be cultivated in warm-dry tropical weather with irrigation and certain genotypes may be used for a breeding program of wheat with abiotic stress tolerance for such geographical zone.

Key words: Flag leaf area, Harvest index, Green leaf duration, Stress susceptibility index.

Introduction

Bread wheat (*Triticum aestivum* L.) has been described as a cool climate or temperate (Briggle and Curtis, 1987) and sub-tropical even a tropical crop (Midmore *et al*., 1984). It follows varying patterns of the growing season in different parts of the world. In countries like Pakistan where winters are mild, spring wheat is planted in October to November and harvested around April and May. Contrarily, spring wheat in Huang He River Valley, China is sown in March-April and harvested in July-August (Leff *et al*., 2004). Such variations in the planting pattern warrant a phenological adjustment from the crop resulting in a shorter growing season. If the sowing is delayed for any reason high-temperature stress at anthesis and during grain filling period affect the wheat yield adversely (Balouch *et al*., 2012; remove). Moreover, the wheat plant may have to go through all the growth and development stages in a shortened duration facing high temperatures (Akter & Islam, 2017). The high-temperature stress may hit plant at early vegetative development, flag-leaf appearance, flowering, anthesis and grain filling duration or may continue to hit at more than one or all stages (Rezaei *et al*., 2018; Aiqing *et al*., 2018). Tolerance to abiotic stresses in *Triticum aestivum* L. has always been a complex proposition that involves many agronomic and physiological traits in addition to phenological adjustments (Bala & Sikder, 2018).When high-temperature strikes before the anthesis vegetative features and consequently grain yield are adversely affected (Wardlaw, 1994; Calderini *et al*., 1999). After the anthesis high temperatures result in the reduction in grain filling rate (Al-Khatib & Paulsen, 1984; Wardlaw & Moncur, 1995), grain development and eventually the yield and quality (Lyman *et al*., 2013). Yield components including the number of spikes per plant, number of grains per plant, and 1000-grain weight directly contribute to the yield (Wu *et al*., 2012). During reproductive development, high-temperature stress impairs photosynthesis and give rise to early senescence (Feng *et al*., 2014; Siebert *et al*., 2014). The flag leaf supplies major photosynthetic assimilates which contribute to the grain yield (Olszewski *et al*., 2014; Sanchez-Bragado *et al*., 2014). High temperatures before and after the anthesis, diminishes the photosynthetic capacity of a leaf (Wang *et al*., 2011).

In this study, a panel of 15 local genotypes including a high yielding Mexican variety was selected to undergo high-temperature stress through early-, mid-, and late-sowing regimes to evaluate their response in terms of agronomic and photosynthesis-related traits. The experiments were carried out in a sub-tropical and arid mega environment, located merely eight meters above the sea level. This region falls between the latitude of 24° and longitude 67° and experiences an average high-temperature 33.9°C and rainfall 5.8mm between October and March. It may be one of its kind studies in this region where wheat genotypes developed for other geographical regions are being evaluated for high-temperature tolerance at the different latitude with a different mega environment to identify their true potential in the harsh natural climate.

Materials and Methods

Location and weather: This study was carried out at the Nursery of the Department of Genetics, University of Karachi, Karachi, Pakistan from 2012 to 2015. Karachi is located on coordinates 24.86°N, 67.00°E, with an average high temperature of 33.9°C and 5.8 mm rainfall in the wheat season from October to March.

Plant material: Grains of seven cultivars were obtained from the Germplasm Resource Center, National Agricultural Research Council (NARC) and University of Agriculture, Peshawar (Table 1). Four of these cultivars have been bred for the Punjab province with an average maximum temperature 27.2ºC and rainfall 123mm from October to March. The other three genotypes were from Sindh province where the average maximum temperature is 29.1ºC and rainfall is 35mm. One cultivar is grown in Khyber Pakhtunkhwa (KPK) province, where the average maximum temperature and rainfall in the season are 23ºC and 192mm, respectively. Grains of three landraces were obtained from the farmers in Kashmir valley where average season maximum temperature and rainfall are 20.9ºC and 485mm respectively in the wheat season. A well-studied Mexican variety Baviacora M92 was also included in this study. This is a semi-dwarf high yielding variety known for drought tolerance and has been used in many pedigrees in Pakistan. Baviacora M92 seeds were obtained from CIMMYT, Mexico.

Experimental design: Grains were sown on October 15th, November 15th and December 15th, considered as early-, mid- and late-sowing regimes. To estimate the differences between genotypes for each of the three experiments for the corresponding sowing date, analysis of variance (ANOVA) was performed for the three experiments individually for the agronomical parameters. A combined analysis of variance was carried out to determine the effects of genotype (G), sowing regimes (T) and G x T interaction between experiments; a combined analysis was conducted with sowing regimes as fixed factors and genotypes as dependent variables. SPSS© release 17.0 was used to analyze the data for agronomic traits as a randomized complete block design in the General Linear Model (GLM) Univariate analysis.

Culture conditions: Sandy loam soil mixed with manure in a ratio of 1:1 was used in plots for the plantation. Fifty seeds per row were sown. Thinning was done manually after the emergence of seedlings leaving ten plants of each genotype per replication with a distance of 1.5 inches in between. Urea was applied for fertilization at the time of tillering to maintain the supply of Nitrogen. After maturation, the crop was harvested in the month of April. Record of daily maximum and minimum temperatures and rainfall were maintained throughout the study.

Agronomical traits: Number of tillers included both with spike and without spike, flag leaf area (Simpson, 1968), plant height as length of main tiller at maturity from the base of the plant to the tip of the spike leaving out the awns, spike length from the base to the tip of the spike without awns at maturity, grain number per plant, grain weight per plant and 1000-grain weight were recorded. The total dry weight (gm) of each plant and biomass were also recorded. The harvest index was considered as the ratio of total grains weight and total dry weight of each plant.

Green leaf duration (GLD): The green leaf score for flag leaf senescence was ranked on a scale from 0 (no senescence) to 10 (complete senescence) (Pask & Pietragalla, 2012). Status of leaf senescence was monitored every day for each genotype until physiological maturity was reached and used to determine the green leaf duration (GLD) for each genotype.

Stress susceptibility index (SSI): The stress susceptibility indices for temperature stress were calculated as described by Fischer & Maurer, 1978:

$$SSI = \frac{1\text{-}Y_{Tm} / Y_C}{1\text{-}\bar{Y}_{Tm}/\bar{Y}_c}$$

and

$$SSI = \frac{1\text{-}Y_{Tl} / Y_C}{1\text{-}\bar{Y}_{Tl}/\bar{Y}_c}$$

where

Y_C is the mean grain yield per plant of a genotype under early-sowing
Y_{Tm} is the mean grain yield per plant of the same genotype under mid-sowing
Y_{Tl} is the mean grain yield per plant of the same genotype under late-sowing
$\bar{Y}_c$ is the mean yield of all genotypes under early sowing
$\bar{Y}_{Tm}$ is the mean yield of all genotypes under mid sowing
$\bar{Y}_{Tl}$ is the mean yield of all genotypes under late sowing

Table 1. List of the selected genotypes alongwith origin and selection criteria.

Wheat genotypes	Origin	Remarks	Reference
Baviacora M92	Mexico	Drought tolerant & high yielding	Pinto R *et al.*, 2010
Blue Silver	Punjab	Drought tolerant	Akram HM *et al.,* 2010
Bulbul	Punjab	Drought tolerant	Akram HM *et al.*, 2010
Chakwal-86	Punjab	Drought tolerant	Ahmad I *et al.,*2015
Chenab-2000	Punjab	Heat tolerant	Farooq J, 2010
Dera-98	Kyber Pakhtunkhwa	Heat resistant	Nasir uddin *et al.,* 2000
Fodder	Punjab	Landrace	Afshan and Naqvi, 2011
Inqilaab-91	Punjab	Heat sensitive & high yielding	Hussain M *et al*. 2011; Farooq J, 2010
Macs	Punjab	Landrace	Afshan and Naqvi, 2011
Marvi-2000	Sindh	Commercial	Panhwar F, 2005
Mehran-89	Sindh	Heat tolerant	Buriro *et al.,* 2011
Moomal-2002	Sindh	Heat tolerant	Buriro *et al.,* 2011
Punjab-96	Punjab	Drought tolerant	Bahar and Yildirim, 2010
Sagar	Punjab	Landrace	Afshan and Naqvi,2011
Shalimar-88	Punjab	Heat tolerant	Farooq J, 2010

Results and Discussion

Delayed sowing dates mediating heat stress have been used to perform a selection for the temperature tolerance in wheat (Elbasyoni, 2018; Jat *et al*., 2018). Three sowing regimes namely early (planted on October 15), mid (planted on November 15) and late (planted on December 15) were used. Average high and low temperatures in October, November, and December were recorded as 39.5 and 20.3, 34.8 and 11.7 and 31 and 6.5°C, respectively. In January, February and March average high and low temperatures were 29.8 and 7.3, 32.2 and 10.8 and 36.3 and 14oC, respectively. Significant differences were observed in the effects of genotypes and the three different sowing regimes, as well as in the interaction between genotypes and sowing regimes at p<0.01, suggesting the response of genotypes was modified by the different sowing dates (Table 2).

Morphological traits: The analysis of variance found highly significant differences in the number of tillers per plant, number of spikes per plant, flag leaf area, plant height without awns, spike length, number of grains, grain yield, 1000-grain weight, and biomass within and between the wheat genotypes. Late and mid-sowing resulted in significant differences in the growth traits. Sowing dates affected plant height for all the genotypes, showing significant differences. The tallest plants were measured in Fodder (104.8 cm; 93.9 cm; 80.2 cm) in early, mid and late sowing experiments. On average a reduction of 16% in mid sowing and 13% in late sowing were recorded. Previously, Buriro *et al*., 2011 found Mehran having the longest shoot length, especially at 30°C. Akram *et al*., (2010) reported Blue Silver had a maximum growth rate followed by Chakwal-86 in normal as well as water deficit conditions.

Dera-98 produced a significantly high number of tillers in the pre-sowing so as spikes per plant, however, in mid-sowing, it was joined by Blue Silver, Bulbul and Chenab-2000. In late-sowing, Chakwal-86 and Chenab-2000 produced a significantly higher number of tillers as well as spikes per plant. Anwer *et al*., (2007) found Chenab-2000 producing one of the highest numbers of tillers in late sowing in their study. Mehran-89 (7.9) showed the lowest number of tillers. Yousufzai *et al*., (2009) ranked Mehran-89 as semi-dwarf variety and found it to produce the highest number of tillers in their study. All the genotypes showed a decline in the number of tillers at later sowing dates. At mid sowing, a 23% reduction in tillers per plant was measured. At late sowing, a reduction of 32% was calculated.

Agronomic traits: At early sowing maximum biomass was observed in BaviacoraM92 (29.3gm) followed by Chakwal-86, Chenab-2000, Inqilab-91and Mehran-89 (Table 3). Chakwal-86 and Blue Silver have been shown to have high total dry matter (Akram *et al*., 2010). But in this study Baviacora M-92 has been significantly high in biomass in all three-sowings; however, its harvest index took a deep plunge in both the mid- and late-sowing. A significant decrease in biomass for all the genotypes was recorded in mid and late sowings (Tables 4 and 5). Similarly, all the genotypes showed significant differences in harvest index between sowing dates. Baviacora M92 had a maximum value of 63.8% at early sowing, Sagar (45.6%) in mid sowing, while Shalimar-88(44.3%) in late sowing.

Table 2. Mean squares for number of tillers (T), number of spikes (S), plant height (PH), spike length (SL), number of grains per plant (G), grain weight per plant (GW), thousand grain weight (TGW), biomass (B), harvest index (HI) and flag leaf area (FLA) of bread wheat genotypes under early, mid and late sowing.

Sources of variation	Df	T	S	PH (cms.)	SL (cms.)	G per plant	GW (gms.)	TGW (gms.)	B (gms.)	HI (%)	FLA (cms.)
Treatments (T)	2	6351.43**	7837.50**	89220.00**	6548.26**	758832.35**	15839.69**	2562077.47**	36237.93**	20993.62**	50302.04**
Error (a)	2	108.40	84.76	225.25	30.02	2948.69	59.81	770.83	96.82	317.67	198.76
Genotypes (G)	14	431.09**	298.84**	16216.37**	329.66**	17838.72**	516.68**	178947.97**	1053.95**	2596.65**	2501.43**
T x G	28	223.80**	184.06**	2498.69**	41.94**	9447.50**	391.67**	109266.88**	352.44**	4896.49**	805.42**
Error (b)	84	16.16	14.73	101.66	4.99	275.73	9.92	1021.04	39.73	205.84	53.48
Total	134										

*Significance at the 0.05 probability level (p≤0.05)

**Significance at the 0.01 probability level (p≤0.01)

NS, non-significant at the 0.05 probability level

Table 3. Mean values of number of tillers per plant (T), number of spikes per plant (S), plant height (PH), spike length (SL), number of grains per plant (G), grain weight per plant (GW), thousand grain weight (TGW), biomass (B), harvest index (HI), flag leaf area (FLA) and days to flowering (DTF) of bread wheat genotypes under early sowing.

Wheat genotype	T	S	PH (cms.)	SL (cms.)	G	GW (gms.)	TGW (gms.)	B (gms.)	HI (%)	FLA (cms.)	DTF
Baviacora M92	12.23^{c}	12.06^{b}	83.88^{c}	15.23^{a}	89.84^{a}	18.70^{a}	293.65^{a}	29.30^{a}	63.85^{a}	34.37^{b}	80.25^{c}
Blue Silver	12.38^{bc}	12.38^{b}	82.17^{c}	12.08^{fg}	66.81^{d}	11.96^{cd}	168.56^{b}	22.69^{fg}	54.28^{b}	26.18^{ef}	47.50^{j}
Bulbul	10.60^{de}	10.53^{cd}	79.64^{d}	12.59^{defg}	74.82^{c}	8.98^{efg}	106.81^{h}	24.12^{ef}	38.02^{f}	26.86^{e}	53.25^{gh}
Chakwal-86	12.14^{c}	12.04^{b}	83.97^{c}	14.24^{b}	82.32^{b}	11.51^{cd}	100.59^{h}	27.11^{b}	43.15^{cde}	40.29^{a}	83.50^{b}
Chenab-2000	13.40^{b}	12.27^{b}	77.23^{e}	12.03^{gh}	70.68^{cd}	12.57^{c}	145.12^{cd}	26.23^{bcd}	47.11^{c}	34.04^{b}	52.75^{h}
Dera-98	14.53^{a}	13.93^{a}	76.21^{ef}	11.33^{hi}	59.61^{e}	7.69^{gh}	110.97^{gh}	25.05^{de}	32.67^{g}	29.47^{d}	54.00^{gh}
Foder	12.64^{bc}	12.21^{b}	104.82^{a}	9.48^{j}	56.82^{ef}	7.23^{h}	87.82^{i}	23.45^{fg}	33.04^{g}	26.68^{e}	88.25^{a}
Inqilaab-91	11.92^{c}	11.65^{bc}	70.77^{h}	12.38^{defg}	74.57^{c}	14.15^{b}	134.46^{de}	26.10^{bcd}	53.87^{b}	30.13^{cd}	56.75^{f}
Macs	12.17^{c}	11.67^{b}	74.93^{fg}	13.02^{cd}	71.08^{cd}	9.70^{e}	121.30^{fg}	25.65^{bcd}	38.98^{ef}	34.62^{b}	57.00^{f}
Marvi-2000	8.51^{gh}	8.03^{f}	74.02^{fg}	11.86^{gh}	47.11^{g}	8.10^{fgh}	154.56^{c}	20.08^{h}	42.28^{def}	31.82^{c}	50.25^{i}
Mehran-89	7.93^{h}	7.90^{f}	87.55^{b}	13.47^{c}	87.20^{ab}	13.96^{b}	112.55^{gh}	26.61^{bc}	53.21^{b}	29.50^{d}	74.25^{d}
Moomal-2002	9.57^{efg}	9.40^{e}	83.00^{c}	12.80^{cdef}	70.29^{cd}	11.27^{d}	127.79^{ef}	25.41^{cde}	44.91^{cd}	29.33^{d}	54.25^{g}
Punjab-96	9.88^{ef}	9.68^{de}	73.90^{g}	12.85^{cde}	51.56^{fg}	9.43^{e}	139.82^{de}	22.53^{g}	43.23^{cde}	31.55^{c}	53.25^{gh}
Sagar	11.63^{cd}	11.53^{bc}	74.44^{fg}	12.22^{efg}	85.29^{b}	14.87^{b}	142.48^{cd}	26.43^{bcd}	57.22^{b}	24.53^{f}	72.25^{e}
Shalimar-88	8.93^{fgh}	8.83^{ef}	69.91^{h}	10.88^{i}	54.07^{f}	9.37^{ef}	143.44^{cd}	21.95^{g}	44.19^{cd}	27.29^{e}	50.50^{i}
Mean	11.23	10.94	79.76	12.43	69.47	11.30	139.33	24.85	46.00	30.44	61.87
St. Dev	4.80	4.74	12.22	3.17	24.44	5.92	66.97	6.35	19.46	8.57	13.38
CV (%)	42.74	43.32	15.32	25.50	35.18	52.38	48.06	25.55	42.30	28.15	21.63
$LSD_{(0.05)}$	1.12	1.12	2.26	0.73	5.26	1.29	12.29	1.50	4.43	1.92	1.29

Table 4. Mean values of number of tillers per plant (T), number of spikes per plant (S), plant height (PH), spike length (SL), number of grains per plant (G), grain weight per plant (GW), thousand grain weight (TGW), biomass (B), harvest index (HI), flag leaf area (FLA) and days to flowering (DTF) of bread wheat genotypes under mid sowing.

Wheat genotype	T	S	PH (cms.)	SL (cms.)	G	GW (gms.)	TGW (gms.)	B (gms.)	HI (%)	FLA (cms.)	DTF
Baviacora M92	8.25^{cd}	7.75^{cde}	71.44^{c}	12.29^{a}	52.11^{c}	6.77^{bcd}	106.37^{c}	24.94^{a}	28.68^{h}	27.47^{ab}	77.50^{b}
Blue Silver	11.11^{a}	9.01^{ab}	64.73^{fg}	8.22^{g}	27.98^{h}	6.73^{cd}	81.56^{fg}	17.11^{cd}	42.76^{abcd}	22.24^{fg}	53.92^{h}
Bulbul	10.00^{b}	9.27^{a}	65.41^{ef}	9.11^{def}	33.69^{g}	6.11^{efg}	92.64^{d}	17.66^{c}	39.18^{ef}	23.96^{ef}	63.50^{def}
Chakwal-86	6.29^{g}	5.76^{g}	64.79^{efg}	10.23^{b}	37.53^{fg}	6.64^{cd}	87.58^{de}	16.73^{cde}	43.90^{ab}	24.68^{cde}	84.00^{a}
Chenab-2000	10.50^{ab}	7.77^{cde}	67.30^{de}	8.90^{ef}	37.70^{fg}	6.38^{def}	65.47^{i}	19.73^{b}	35.78^{g}	26.47^{c}	58.83^{g}
Dera-98	9.57^{b}	8.03^{cd}	69.79^{cd}	9.30^{de}	41.37^{ef}	6.10^{efg}	47.10^{j}	17.66^{c}	39.00^{f}	21.17^{gh}	64.83^{de}
Foder	9.90^{b}	8.23^{bc}	93.94^{a}	8.86^{f}	46.05^{d}	7.24^{b}	113.38^{b}	20.08^{b}	39.02^{ef}	20.58^{ghi}	84.58^{a}
Inqilaab-91	7.91^{cde}	6.34^{fg}	61.23^{hi}	8.98^{ef}	29.08^{h}	5.71^{gh}	77.45^{gh}	15.31^{ef}	40.83^{cdef}	19.46^{hij}	63.25^{def}
Macs	7.21^{efg}	6.91^{ef}	55.87^{j}	8.90^{ef}	27.18^{h}	5.56^{h}	74.69^{h}	14.80^{f}	40.39^{cdef}	18.84^{ij}	65.50^{d}
Marvi-2000	7.82^{cde}	6.32^{fg}	62.44^{gh}	9.90^{bc}	34.54^{g}	6.00^{fgh}	64.72^{i}	15.48^{ef}	42.16^{bcdef}	28.47^{a}	60.75^{fg}
Mehran-89	7.70^{cdef}	7.30^{de}	74.30^{b}	10.28^{b}	61.80^{a}	6.51^{de}	59.82^{i}	21.01^{b}	34.35^{g}	24.31^{de}	78.00^{b}
Moomal-2002	7.35^{def}	6.12^{fg}	62.46^{gh}	8.84^{f}	37.13^{fg}	5.81^{gh}	84.18^{ef}	15.98^{def}	40.61^{def}	24.99^{cde}	61.50^{efg}
Punjab-96	9.65^{b}	8.12^{bc}	63.48^{fgh}	9.51^{cd}	45.30^{de}	7.11^{bc}	80.80^{fg}	17.36^{cd}	44.68^{ab}	26.16^{cd}	66.50^{d}
Sagar	8.43^{c}	7.57^{cde}	63.53^{fgh}	8.98^{ef}	56.68^{b}	9.20^{a}	160.98^{a}	21.32^{b}	45.66^{a}	18.28^{j}	70.50^{c}
Shalimar-88	6.75^{fg}	6.25^{fg}	58.76^{i}	7.95^{g}	41.57^{def}	5.99^{fgh}	52.60^{j}	15.38^{ef}	42.36^{bcde}	26.50^{bc}	61.50^{efg}
Mean	8.56	7.38	66.63	9.35	40.65	6.52	83.29	18.04	39.96	23.57	67.64
St. Dev	4.27	3.78	13.21	1.87	20.46	1.97	35.30	6.89	13.31	8.42	9.86
CV (%)	49.88	51.21	19.82	20.00	50.33	30.21	42.38	38.19	33.30	35.72	14.58
$LSD_{(0.05)}$	1.02	0.92	2.55	0.40	4.54	0.45	5.69	1.60	3.21	1.98	3.39

Table 5. Mean values of number of tillers per plant (T), number of spikes per plant (S), plant height (PH), spike length (SL), number of grains per plant (G), grain weight per plant (GW), thousand grain weight (TGW), biomass (B), harvest index (HI), flag leaf area (FLA) and days to flowering (DTF) of bread wheat genotypes under late sowing.

Wheat genotype	T	S	PH (cms.)	SL (cms.)	G	GW (gms.)	TGW (gms.)	B (gms.)	HI (%)	FLA (cms.)	DTF
Baviacora M92	7.70^{cde}	7.40^{bcd}	68.96^{d}	10.44^{a}	34.29^{b}	6.14^{b}	67.02^{e}	17.92^{a}	38.30^{def}	18.75^{fg}	71.00^{bc}
Blue Silver	6.11^{f}	5.84^{e}	73.81^{b}	8.62^{de}	28.09^{def}	5.81^{de}	98.91^{a}	17.92^{a}	36.82^{f}	20.24^{cdef}	53.75^{i}
Bulbul	6.21^{f}	5.94^{e}	70.51^{cd}	8.84^{cde}	28.00^{def}	5.91^{cd}	47.38^{j}	15.98^{cde}	42.19^{ab}	19.54^{efg}	63.75^{efg}
Chakwal-86	9.63^{a}	9.17^{a}	61.82^{g}	9.63^{b}	27.10^{ef}	5.73^{de}	64.89^{ef}	16.09^{cd}	40.44^{bcde}	21.82^{bc}	76.75^{a}
Chenab-2000	9.60^{a}	9.03^{a}	72.36^{bc}	7.98^{g}	28.97^{de}	6.04^{bc}	74.40^{cd}	16.93^{abcd}	38.95^{cdef}	19.90^{defg}	61.25^{fgh}
Dera-98	7.60^{cde}	7.37^{bcd}	65.52^{ef}	8.29^{efg}	28.70^{de}	5.77^{de}	61.87^{fg}	15.38^{de}	42.19^{ab}	20.38^{cde}	65.25^{e}
Foder	8.15^{bc}	7.96^{b}	80.27^{a}	8.43^{efg}	43.98^{a}	6.46^{a}	57.35^{hi}	17.37^{abc}	41.42^{abc}	15.33^{h}	73.00^{bc}
Inqilaab-91	6.97^{ef}	6.93^{d}	68.09^{de}	8.95^{cd}	28.71^{de}	5.72^{de}	67.14^{e}	16.99^{abcd}	37.49^{ef}	19.37^{efg}	63.50^{efg}
Macs	7.47^{cde}	7.23^{bcd}	70.06^{cd}	9.58^{b}	29.56^{cd}	5.66^{e}	54.28^{i}	16.05^{cd}	39.49^{bcdef}	19.01^{efg}	65.00^{e}
Marvi-2000	7.23^{def}	7.07^{cd}	64.58^{fg}	9.52^{b}	27.24^{ef}	5.78^{de}	73.09^{d}	16.46^{abcd}	39.37^{bcdef}	24.28^{a}	59.75^{h}
Mehran-89	7.88^{cd}	7.51^{bcd}	68.63^{d}	9.73^{b}	29.76^{cd}	5.70^{e}	48.87^{j}	16.11^{cd}	39.27^{bcdef}	22.12^{b}	74.50^{ab}
Moomal-2002	8.97^{ab}	7.90^{bc}	65.12^{f}	8.54^{def}	26.80^{ef}	5.74^{de}	67.38^{e}	15.33^{de}	42.04^{abc}	21.35^{bcd}	64.75^{ef}
Punjab-96	7.53^{cd}	7.27^{bcd}	70.05^{cd}	9.26^{bc}	27.01^{ef}	5.69^{e}	59.15^{gh}	16.28^{bcd}	39.45^{bcdef}	24.21^{a}	66.50^{de}
Sagar	8.00^{cd}	7.53^{bcd}	62.23^{g}	8.33^{efg}	31.42^{c}	6.11^{bc}	94.68^{b}	16.59^{abcd}	41.25^{abcd}	15.85^{h}	69.75^{cd}
Shalimar-88	5.03^{g}	4.93^{f}	69.91^{cd}	8.04^{fg}	26.30^{f}	5.66^{e}	76.82^{c}	14.34^{e}	44.32^{a}	18.59^{g}	61.00^{gh}
Mean	7.60	7.27	68.80	8.95	29.73	5.86	67.54	16.38	40.22	20.05	65.98
St. Dev	3.70	3.51	11.98	2.10	9.66	0.85	20.01	6.64	12.36	6.85	7.36
CV (%)	48.68	48.28	17.41	23.46	32.49	14.50	29.62	40.53	30.73	34.16	11.16
$LSD_{(0.05)}$	0.89	0.85	2.81	0.50	2.20	0.20	3.58	1.67	3.10	1.62	3.64

In early-sowing, Baviacora M-92 performed outstandingly in all yield traits. Only Sagar and Mehran-89 came in the same significant group for the number of grains per plant, grain weight per plant and harvest index. Nevertheless, Mehran-89 was significantly low in thousand-grain weight. In mid- and late-sowing, Baviacora M-92 got incrementally affected and the landrace Sagar exceeded in grain weight per plant, thousand-grain weight and harvest index.

Spike length showed highly significant differences between genotypes at early sowing with maximum length recorded in BaviacoraM92 (15.2cm). At both mid and late sowings, a significant decrease in spike length was demonstrated by all the genotypes. At mid and late sowings, maximum values were measured in BaviacoraM92, Mehran-89, and Chakwal-86.

The number of grains at early sowing was significantly higher in BaviacoraM92 (89.8), Mehran-89(87.2) and Sagar (85.2) from the rest of the genotypes. All genotypes showed a significant decrease in the number of grains per plant at mid and late sowings (Fig. 1). The average number of grains at early-, mid- and late sowings is 69.53, 40.68, and 29.73 respectively.

Grain weight per plant was greatly affected by the sowing dates. Among all the genotypes Fodder (7.2 gm) remained stable from early to mid-sowing. No change was noted in grain weight per plant between the two conditions. Fodder (6.4) had the highest value for grain weight at late sowing, despite a decrease of 11% from the value at early sowings (Fig. 2).

Comparing the three experiments, significant differences were observed for 1000-grain weight. Baviacora M92 has the highest value of 293.6gm at early sowing but at later sowings, a significant reduction has been observed. All the genotypes showed a significant decrease in 1000-grain weight at mid sowing except for two genotypes Fodder (29%) and Sagar (13%) showed an increase in grain yield. At late sowing, Blue Silver (20%), Chenab-2000 (13%), Dera-96 (31%), Marvi-2000 (13%) and Shalimar-88 (46%) significantly increased in 1000-grain weight compare to mid sowing (Fig. 3).

Green leaf duration: Days to senescence of flag leaf after anthesis represent the green leaf duration. In late sowing, the average green leaf duration (GLD) of early genotypes was 33.23±5.21 whereas that of late genotypes was 29.3±3.23. Nevertheless, the late genotype Fodder has GLD 33.67. Significant differences between genotypes are observed for green leaf duration under different sowing dates (Fig. 4). In the early sowing, most genotypes have completed senescence within 60 days of anthesis. Baviacora M92 has the maximum green leaf duration; it also has the highest yield. The majority of the genotypes demonstrate an increase in the rate of senescence in mid and late sowing experiments. At mid sowing, maximum days to complete senescence was in Sagar (51 days), producing the highest yield. In late sowing, Blue Silver demonstrated 46 days to reach complete senescence and had the highest yield. The rest of the genotypes show a significant reduction in the total green leaf duration.

Significant differences for the flag leaf area among the wheat genotypes were observed. At early sowing, Chakwal-86 (40.3 cm2) had the maximum value, followed by Baviacora M92, Macs, and Chenab-2000. Flag leaf area was decreased by 22% at mid sowing while 34% decrease was measured at late sowing (Fig. 5). Marvi-2000 had the maximum flag leaf area of 28.4 cm2 and 24.2 cm2 under late sowing conditions.

Interestingly, the green leaf duration in this study was not found to be consistently associated with the grain yield. This finding is in agreement with Christopher *et al.*, 2016, where during wheat crop development under normal and moisture deficit conditions stay-green traits were examined. Borrell *et al.*, (2000) also reported a negative correlation between the rate of senescence and grain yield under drought stress. It may be suggested that certain genotypes, to keep the flag leaf green for longer duration may adopt some kind of strategy to spare the supply of leaf carbohydrate to the developing grain. Longer green leaf duration at the expense of developing grain seems to have a hypothetical value that needs further focused investigation. A similar phenomenon was previously reported in wheat and rice by Gong *et al.*, (2005) and Yang & Zhang (2006). Another argument is available from Shirdelmoghanloo *et al.*, (2016) suggesting an increase in the senescence of flag leaves and grain shrinkage might be controlled by a bilateral genetic manipulation that seems to be well-coordinated, however, lack a cause-effect relationship.

None of the genotypes appeared to perform better in terms of grain yield in mid- and late-sowing, nevertheless the landrace Fodder seemed to be unaffected in mid-sowing and least affected in late-sowing. Baviacore M-92, in spite of outstanding yield, showed the highest stress susceptibility index both in mid-as well as late sowing. The lowest stress susceptibility index was demonstrated by landrace Fodder. Based on the time of heading, genotypes in this study form two distinct groups. The early group includes Inquilab-91, Dera-98, Chenab-2000, Moomal-2002, Bulbul, Marvi-2000, Shalimar-88 and Blue Silver. The late group comprises Fodder, Chakwal-86, Baviacora M-92, Mehran-89, and Sagar. If planting is late, earliness in flowering and physiological maturity may help plants (Anwar *et al.*, 2007). The days to flower average for the early group were 53±3 days whereas for late group 79.6±6.7. Most of the early genotypes showed low heat stress susceptibility index (SSI) ≤0.5 in terms of grain yield (Table 6). However, a late genotype Fodder, which is a landrace, remained lowest in SSI. The highest SSI (≤1) was shown by Baviacora M-92, was reported to be high yielding and drought tolerant genotype. Although most of the genotypes performed consistently in mid- and late-sowing, Punjab-96 and Sagar appeared to be more affected by late sowing.

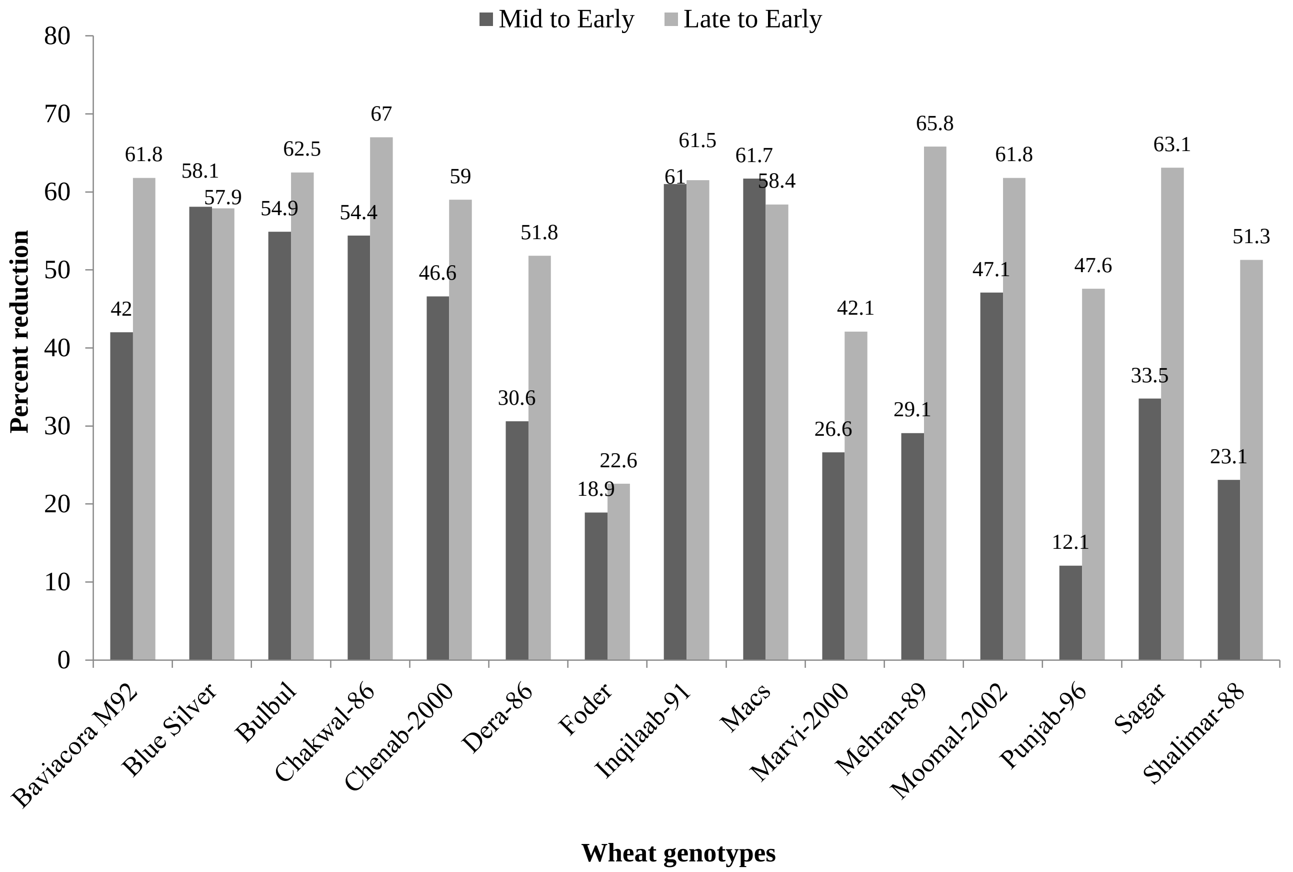

Fig. 1. Percent reduction in number of grains per plant in comparison of mid- to early and late- to early sowing.

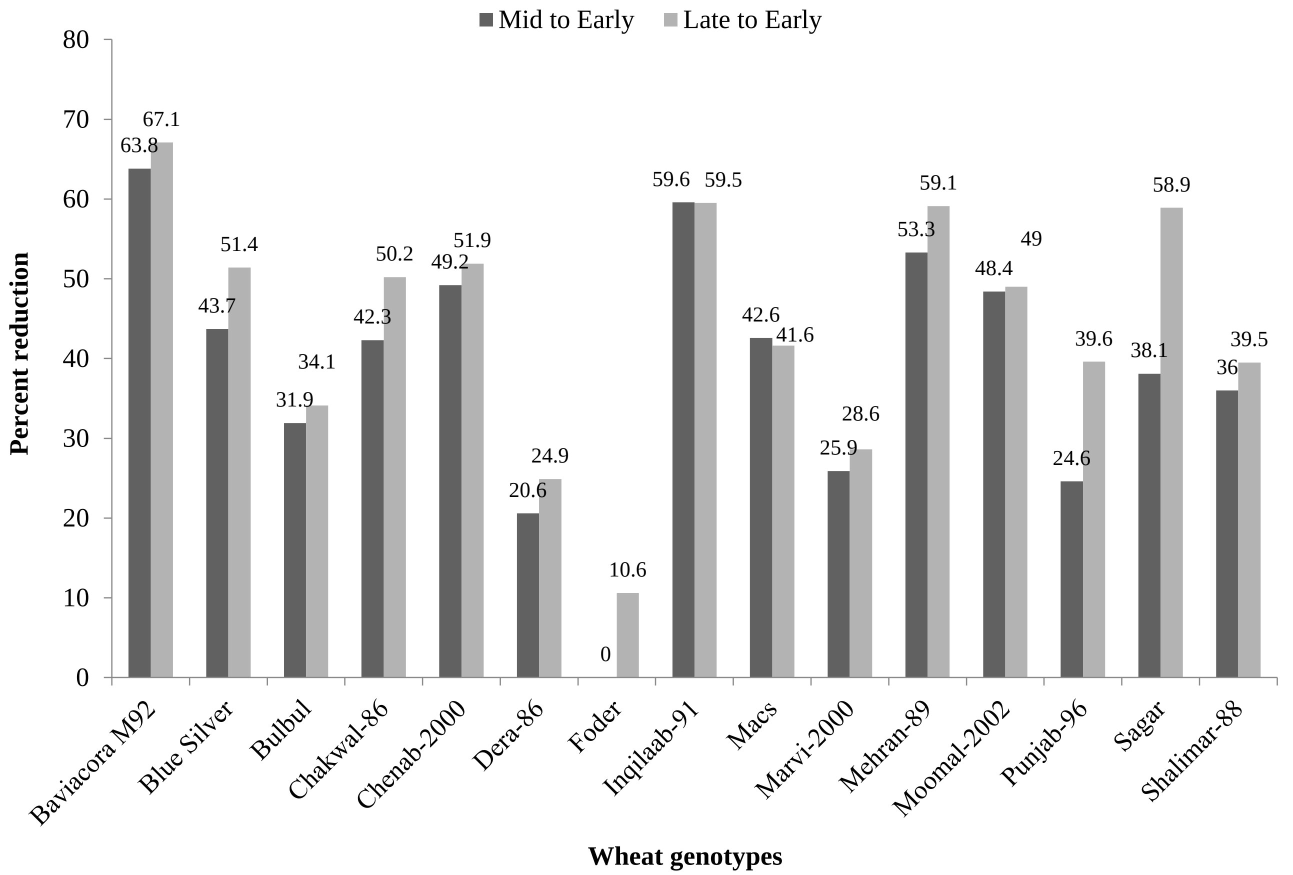

Fig. 2. Percent reduction in grain weight per plant in comparison of mid-to early and late- to early sowing.

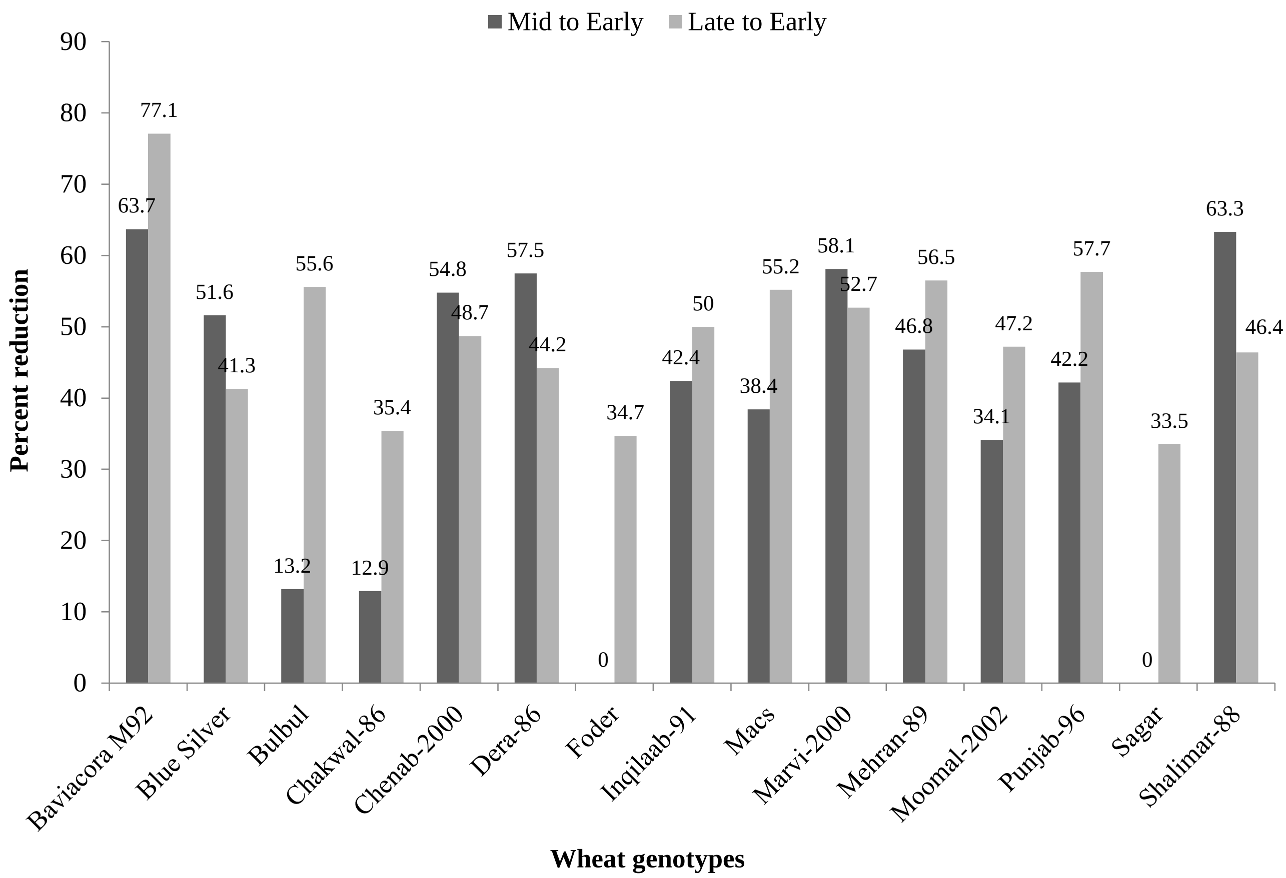

Fig. 3. Percent reduction in thousand grain weight in comparison of mid-to early and late- to early sowing.

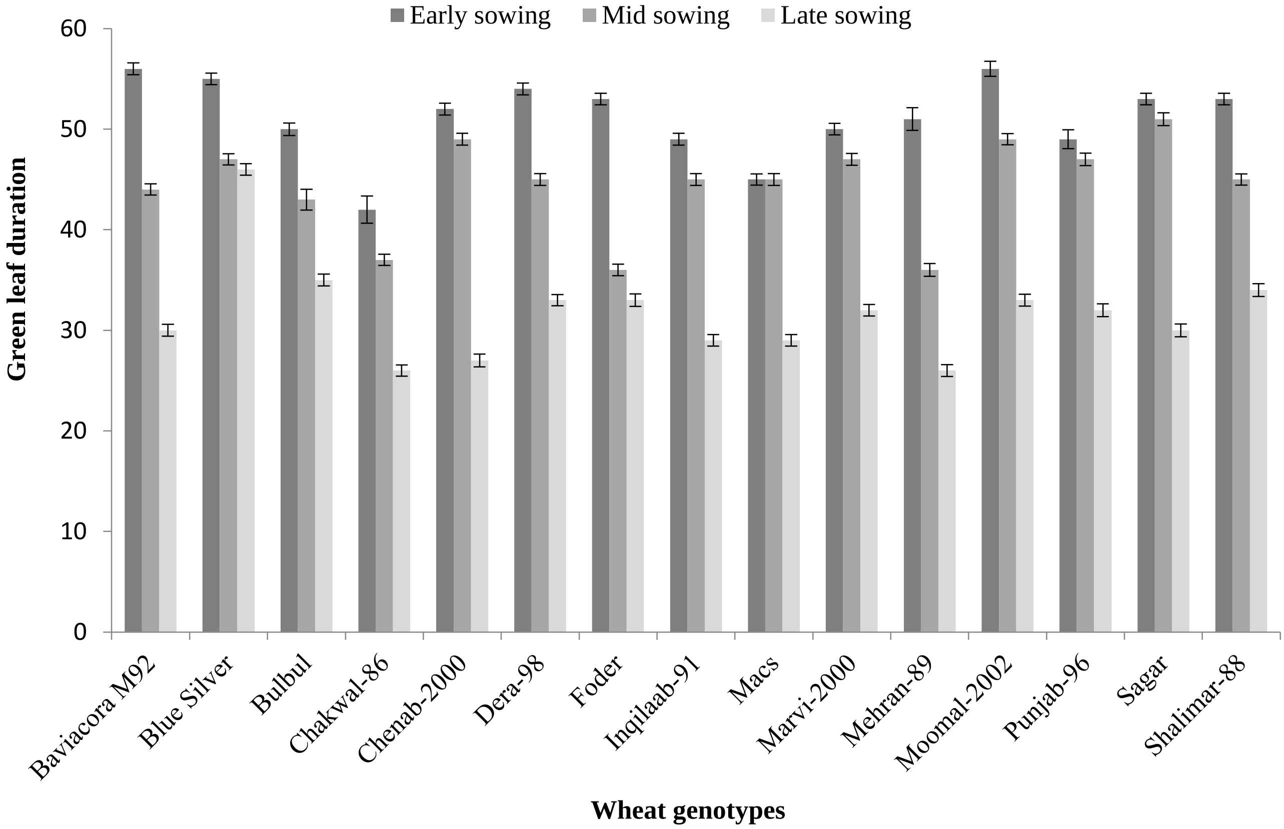

Fig. 4. Effect of sowing dates on green leaf duration of flag leaf from the beginning of anthesis till physiological maturity of spring wheat genotypes. Vertical lines on the bars indicate standard error of the means.

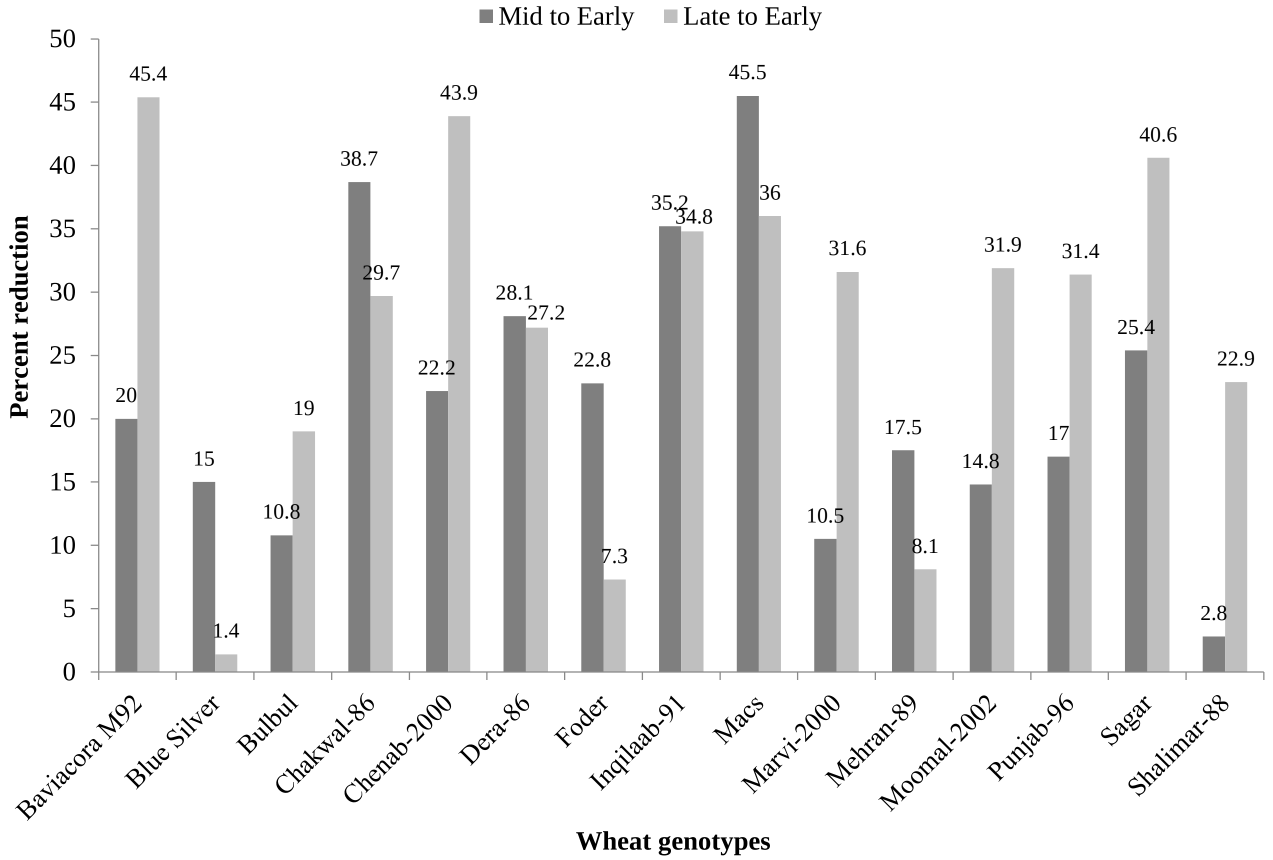

Fig. 5. Percent reduction in flag leaf area in comparison of mid- to early and late- to early sowing.

Table 6. Stress susceptibility index for grain yield in mid and late sowing.

Wheat genotypes	Mid sowing	Late sowing
Baviacora M92	1.51	1.40
Blue Silver	1.03	1.07
Bulbul	0.76	0.71
Chakwal-86	1.00	1.04
Chenab-2000	1.16	1.08
Dera-98	0.49	0.52
Foder	0.00	0.22
Inqilaab-91	1.41	1.24
Macs	1.01	0.87
Marvi-2000	0.61	0.59
Mehran-89	1.26	1.23
Moomal-2002	1.15	1.02
Punjab-96	0.58	0.82
Sagar	0.90	1.22
Shalimar-88	0.85	0.82

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