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COMPARATIVE PERFORMANCE OF SPRING WHEAT (*TRITICUM AESTIVUM* L.) THROUGH HEAT STRESS INDICES

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Abstract

Temperature is increasing continually which limited the production of wheat. Six spring wheat genotypes were evaluated on the basis of relative performance, heat susceptible indices (HSI) and their association with the grain yield in normal and heat stress conditions at University of Agriculture, Faisalabad, Pakistan (31.43 °N, 73.06 °E) to identify thermotolerant genotypes against future climatic change. Data were recorded for phenological, physiological and morphological traits which revealed that genotypes Aas-11 and SH-95 were tolerant to heat on the basis of their relative performance and HSI. Furthermore selection of genotypes for early heading and delay maturity is suggested to develop high yielding wheat cultivars in Pakistan under heat stress. Correlation analysis revealed positive association of yield with days to maturity, days to heading, thousand grain weight, tillers per plant, stomata frequency, leaf venation and stomata size under heat stress. Direct selection for these attributes might be criteria against heat stress. Whereas grain yield was negatively correlated with HSI indicated the tolerance of genotypes under heat stress. Selection for thousand grain weight, number of seeds, stomata frequency, biomass and grain yield under heat stress would result in decreased susceptibility of genotypes to heat stress.

Key word: Spring wheat, Heat stress, HSI, Physio-morphic traits.

Introduction

Climate change is significant issue which affects the growth and productivity of crop. Climatic model predictedan increase of (2.3-4.8°C) of temperature at the end of 21st century due to emission of green house gases viz., nitrous oxide, methane gas and carbon dioxide (Anon., 2013). It generates different types of abiotic stresses viz., heat and drought which affect the development of crops (Tisdell, 2008). Heat stress (HS) is major constraints which affect the productivity of wheat. High temperature between 3-4°C in Asia causes 20-35% reduction in grain yield of wheat (Ortiz *et al.*, 2008). It reduces the grain filling duration and phenology which decreases the weight of grain (Inamullah *et al*., 2007; Mondal *et al.*, 2013). It also effect on translocation of photosynthates to grains which reduces grain weight and grain yield (Tahir *et al*., 2009). It completely inhibits the metabolic activities, production of photosynthates and their translocation (Cleland *et al.*, 2007).

High temperature drastically affects the development of ovaries and pollen viability which causes reduction in number of seeds (Calderini *et al.*, 1999). It affects the enzymes responsible for starch accumulation which ultimately reduces the grain weight (Zhao *et al*., 2008). Wheat grain yield is associated with grains per spike and grain size which were reduced under high temperature (Hossain *et al*., 2011). Normal planting enhances the area of leaf which stimulates the activity of photosynthesis and ultimately enhanced grain yield in wheat (Rahman *et al*., 2009b). Stomatal frequency, distribution and morphology on leaf surface may be significant selection criteria in adapting wheat to stress conditions (Ahmad *et al*., 2006). Stomata size plays important role in exchange of gases and declined in wheat yield may be due to reduction in pores of stomata (Alam *et al*., 2011).

Heat stress is a complex process in which selection criteria based on the performance of different phenological, morphological and physiological attributes under heat stress condition. Heat susceptible indices (HSI) are criteria for evaluation of heat tolerant genotypes under heat stress conditions (Sharma *et al*., 2013). Keeping in view, it would be important to estimate and examine the effect of heat stress on growth and productivity of wheat genotypes and selection criteria to cope with this stress. Therefore, present research work was designed to investigate (i) relative performance (ii) correlation and (iii) heat susceptible indices to compare performance of different wheat genotypes and estimation of association amongphenological, physiological and morphological attributes. The obtained information would be useful to overcome yield losses and further breeding program to incorporate thermotolerance in wheat.

Materials and Methods

The experiment was laid down in the research area at University of Agriculture, Faisalabad, Pakistan (31.43 °N, 73.06 °E) during 2012-13 and 2013-14. Six wheat genotypes viz., Iqbal-2000, Aas-11, SH-95, 9516, 9515 and 9512 were evaluated under field condition at Normal (20th November) and heat stress (20th December). Randomized complete block design was followed with three replications. The distance from row to row was kept at 30 cm and plant to plant 10 cm. Thirty plants were grown in 5 m long row in each replication. Nitrogen and phosphorous were applied at 120 and 60 kg ha^{-1} as urea and diamonium phosphate respectively. All other agronomic practices such as irrigation, weeding and hoeing were done uniformly. Ten plants were selected randomly for data collection. Data were collected for different attributes such as days to heading, days to physiological maturity following Hossain and Silva (2012), flag leaf area, 1000-grain weight, seeds per spike, number of fertile tillers, biomass, grain yield following Inamullah *et al*. (2007) whereas physiological traits were measured following Ahmad *et al*. (2006) at morning 9:00 am. The leaf strips were taken from third nodal leaf of the mother shoot of each selected randomly selected plant and dipped in the Carnoy's solution (10% acetic acid, 30% chloroform and 60% ethanol) to fix the stomata and remove the chlorophyll from the tissues of leaf. After 15 hours, strips were removed from the solution, washed with acetone and stored in the formalin solution for further examination. The strips were examined under low power (10X) objective of microscope for counting the total number of stomata per unit of area and leaf venation. Then leaf strips were examined under higher power (40X) objective of microscope to measure the length and width of stomata size and epidermal cell size. The length and breadth were multiplied separately with standardized value (3.44). The stomata size and epidermal cell size were calculated by multiplying the length and breadth.

Relative performance (RP) of wheat genotypes was expressed in percentage using formula given by Asana and Williams (1965).

$$\text{RP \%} = \frac{\text{Performance under stress condition}}{\text{Performance under normal condition}} \times 100$$

HSI (heat susceptible indices) were estimated by the formula described by Fisher and Maurer (1978) which was used to measure the tolerant genotypes which perform better in heat stress conditions.

$$\text{HSI} = (1\text{-}Y/Y_p)/(1\text{-}X/X_p)$$

whereas, Y = Mean grain yield of genotype under stress,
X = Mean yield of all genotypes under stress,
Y_p = Mean yield of same genotype under normal, X_p = Mean yield of all genotypes under normal.

If HSI is < 0.5, then genotype is highly tolerant to stress whereas HSI > 0.5 < l.0 is moderately stress tolerant and if HSI > 1.0, it is susceptible to stress.

The collected data were statistically analyzed by ANOVA technique as described by Steel *et al.* (1997) followed by least significant (LSD) test at 5% level of significance. Pearson correlation was estimated following Singh & Choudhary (1985).

Results and Discussion

Phenological attributes: Days to heading plays significant role to distinguish genotypes under different conditions of environment. In present study, the overall reduction in days to heading under heat stress conditions was recorded. It was probably due to photoperiodic and vernalization sensitive gene which determined the developmental phases at different temperature. These genes are responsive to heat stress which causes earliness in wheat (Slafer, 1996). Sial *et al*. (2005) also observed reduction in heading period due to planting delayed. Moreover, genotypes Aas-11 and Iqbal-2000 followed by SH-95 took minimum days to reach the heading stage under normal and heat stress conditions. Hossain *et al*. (2011) suggested that delayed planting reduces the growth phase and plant faced enhanced temperature during its developmental stages. Cleland *et al*. (2007) and Mondal *et al*. (2013) also found reduction in phenology and grain filling duration of wheat under heat stress.

Days to physiological maturity significantly declined from NS to HS. In this study, the reduction in days to physiological maturity of genotypes under HS as compared to NS was observed (Table 1). It is probably due to high temperature which reduced the efficiency of photosynthetic translocation and capacity of nutrients uptake and ultimately leads to reduction in various growth phases such as heading and maturity (Hossain *et al*., 2011). Sial *et al.* (2005) and Inamullah *et al.* (2007) also observed reduction in days to maturity under HS conditions. In normal condition, genotypesSH-95 and Aas-11 had taken maximum days to reach physiological maturity under NS and HS. Rahman *et al*. (2009a) also observed reduction in phenology due to delayed planting. Hossain & Silva (2012) suggested that short heading and long maturity phase would have longer grain filling duration for development of grain weight in wheat.

Physiological attributes: Stomata are arranged in rows parallel of the leaves in monocotyledons. In this study, it was observed an overall decline in frequency of stomata was observed under HS in respect to NS. Enhanced temperature declined the stomatal frequency which caused reduction in transpiration rate and exchange of gases (Alam *et al*., 2011). Highest frequency of stomata was observed in genotype SH-95 in NS whereas Aas-11 in HS as shown in (Table 3). High stomatal frequency of genotype AAS-11 under heat stress conditions was due to higher veins per unit area of leaf and smaller size of stomata and epidermal cell. Higher stomatal frequency would lead to increase in transpiration and photosynthetic rate ultimately enhance the translocation of photosynthates during grain filling duration under heat stress conditions (Maghsoudi & Moud, 2008).

Leaf venation had positive association with frequency of stomata. In this study, the genotypes Aas-11 followed by SH-95 had highest veins under NS and HS as compared to other genotypes. Higher number of veins contained maximum stomatal frequency. Ahmad *et al*. (2006) also observed that higher stomatal frequency may lead to thick veins.

Stomata size was related inversely to stomatal frequency. These results are in agreement with those of Maghsoudi & Moud (2008) who reported that higher stomatal frequency would lead to decreases in stomatal size. In this study, genotypes Aas-11 followed by SH-95 had minimum stomata size whereas genotypes 9515 and 9516 had maximum stomata size. Ahmad *et al*. (2006) suggested that less frequency of stomata led to increase instomatal size per unit area of leaf in stress conditions. Epidermal cell size was least in genotype SH-95 under NS and HS conditions respectively. From these results it is concluded that greater stomatal size and epidermal cell size will lead to less stomatal frequency.

Table 1. Performance of six wheat genotypes for different phenological and morphological attributes under heat stress conditions.

Genotypes	Days to heading				Days to maturity				Flag leaf area (cm^2)				Number of seeds per spike			
	2012-13		2013-14		2012-13		2013-14		2012-13		2013-14		2012-13		2013-14	
	NS	HS	NS	HS	NS	HS	NS	HS	NS	HS	NS	HS	NS	HS	NS	HS
AAS-11	93.3c	82.3b	93.6c	83.3c	128.7ab	121.7a	130.3a	122.6a	35.1ab	24.9bc	34.4ab	24.7ab	54.2a	55.7a	55.8a	55.6a
Iqbal-2000	94.3bc	82.7b	94.3c	83.3c	127.3bc	119.7ab	128.3b	119.6b	32.4c	26.3a	31.5d	25.8a	48.9b	47.8bcd	48.5c	47.6bc
SH-95	94.7bc	83.7ab	94.6bc	84.0c	130.0a	120.0ab	128.6b	117.0c	35.3a	20.6e	34.6a	20.2d	47.1c	46.7cd	46.6d	46.5cd
9512	97.0a	84.7a	96.3ab	84.3b	127.7bc	117.3c	127.3b	118.6bc	34.0b	25.7ab	33.8bc	25.1ab	49.1b	48.8bc	48.6c	48.4bc
9515	95.3b	85.0a	95.3bc	85.3a	128.3bc	119.0bc	127.3b	121.3a	34.0b	22.9d	33.4c	22.5c	48.1bc	46.1d	47.6cd	46.1d
9516	95.0b	83.3ab	97.3a	84.6ab	127.0c	119.0bc	127.3b	119.6b	35.0ab	24.5c	34.3ab	24.1b	52.9a	49.5b	52.3b	49.4b
LSD at 5%	1.47	1.75	1.9	0.99	1.37	2.14	1.36	1.63	1.14	0.79	0.8	1.19	1.29	2.22	1.15	2.31

NS= normal sowing, HS= heat stress

Table 2. Performance of six wheat genotypes for different morphological attributes and HSI (heat susceptible index) under terminal heat stress conditions.

Genotypes	1000-grain weight (g)				Number of tillers per plant				Biomass (t/ha)				Heat susceptibility indices	
	2012-13		2013-14		2012-13		2013-14		2012-13		2013-14		2012-13	2013-14
	NS	HS	NS	HS	NS	HS	NS	HS	NS	HS	NS	HS		
AAS-11	51.4a	45.8a	49.38b	43.72b	12.7a	11.0a	12.40a	10.53ab	7.9a	6.5a	7.37a	6.17b	0.49	0.48
Iqbal-2000	44.1e	40.2d	43.98f	40.08d	11.8c	9.9d	11.73ab	9.77d	7.5b	5.3e	7.34a	5.19f	1.58	1.76
SH-95	49.7b	42.2c	49.51a	47.53a	12.0bc	11.1a	11.87ab	10.90a	7.6b	6.3ab	7.12b	6.63a	0.54	0.49
9512	47.7c	45.3ab	47.38c	45.15ab	12.5ab	10.7ab	12.37a	9.87cd	6.8d	6.0bc	6.47d	5.59e	0.98	0.99
9515	46.0d	44.0b	46.92cd	45.48bc	11.7c	10.0cd	11.47b	9.80cd	6.9d	5.8cd	6.79c	5.75d	1.05	1.43
9516	47.5c	43.9b	45.79d	41.95c	10.1d	10.4bc	10.20c	8.83bc	7.2c	5.7d	7.03b	5.94c	1.2	0.88
LSD at 5%	1.31	1.44	1.53	1.67	0.6	0.42	0.74	0.42	0.18	0.26	0.12	0.1		

NS= normal sowing, HS= heat stress

Table 3. Performance of six wheat genotypes for different for stomatal attributes under heat stress conditions at 5% probability.

Genotypes	Stomata frequency				Leaf venation				Stomata size (μm^2)				Epidermal cell size (μm^2)			
	2012-13		2013-14		2012-13		2013-14		2012-13		2013-14		2012-13		2013-14	
	NS	HS	NS	HS	NS	HS	NS	HS	NS	HS	NS	HS	NS	HS	NS	HS
AAS-11	51.0b	50.0a	50.67b	49.67a	9.0a	8.7a	8.67a	8.00a	1241.7c	1382.0ab	1270c	1408b	3114.8ab	3408.1b	3155b	3462b
Iqbal-2000	49.3bc	46.3c	48.67c	45.67d	7.3d	7.3b	7.00d	6.67c	1382.2ab	1356.9b	1349bc	1396b	2958.9c	3411.3b	3013d	3465b
SH-95	53.3a	49.3ab	52.67a	48.67b	8.3abc	8.7a	8.00abc	7.67ab	1308.0bc	1389.9ab	1317bc	1443ab	2828.6d	2958.3c	2887e	3035c
9512	48.0cd	45.7c	47.33d	46.67c	7.7cd	7.7ab	7.33cd	7.00bc	1373.7ab	1401.1ab	1412ab	1420b	3211.2a	3555.7a	3281a	3597a
9515	47.3d	45.7c	46.67d	45.67d	8.0bcd	7.7ab	7.67bcd	7.33abc	1450.2a	1446.6ab	1491a	1502a	3067.1bc	3578.5a	3124bc	3644a
9516	51.0b	48.7b	50.67b	48.33b	8.7ab	6.7b	8.33ab	8.00a	1325.6bc	1471.0a	1333bc	1495a	2983.2c	3431.0b	3045cd	3475b
LSD at 5%	1.79	1.27	0.79	0.92	0.88	1.08	0.74	0.79	101.21	99.36	107.1	62.94	118.78	83.37	109.35	87.18

NS= normal sowing, HS= heat stress

Morphological attributes: Flag leaf involves in the process of photosynthesis and translocation of photosynthetic products into grains. Senescence of leaf enhanced at high temperature which led to reduction in photosynthetic process and ultimately grain yield. Highest flag leaf area was observed for genotypes SH-95 followed by AAS-11 under NS and HS and it was significantly reduced under HS in other genotypes. Rahman *et al*. (2009b) also found decrease in area of flag leaf under high temperature.

Number of seeds is a significant yield contributing attribute. High temperature at anthesis decreases the fertility of spike causes declined in formation of the grains (Hossain *et al*., 2011). Reduction in seeds per spike under heat stress as compared to normal planting was observed in this study. Aslam *et al*. (2013) and Sial *et al*. (2005) also found reduction in number of seeds under delayed planting. However, maximum seeds were observed in genotypeAas-11 under NS and HS.

Thousand-grain weight is also imperative yield related attribute of wheat. Late planting decreases the grain filling period and starch translocation towards the grains (Zhao *et al*., 2008; Hossain & Silva, 2012).Enhanced temperature due to delayed planting causes reduction in grain weight (Calderini *et al*., 1999; Inamullah *et al*., 2007). Highest grain weight was observed for AAS-11 followed by SH-95 and reduction in grain weight was observed under HS conditions. Tahir *et al.* (2009) also observed decrease in weight of grains under HS. Delayed planting of wheat faced high temperature at anthesis and decreased the weight of grains (Rahman *et al*., 2009a).

Tillers per plant are also important attribute in wheat. Delayed sowing decreases the tillers due to high temperature (Aslam *et al*., 2013). In our study, maximum tillers were observed in genotypes SH-95 and Aas-11. Baloch *et al.* (2010) also suggested that normal planting of wheat have more tillers per plant than heat stress conditions.

Biomass depicts significant criteria in wheat for selection under heat stress. Late sowing decreases the vegetative period and stimulates flowering in respect to NS due to raise temperature (Akmal *et al*., 2011). In our study, genotypes AAS-11 and SH-95 gave maximum biomass yield and least reduction in HS indicated that these genotypes perform better in heat stress conditions.

High temperature reduces the vegetative phase and the translocation of photosynthetic products at grain filling duration which decreases grain yield (Aslam *et al*., 2013). Enhanced temperature at pre-anthesis reduces synthesis of grains per spike (Inamullah *et al*., 2007) whereas high temperature at post anthesis decreases the weight of grains (Rahman *et al*., 2009a). In present study overall, 28% grain yield was decreases in late planting with respect to normal planting. Ali *et al*. (2010) suggested that delayed planting decreases 18.55% grain yield from 20th of November to 20th of December due to enhanced temperature at grain filling phase. In this study, maximum grain yield was observed for genotypes AAS-11 followed by SH-95 under heat stress conditions. Relative performance indicated maximum percentage by genotypes Aas-11 and SH-95 which depicted that these genotypes were least effective by high temperature. Tahir *et al*. (2009) and Baloch *et al*. (2012) also observed that high temperature at reproductive phase decreased the grain yield.

Heat susceptible indices: HSI is very imperatives to estimate the potential of genotypes for yield in heat stress conditions. Hossain *et al*. (2011) also used heat susceptibility index to estimate yield stability. In this study, genotypes Aas-11 and SH-95 gave least value of "S" indicated that these genotypes use highly tolerant to heat stress whereas genotypes Iqbal-2000 and 9515 were susceptible to heat stress conditions as shown in (Table 2.)

Correlation analysis: Correlation of different attributes in normal and heat stress conditions was shown in (Tables 4 and 5.) Days to heading (DH) showed significantly positive correlation with flag leaf area (FLA) and stomatal frequency (SF) under normal sowing (NS) but negative relation under heat stress (HS). Flag leaf area showed negative association with number of tillers per plant (NOT), SF, LV and SS. Seeds per spike was strongly positive associated with BM and LV under normal conditions of planting. Moreover it was positively associated with TGW, BM, SF and LV under heat stress conditions. Thousand grain weight was found to has significant positive correlation with LV under NS whereas BM, LV, ECS under HS. Biomass showed significantly positive association with FLA, SF and LV under NS and HS. Stomata frequency was significantly positive correlated with LV but it showed negative relation with SS and ECS under both conditions of planting. Maghsoudi & Moud (2008) also reported that increase in number of stomata would ultimately decrease the size of stomata. Grain yield was significant positively association with NOT, DM, TGW and ECS while it was negatively related with SF and SS under normal condition of planting. Furthermore under heat stress conditions it was significant positively associated with DM, NOS, NOT, SF and LV whereas negatively relation with DH, FLA, BM and ECS. Alam *et al*. (2011) presented that increased size of stomata occurs in stress condition and decreased in yield. Ahmad *et al*. (2006) observed positive relationship of grain yield with SF and DM. Heat susceptible indices (HSI) showed that there was significantly positive association with DH while negatively relation with DM indicated that decrease heading and increased maturity period of genotypes might enhances tolerance of genotypes to heat stress. Strong positive association of HSI was shown by ECS indicated that increased epidermal cell size would reduce its tolerance to heat stress. Whereas it showed the strong negative association with NOS, TGW, NOT, SF, LV, BM and GY indicated increase in number of seeds, thousand grain weight, number of tillers, stomata frequency, leaf venation, biomass and grain would increase in tolerance of genotypes and perform better in heat stress condition. Khan *et al*. (2014) also observed the negative relation of "S" value with DM, NOS, BM, TGW and GY. These results showed that selection for these attributes would lead to decrease in susceptibility of genotypes to heat stress condition. Sharma *et al*. (2013) also observed negative association of heat susceptibility index with yield and yield related traits.

Table 4. Correlation of HSI with phenological, physio-morphic attributes under normal (N) and late during 2012-13 at 5%.

Traits		DH	DM	FLA	NOS	TGW	NOT	BM	GY	SF	LV	SS	ECS
DM	N	0.59*											
	L	0.59											
FLA	N	0.68	0.46										
	L	-0.31	0.04										
NOS	N	0.28	-0.29	0.24									
	L	-0.66	-0.6	0.42									
TGW	N	0.49	0.1	0.93**	0.45								
	L	0.26	-0.19	0.08	0.57								
NOT	N	-0.07	0.25	-0.39	-0.13	-0.54							
	L	-0.18	-0.05	-0.39	0.46	0.46							
BM	N	-0.07	-0.13	0.04	0.79**	0.18	-0.07						
	L	-0.08	-0.27	0.44	0.52	0.64	0.91**						
GY	N	-0.08	0.71	0.07	0.2	0.17	0.62	0.32					
	L	-0.15	0.19	-0.59	0.31	0.59	0.82	0.96**					
SF	N	0.78*	0.43	0.68	0.32	0.61	-0.15	0.56	0.2873				
	L	-0.66	-0.6	-0.34	0.59	0.18	0.71	0.64	0.49				
LV	N	0.51	0.55	0.86*	0.52	0.78	-0.25	0.45	0.44*	0.78*			
	L	0.01	0.37	-0.25	-0.49	-0.73*	-0.06	-0.15	-0.06	-0.22			
SS	N	-0.32	-0.21	-0.45	-0.73*	-0.47	-0.26	-0.77*	-0.54	-0.77	-0.72*		
	L	0.46	-0.09	-0.23	-0.21	0.37	-0.19	-0.1	-0.02	-0.04	-0.72		
ECS	N	-0.42	-0.39	-0.21	0.35	-0.07	0.58	-0.06	0.08	-0.36	-0.23	-0.2	
	L	0.29	-0.01	0.69	0.14	0.41	-0.58	-0.38	-0.38	-0.62	-0.52	0.31	
HIS		0.04	-0.34	0.44	-0.53	-0.68	-0.85*	-0.99**	-0.98**	-0.62	-0.21	0.04	0.31

DH (days to heading), DM (days to maturity), FLA (flag leaf area), NOS (number of seeds per spike), TGW (1000-grain weight), NOT (number of tillers per plant), BM (biomass), GY (grain yield), SF (stomata frequency), LV (leaf venation), SS (stomata size), ECS (epidermal cell size) and HSI (heat susceptibility indices) under N (normal sowing) and HS (heat stress)

Table 5. Correlation of HSI with phenological, physio-morphic attributes under normal (N) and late during 2013-14 at 5%.

Traits		DH	DM	FLA	NOS	TGW	NOT	BM	GY	SF	LV	SS	
DM	N	0.23											
DM	L	0.24											
FLA	N	0.42*	0.1										
FLA	L	-0.57	-0.11										
NOS	N	-0.12	-0.61	0.32									
NOS	L	-0.55	-0.4	0.38									
TGW	N	-0.28	-0.29	0.46*	0.25								
TGW	L	0.02	-0.05	0.08	0.49								
NOT	N	0.33*	0.08	-0.04	-0.08	-0.66							
NOT	L	0.17	0.68	-0.52	-0.18	0.06							
BM	N	-0.17	-0.08	0.09	0.71*	-0.11	-0.11						
BM	L	-0.3	-0.14	0.06	0.46	0.62	0.05						
GY	N	-0.21	0.06	0.28	0.27	0.2	0.74	0.03					
GY	L	-0.51	0.31	-0.75	0.14	0.18	0.67	-0.03					
SF	N	0.54*	0.34*	0.48*	0.25	-0.13	-0.16	0.56	-0.1				
SF	L	-0.36	-0.12	-0.18	0.63	0.27	0.32	0.52	0.42				
LV	N	-0.06	-0.02	0.64*	0.59*	0.44	-0.23	0.56	0.18	0.42			
LV	L	-0.2	-0.32	-0.26	0.43	0.36	0.1	0.65	0.31	0.65			
SS	N	-0.3	0.07	-0.17	-0.48	0.27	-0.11	-0.64	-0.01	-0.62	-0.38		
SS	L	0.12	-0.12	-0.39	-0.28	0.1	-0.03	0.35	0.05	-0.01	0.31		
ECS	N	-0.19	-0.55	0.05	0.2736	0.23	0.3	-0.31	0.45	-0.65	-0.13	0.27	
ECS	L	0.02	-0.19	0.62	0.11	0.33	-0.6	0.22	-0.59	-0.47	-0.26	0.12	
HIS		0.05	-0.12	0.41	-0.46	-0.5	-0.54	-0.53	-0.67	-0.86	-0.63	0.02	0.53

DH (days to heading), DM (days to maturity), FLA (flag leaf area), NOS (number of seeds per spike), TGW (1000-grain weight), NOT (number of tillers per plant), BM (biomass), GY (grain yield), SF (stomata frequency), LV (leaf venation), SS (stomata size), ECS (epidermal cell size) and HSI (heat susceptibility indices) under N (normal sowing) and HS (heat stress)

Conclusion

Wheat genotypes had variations regarding physiological, phenological and morphological attributes. In present study AAS-11 showed minimum days to heading and maximum days to maturity. Selection of genotypes for short days to heading and long days to maturity might be effective for selecting heat tolerant genotypes. Higher frequency of stomata is reliable physiological trait for the selection of genotypes in heat stress conditions. The reduction in grain yield with delayed planting was due to pre-anthesis and grain filling duration which causes reduction in number of grains per spike and 1000-grain weight respectively. Furthermore, there was less (13%) reduction in performance in grain yield of AAS-11 followed by SH-95 (18%) under heat stress. Grain yield was positively associated with number of tillers, 1000-grain weight, number of seeds per spike, leaf venation and stomatal frequency. Direct selection for these traits can improve grain yield under heat stress. From these results it is suggested that AAS-11 and SH-95 can tolerate heat stress conditions with least reduction in grain yield. So these genotypes can be used in further breeding program for the improvement of wheat cultivars against heat stress.

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