Tropical Agricultural Research & Extension 17(1): 2014

SCREENING FOR HEAT TOLERANCE IN SPRING WHEAT (*TRITICUM AESTIVUM L.*)

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Accepted: 12th September 2014

ABSTRACT

The present investigation was undertaken to identify the promising heat tolerant lines and to evaluate their heat stress responses. Twenty five spring wheat genotypes were studied in non-stressed (optimum sowing) and stressed (late sowing) environments. The experiments were conducted at Regional Wheat Research Centre, Bangladesh Agricultural Research Institute, Gazipur, during the cropping season of 2009-10. Randomized complete block design was used with three replications. Yield and yield contributing phenological and physiological characters varied among the genotypes under both optimum and late sowing conditions. Ground cover, grain filling duration, canopy temperature at grain filling and biomass production were severely affected by the heat stress leading to low grain yield under late sowing condition. G-12, G-13, G-14, G-18, and G-19 were identified as heat tolerant genotypes based on their relative performance in yield components, grain yield and heat susceptibility indices. Present genotypes are found to be ideal candidates to be used in developing heat tolerant wheat varieties.

Key words: Heat tolerance, Heat stress susceptibility index, Spring wheat

INTRODUCTION

Wheat (*Triticum aestivum* L.) ranks second among major cereals next to rice and plays a vital role in food security of teeming hungry millions of Bangladesh. In the coming period leading up to 2020, demand of wheat for human consumption in developing countries is expected to grow at 1.6% per annum (Ortiz *et al.* 2008). Thus yield increase is very much essential to maintain global food security. Recent researches on climate change predict marked increases in both rainfall and temperature. The temperature is projected to rise by as much as 3-4 ^{0}C by the end of the century in South Asia (DEFRA 2005). Therefore, heat stress has been given the top research priority in major wheat growing regions, in particular in the developing world including Bangladesh (CIMMYT 1995). In the rice-wheat cropping system of Bangladesh, 80-85% of wheat is grown after harvesting of transplanted aman rice, of which about 60% are late planted due to delayed harvesting of rice (Barma *et al.* 2011). Late planted wheat often encounters high temperature stress during late March to mid April at grain filling period causing significant yield reduction. There is a potential yield decline (1.3% per day) when sown beyond optimum time (30th November) in Bangladesh condition (Saunders 1988).

Heat tolerance is a complex phenomenon thus difficult to assess. Many selection criteria based on morpho-physiological traits were reported to be associated with performance under heat stress in wheat. Heat tolerant metabolism was reported to be indicated by longer leaf chlorophyll retention, canopy temperature depression, photosynthetic rate and leaf senescence (Rees *et al*. 1993, Rahman 1996, Reynolds *et al*. 1997 and Al-Khatib and Paulsen 1999). The other traits like biomass, 1000-grain weight and grain yield are also highly sensitive to heat stress (Barma 2005; Rahman 2009). Tillering capacity, grain weight, spike fertility, spike number, grains per spike, early ground cover etc were also reported to be associated with yield under heat stress and hence heat tolerance (Acevedo *et al.* 1991; Kohli *et al*. 1991; Samad 1994; Mann,1994).

Genetic variation may exist within the wheat genotypes for heat tolerance, thus evaluation of

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local and exotic germplasm for heat tolerance is important. Xiyong *et al*. (2000) suggested that combination of both heat susceptibility index and geometric mean yield per plant (or kernel weight per spike) could be used as selection criteria for the evaluation of heat tolerant genotypes. Bruckner and Frohberg (1987) measured stress tolerances using stress susceptibility indices based on grain yield. Barma (2005) estimated heat stress susceptibility indices for 1000-grain weight and grain yield to differentiate overall heat tolerance of the genotypes. Taking the above mentioned views into account, the present study was aimed at identifying genotypes of wheat for heat tolerance.

MATERIALS AND METHODS

Twenty four spring wheat genotypes along with a popular heat tolerant variety 'Shatabdi' (as a check) were collected from the ongoing breeding program of Wheat Research Centre, Bangladesh Agricultural Research Institute, Dinajpur to establish two experiments during the cropping season of 2009-2010. The experiments were conducted at the experimental field of Regional Wheat Research Centre, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur. Randomized complete block design was used with three replications. The experimental site was situated between 23°46′N latitude and 90°23′E longitude with elevation of 8m above sea level. The climate of the area is characterized by wet summer and dry winter. Temperature data recorded during the concerned period is graphically presented in Fig. 1. Seeds of each genotype were sown in 6 lines (20cm apart) of plots of 2.5m long. Standard agronomic practices were practiced during the crop growth. The central 1 metre of 4 rows of each plot were harvested for recording yield and primary yield contributing characters. Ground coverage was recorded visually at 35 days after sowing using 0-10 scale. Chlorophyll content of leaves was measured in 5 fully expanded flag leaves *in vivo* by a Minolta SPAD metre at anthesis and 21 days after anthesis and expressed in spad unit. The canopy temperature was measured by a hand held infra-red thermometer twice at 3 days interval at vegetative and grain filling stage.

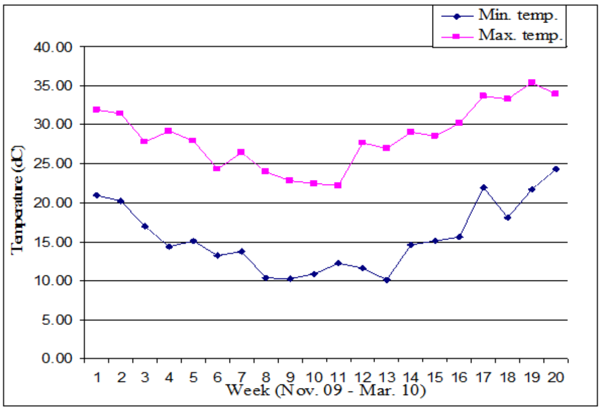

Fig. 1. Weekly average maximum and minimum temperatures at Regional Wheat Research Centre, Gazipur during the cropping season 2009-10

Analysis of variances was done for different characters according to the formula suggested by Steel and Torrie (1960). The 't' values were calculated from the accession mean for each pair of characters under normal and late sowing following the formula used by Singh and Choudhary (1985). Heat stress susceptibility indices "S" were estimated for each character according to the equation as described by Fischer and Maurer (1978). The lower the "S" value the higher would be the level of tolerance to stress condition. The collected data were subjected to analysis of variance by using the statistical software MSTATC and mean separation was done by Duncan's Multiple Range Test (DMRT) (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Performances of the genotypes in late sowing environment

The genotypes differed significantly in phenological, physiological and primary yield contributing characters related to heat tolerance (Tables 1). The performances under late sowing condition (Tables 2) revealed pronounced effects of heat stress on the traits. In this study, heat stress resulted in early anthesis, senescence and physiological maturity, shortened grain filling duration, decreased chlorophyll content of flag leaf at 21 days after anthesis, 1000-grain weight and biomass, reduced the number of spikes per unit area and grains per spike. Nevertheless, heat stress enhanced early ground cover and increased canopy temperature, chlorophyll content at anthesis and grain filling rate.

Genotypes G-2, G-3, G-4, G-12, G-13, G-14, G-17, G-18, G-19, G-21, G-24 and G-25 showed delayed anthesis suggesting their ability to withstand against heat stress. Al-Karaki (2012) reported that lengthening the preheading period of development would provide a better means of increasing grain yield under heat stress in durum wheat cultivars. Stay green of plants under stress conditions could be considered as an important trait since, longer stay green would be beneficial as it allows plants to retain their leaves actively for photosynthesis under stress condition (Koc *et al.* 2008). In this study, the genotypes G-1, G-6, G-10, G-14, G-17, G-18, G-21 and G-24 delayed leaf senescence in late sowing condition, implying that these genotypes had the green foliage for longer period under heat stress condition. Similarly, the genotypes G-1, G-17 and G-18 showed delayed maturity in heat stress indicating their ability to stay green under heat stress. The genotypes G-1, G-5, G-11, G-16, G-17 and G-18 took longer period for grain filling compared to those of the other genotypes under heat stressed condition. Paknejad *et al.* (2007) reported that the improvement of yield under drought stress has resulted from a more extended grain filling duration and a higher chlorophyll content.

Early ground cover was reported to be important in agronomic context (Rawson 1988; Badaruddin *et al*. 1999). High ground cover might reduce evaporative water loss from soil by providing better shade. Reynolds *et al.* (2001) stated that trait like ground cover could be important under heat stress. In wheat, ground cover probably a greater proportion of total evapotranspiration used in crop transpiration rather than soil evaporation. In this context, the genotypes G-1, G-3, G-5, G-6, G-9, G-12, G-13, G-14, G-15, G-16, G-17, G-18, G-19, G-20, G-21, G-22, G-24 and G-25 were found to have high ground coverage at mid vegetative stage under late sowing condition. Low canopy temperature and/or high canopy temperature depression have been used by several authors in screening for highly tolerant varieties to drought and heat (Amani *et al*. 1996; Ayeneh *et al*. 2002; Talebi 2011; Guendouz *et al*. 2012). Wheat genotypes with a low canopy temperature can maintain high transpiration and photosynthetic rate as well as produce a high yield under stressed conditions (Talebi 2011). Therefore, lower canopy temperature is regarded as an important mechanism of heat stress escape. In this study, the genotypes G-4, G-5, G-7, G-8, G-9, G-10, G-11, G-12, G-13, G-14, G-15, G-17, G-18, G-19, G-20, G-21, G-22 and G-24 showed low canopy temperature at vegetative stage suggesting that these genotypes can keep their canopy cool at vegetative stage under heat stressed condition. On the other hand, the genotypes G-4, G-7, G-9, G-15 and G-22 showed low canopy temperature at grain filling stage under late sowing condition suggesting their tolerance to high temperature at late sowing. Heat stress attributed to decline chlorophyll contents in cool-season cereal species leading to physiological changes and thereby leaf senescence (Almeselmani *et al*. 2011 and Dhyani *et al*. 2013). Therefore, higher retention of leaf chlorophyll under hot environment is often regarded as an expression of heat tolerance. Talebi (2011) confirmed chlorophyll content as a potential indicator for screening wheat genotypes for drought response. In this study, high chlorophyll contents of flag leaf at anthesis were found in the genotypes G-1, G-2, G-4, G-5, G-6, G-7, G-8, G-10, G-11, G-12, G-14, G-15, G-16, G-17, G-18, G-19, G-20, G-21, G-22 and G-24 indicating their ability for the fixation of photosynthate under late sowing condition. Moreover, the genotypes G-5, G-6, G-7, G-10, G-11, G-13, G-14, G-15, G-16, G-17, G-18, G-19, G-20, G-21, G-22 and G-24 showed high chlorophyll content of flag leaf at 21days after anthesis under late sowing condition. Several authors (Blum *et al.* 1997; Khanna-Chopra and Viswanathan 1999; Singh *et al*. 2011) emphasized that selection for high biomass yield should bring about positive improvement in grain yield under drought and heat stress. Therefore, selection for biomass yield is one of the most important ways to improve the productivity under late sowing conditions. In our study, the genotypes G-1, G-2, G-5, G-6, G-14, G-17 and G-22 had produced high biomass under heat stressed condition.

der late planting condition. Spikes number per unit area has been considered as a potential selection criteria for grain yield under heat stress (Reynolds *et al.* 1992; Hu and Rajaram 1994). In the present investigation, the genotypes G-2, G-5, G-9, G-10, G-13, G-17, G-19, G-22, G-23 and G-24 have produced higher number of spikes per square meter under late sowing condition. Grain weight is the most sensitive yield component to high temperature and could be used as a reliable trait to assess the responsiveness of genotypes to high temperature (Sharma *et al*. 2008). The genotypes G-1, G-2 and G-13 showed higher 1000-grain weight under late sowing condition. However, the genotype G-16 has produced the highest number of grains per spike under late sowing condition. Grain yield is an important selection criteria for heat stress. Singh *et al*. (2011) stated that high grain yield of a genotype under late sowing condition indicates the pres-

Table 1 Analysis of variance (Mean square) for phenological, physiological and primary yield contributing characters in spring wheat under optimum and late sowing conditions

Sources of variation	df	Mean square														
		Anthesis (day)	FLS (day)	PM (day)	GFD (day)	GC_{35} (scale)	CT_{vg} (°C)	CT_{gf} (°C)	CHL_a (spad)	CHL_{21} (spad)	Biom^{-2} (g)	GFR (gm^{-2} d^{-1})	Spikes m^{-2} (no.)	Grains spike^{-1} (no.)	1000-grain wt. (g)	GY m^{-2} (g)
Optimum sowing condition																
Replication	2	3.38	0.50	0.32	1.62	0.27	0.11	0.49	4.15	0.01	1058.00	0.26	144.50	31.05	25.95	18.00
Genotype	24	21.68**	7.01**	8.91**	14.41**	0.46**	2.90**	1.14**	10.94*	12.00**	29064.67**	4.44**	4759.37**	103.25**	43.59**	6479.46**
Error	48	2.75	1.42	1.78	1.33	0.14	0.87	0.35	4.35	2.78	6618.41	1.33	1474.71	26.53	6.33	2183.62
Late sowing condition																
Replication	2	0.18	0.02	0.32	0.02	0.19	0.19	0.08	9.95	0.08	288.00	2.62	722.00	15.79	0.30	1922.00
Genotype	24	4.28**	4.74**	4.83**	5.58**	0.45**	1.49**	1.60**	6.43*	24.50**	14154.71**	5.32**	2948.21*	91.31**	31.73**	3411.33**
Error	48	0.55	0.48	0.44	0.60	0.13	0.37	0.20	2.90	6.90	3941.12	1.68	1218.87	33.82	3.45	1234.50

*and ** indicate significant at 5% and 1% levels of probability, respectively
FLS= Flag leaf senescence (day); PM=Physiological maturity (day); GFD=Grain filling duration (day); GC_{35}=Ground coverage at 35 days; CT_{vg}=Canopy temperature at vegetative stage (°C); CTgf=Canopy temperature at grain filling stage (°C); CHL_a=Chlorophyll content at anthesis (spad unit); CHL_{21}=Chlorophyll content at 21 days after anthesis (spad unit); Bio m^{-2} =Biomass m^{-2}; GFR= Grain filling rate (g m^{-2} d^{-1}); GY= Grain yield (g m^{-2}); df= Degrees of freedom

Grain filling rate in wheat influences grain yield under a wide range of conditions (Wheeler *et al*. 1996). Zahedi and Jenner (2003) reported that relatively higher grain filling rates could be taken as an important criterion for breeding genotypes acclimatized to late planting condition. The genotypes G-2, G-3, G-5, G-12, G-14, G-17, G-22, G-23 and G-24 showed high grain filling rates even un-

Table 2 Mean performances of the genotypes for phenological, physiological and primary yield contributing characters in spring wheat under late sowing condition

Geno-type	Anth-esis (day)	FLS (day)	PM (day)	GFD (day)	GC_{35} (scale)	CTvg (°C)	CTgf (°C)	CHLa (spad)	CHL_{21} (spad)	Bio m^{-2} (g)	GFR ($g\ m^{-2}\ d^{-1}$)	Spike m^{-2} (no.)	Grain spike^{-1} (no.)	1000-grain wt.(g)	Yield m^{-2} (g)
G 01 (ck)	65.5 b-e	91.5 a	96.0 ab	30.5 ab	5.75 ab	26.25 a	33.20 a	49.2 a-e	41.5 d-h	1015.0 a-e	14.42 b-g	332.5 b-e	43.5 bc	43.90 a-c	440.0 ab
G 02	66.0 a-d	88.5 c-f	93.0 c-f	27.0 f-i	4.75 cd	25.78 ab	31.78 c-f	47.2 a-e	42.9 c-g	1017.5 a-d	16.48 ab	365.0 a-e	50.4 bc	45.70 ab	445.0 ab
G 03	66.5 a-c	88.5 c-f	93.0 c-f	26.5 g-j	5.50 a-c	25.35 a-c	31.50 d-g	45.4 e	36.2 h	902.5 b-g	15.13 a-e	317.5 b-e	50.3 bc	38.00 e-k	400.0 b-e
G 04	67.5 a	89.5 b-d	94.5 c	27.0 f-i	5.00 b-d	24.40 b-f	31.35 e-i	48.6 a-e	44.2 b-g	805.0 g	14.31 b-g	285.0 e	49.1 bc	40.25 c-h	385.0 b-e
G 05	62.0 h	87.0 f-h	92.0 ef	30.0 a-c	5.75 ab	23.90 c-f	31.65 c-f	48.5 a-e	46.1 a-e	1037.5 ab	15.00 a-e	395.0 ab	38.3 c	41.95 b-e	450.0 ab
G 06	65.5 b-e	90.0 a-c	94.5 c	29.0 b-e	6.00 a	24.48 b-e	32.35 a-e	49.7 a-d	46.6 a-e	1022.5 a-c	14.51 b-f	337.5 b-e	46.7 bc	39.18 d-i	420.0 a-d
G 07	64.5 d-g	87.5 e-h	93.0 c-f	28.5 c-f	4.25 d	23.68 d-f	30.45 hi	51.0 a	47.6 a-d	930.0 b-g	11.31 g	315.0 b-e	51.0 bc	42.80 b-d	322.5 e
G 08	65.0 c-f	88.5 c-f	92.5 d-f	27.5 e-h	5.00 b-d	23.28 ef	32.70 a-c	48.1 a-e	41.1 e-h	877.5 c-g	14.37 b-g	327.5 b-e	55.7 b	34.58 j-l	395.0 b-e
G 09	65.0 c-f	88.0 d-g	92.5 d-f	27.5 e-h	5.75 ab	23.05 ef	30.35 i	46.5 b-e	40.9 e-h	937.5 b-g	13.25 c-g	365.0 a-e	45.0 bc	39.33 d-i	365.0 b-e
G 10	65.5 b-e	90.5 ab	94.0 cd	28.5 c-f	4.75 cd	24.05 c-f	31.95 b-f	48.6 a-e	44.8 a-f	867.5 d-g	13.24 c-g	375.0 a-d	42.6 bc	39.75 c-i	377.5 b-e
G 11	63.0 gh	86.5 gh	92.5 d-f	29.5 a-d	5.00 b-d	24.33 b-f	33.10 a	51.3 a	50.4 ab	795.0 g	11.52 fg	297.5 de	45.7 bc	41.25 c-f	340.0 c-e
G 12	67.0 ab	88.0 d-g	93.0 c-f	26.0 h-j	6.00 a	24.43 b-f	33.30 a	47.2 a-e	43.0 c-g	982.5 b-f	16.73 ab	315.0 b-e	55.0 b	33.90 kl	435.0 ab
G 13	66.0 a-d	89.0 b-e	93.0 c-f	27.0 f-i	5.25 a-c	23.58 d-f	31.60 d-g	45.6 de	45.3 a-f	922.5 b-g	14.72 b-e	352.5 a-e	46.4 bc	47.70 a	397.5 b-e
G 14	67.5 a	90.5 ab	93.0 c-f	25.5 ij	6.00 a	23.25 ef	31.98 b-f	50.3 a-c	45.6 a-f	1005.0 a-e	16.11 a-c	327.5 b-e	55.4 b	38.93 d-j	410.0 a-d
G 15	64.5 d-g	88.5 c-f	92.0 ef	27.5 e-h	5.25 a-c	24.03 c-f	31.25 f-i	47.2 a-e	45.3 a-f	840.0 fg	12.29 e-g	305.0 c-e	53.0 b	36.63 g-l	337.5 de
G 16	63.5 f-h	88.5 c-f	94.5 bc	31.0 a	5.75 ab	24.98 a-d	31.40 e-h	50.5 ab	50.6 a	902.5 b-g	12.66 e-g	285.0 e	72.3 a	33.13 l	392.5 b-e
G 17	66.0 a-d	90.0 a-c	96.0 ab	30.0 a-c	5.25 a-c	23.58 d-f	32.88 ab	49.1 a-e	44.5 a-g	1017.5 a-d	15.00 a-e	377.5 a-d	46.1 bc	36.55 g-l	450.0 ab
G 18	66.5 a-c	90.5 ab	97.0 a	30.5 ab	6.00 a	24.25 c-f	31.53 d-g	47.2 a-e	45.5 a-f	920.0 b-g	12.80 d-g	332.5 b-e	47.0 bc	41.00 c-g	390.0 b-e
G 19	66.0 a-d	89.5 b-d	94.5 bc	28.5 c-f	5.75 ab	22.98 f	32.35 a-e	50.9 a	48.4 a-c	905.0 b-g	14.02 b-g	360.0 a-e	51.2 bc	35.45 i-l	400.0 b-e
G 20	64.0 e-g	86.0 h	92.0 ef	28.0 d-g	5.75 ab	23.90 c-f	32.30 a-f	49.6 a-d	45.0 a-f	870.0 c-g	13.04 c-g	322.5 b-e	43.2 bc	33.20 l	365.0 b-e
G 21	67.5 a	90.0 a-c	93.5 c-e	26.0 h-j	5.35 a-c	23.73 d-f	32.90 ab	49.3 a-e	47.8 a-d	862.5 e-g	13.17 c-g	307.5 c-e	46.1 bc	33.93 kl	342.5 c-e
G 22	64.0 e-g	86.5 gh	91.5 f	27.5 e-h	5.35 a-c	23.03 ef	30.58 g-i	50.2 a-c	46.5 a-e	1150.0 a	17.90 a	385.0 a-c	52.3 bc	37.38 f-l	492.5 a
G 23	64.0 e-g	86.0 h	90.0 g	26.0 h-j	5.00 b-d	24.83 b-d	33.35 a	46.2 c-e	38.5 gh	917.5 b-g	15.96 a-d	432.5 a	56.1 b	36.35 h-l	415.0 a-d
G 24	66.0 a-d	90.0 a-c	93.5 c-e	27.5 e-h	5.90 a	24.35 b-f	32.53 a-d	49.6 a-d	46.7 a-e	987.5 b-f	15.44 a-e	397.5 ab	42.8 bc	39.35 d-i	425.0 a-c
G 25	67.0 ab	87.5 e-h	92.0 ef	25.0 j	5.75 ab	25.28 a-c	33.05 a	45.7 de	39.6 f-h	840.0 fg	14.70 b-e	302.5 c-e	54.7 b	33.30 l	367.5 b-e
Mean	65.4	88.6	93.3	27.9	5.43	24.19	32.05	48.5	44.6	933.2	14.32	340.6	49.6	38.54	398.4
% Red-uction	6.3	12.2	13.3	26.2					6.4	19.6		9.2	10.1	8.68	22.5
% Increase					17.79	13.41	27.36	3.91			5.04				

Means of the same column followed by the same letter do not differ significantly at 5% level of probability

FLS= Flag leaf senescence (day); PM=Physiological maturity (day); GFD=Grain filling duration (day); GC_{35}=Ground coverage at 35 days; CT_{vg}=Canopy temperature at vegetative stage (°C); CTgf=Canopy temperature at grain filling stage (°C); CHL_a=Chlorophyll content at anthesis (spad unit); CHL_{21}=Chlorophyll content at 21 days after anthesis (spad unit); Bio m^{-2} =Biomass m^{-2}; GFR= Grain filling rate ($g\ m^{-2}\ d^{-1}$)

ence of genes for heat tolerance. Rasal *et al*. (2006) and Amandeep *et al*. (2007) found 17.45% and 28.9% yield reduction, respectively in response to heat stress, though Modarresi *et al*. (2010) showed the highest (46.63%) yield reduction. In spite of this, it was noticed that the genotypes G-1, G-2, G-5, G-6, G-12, G-14, G-17, G-22, G-23 and G-24 had yielded higher grain even under heat stressed condition.

Identification of heat tolerant genotypes through heat stress susceptibility indices

Paired t-test was employed to detect the differences between the effect of heat stress on these genotypes (Table 3). Significant differences between optimum sowing and late sowing environments could be found for all the characters except grain filling rate. In the present study, grain filling rate was excluded for preparing susceptibility indices as it showed insignificant response in paired t-test. Heat stress susceptibility indices "S" were measured for the characters to identify heat susceptible or tolerant genotypes. It adjusts for variations in grain yield, yield contributing, phenological and physiological traits due to differences in environmental stress intensity. The genotypes showed wide range of variations for "S" values. These values were used for identifying heat tolerant genotypes. Low stress susceptibility (S<1) is synonymous with high stress tolerance (Fischer and Maurer 1978). Based upon the value and direction of desirability, different genotypes were ranked as highly heat stress tolerant (S<0.50), moderately heat stress tolerant (S>0.50<1.00) and heat susceptible (S>1.00) (Khanna-Chopra and Viswanathan 1999 and Singh *et al*. 2011). Thus, in order to determine relative tolerance, the heat susceptibility indices were estimated for various characters. Several authors (Khanna-Chopra and Viswanathan 1999; Singh *et al*. 2011 and Sharma *et al*. 2013) evaluated heat susceptibility indices of yield and its different components of wheat genotypes for heat stress tolerance and grouped them into highly tolerant, tolerant and susceptible genotypes as suggested by low and high S values. The present findings revealed that heat susceptibility indices could be taken as important criteria for breeding wheat genotypes suitable for late sowing conditions. Considering heat stress intensity, it was revealed that days to anthesis, chlorophyll content of flag leaf, number of spikes m^{-2} and 1000-grain weight were less affected by late sowing condition, while ground cover, grain filling duration, canopy temperature, biomass and grain yield highly suffered under late sowing environment. This indicates that wheat grain yield depends on its filling duration and canopy structure under late sowing condition which partially supported the findings of Singh *et al*. (2011).

Estimation of heat stress susceptibility indices and raking of genotypes (Table 4) showed that every genotype possess different degree of tolerance to heat stress. According to heat stress susceptibility indices estimated for anthesis period, 13 among 25 genotypes (G-5, G -20, G-11, G-22, G-3, G-18, G-13, G-2, G-19, G-24, G-6, G-8 and G-7) were identified as tolerant and 4 of them were found highly tolerant (S<0.5). The rest of the genotypes including check were found to be heat sensitive. Ten genotypes including check G-5, G-6, G-1, G-20, G-3, G-17, G-18, G-23, G-11 and G-7 were found to be tolerant based on "S" values for physiological maturity. Based on "S" values for grain filling duration, 11 genotypes (G-21, G-1, G-6, G-4, G-23, G-16, G-17, G-25, G-18, G-5 and G-7) seemed to be moderately tolerant (S<1>0.5). Moreover 11 genotypes (G-6, G-16, G-15, G-2, G-10, G-7, G-3, G-4, G-1, G-19 and G-20) showed "S" values less than unity for the estimation of ground coverage while first 6 of them were highly tolerant (S<0.5).

The estimates on "S" values for canopy temperature at vegetative stage revealed that among 25 genotypes, 13 including check (G-15, G-12, G-17, G-14, G-13, G-21, G-25, G-

11, G-16, G-24, G-19, G-18 and G-1) showed tolerance to late sowing. The genotypes G-15 and G-12 were found to be highly tolerant (S<0.5) for this trait. However, fourteen genotypes (G-3, G-15, G-2, G-14, G-16, G-7, G-4, G-1, G-5, G-22, G-13, G-25, G-9 and G-19) showed moderate tolerance (S<1>0.5) based on "S" values for canopy temperature at grain filling. Estimated "S" values for chlorophyll content measured at anthesis showed that fourteen genotypes (G-16, G-14, G-12, G-22, G-4, G-9, G-2, G-3, G-6, G-18, G-21, G-8, G-10 and G-11) were found to be tolerant of which first 8 genotypes were considered as highly tolerant (S<0.5).

"S" values for spikes number m^{-2} showed that 14 genotypes including check G-7, G-23, G-9, G-1, G-14, G-3, G-19, G-13, G-22, G-11, G-5, G-21, G-25 and G-18 were tolerant of which first 10 genotypes were considered as highly tolerant (S<0.5). The estimates of "S" values for the number of grains $spike^{-1}$ revealed that 16 genotypes including check G-1, G-15, G-11, G-7, G-21, G-16, G-13, G-3, G-17, G-20, G-8, G-23, G-14, G-19, G-12 and G-18 displayed tolerance to heat stress of which 7 genotypes were considered as highly tolerant (S<0.5). Besides, 13 genotypes G-10, G-18, G-14, G-4, G-19, G-1, G-12, G-9, G-7, G-23, G-25, G-15 and G-6 were identified as tolerant based on "S" values when estimated for thousand grain weight. Among them, 6 genotypes including check were considered as highly tolerant (S<0.5). Moreover the "S" values of 14 genotypes including check G-14, G-12, G-13, G-25, G-2, G-23, G-18, G-17, G-24, G-6, G-19, G-1, G-9 and G-22 were observed as tolerant when estimated for grain yield. The genotypes G-14 and G-12 were considered as highly tolerant (S<0.5) and rest of the genotypes showed moderate tolerance to grain yield. Several genotypes showed less heat sensitivity to both grain yield and 1000-grain weight. Among 25 genotypes, the genotypes G-14, G-12, G-25 and G-13 showed both tolerances to heat stress for these two traits with moderate yield.

Table 3 Paired t-test for each character using the accession means of optimum sowing and late sowing conditions

Sl. no.	Character	Mean difference ($\bar{d}$)	Standard deviation (s_d)	t-value	Significance level
1	Days to Anthesis	4.44	2.14	10.33	**
2	Flag leaf senescence (day)	12.40	1.19	51.71	**
3	Physiological maturity (day)	14.36	1.63	43.87	**
4	Grain filling duration (day)	9.92	1.94	25.56	**
5	Ground coverage at 35 days (scale)	0.82	0.44	9.28	**
6	Canopy temperature at veg. stage (^{0}C)	2.86	1.04	13.66	**
7	Canopy temperature at grain filling (^{0}C)	6.88	1.02	33.75	**
8	Chlorophyll content at anthesis (spad)	1.82	1.48	6.14	**
9	Chlorophyll content at 21 DAA (spad)	3.06	2.43	6.28	**
10	Biomass m^{-2} (g)	228.20	118.04	9.66	**
11	Grain filling rate (g m^{-2} d^{-1})	0.68	1.86	1.84	ns
12	Spikes number m^{-2}	34.90	32.78	5.32	**
13	Grains number $spike^{-1}$	5.62	4.38	6.41	**
14	1000-grains weight (g)	3.66	3.02	6.05	**
15	Grain yield m^{-2} (g)	116.00	56.08	10.34	**

** indicate significant at 1% level of probability; ns: non significant

Table 4 Heat stress susceptibility indices "S" based on phenological, physiological and primary yield contribut-

	Anthesis		FLS		PM		GFD		GC_{35}		CTvg		CTgf	
Genotype	S_A	Rank	S_{FLS}	Rank	S_{PM}	Rank	S_{GFD}	Rank	S_{GC}	Rank	S_{CTVG}	Rank	S_{CTGF}	Rank
G 01(ck.)	1.12	17	0.77	1	0.86	3	0.75	2	0.85	9	0.99	13	0.96	8
G 02	0.90	8	0.97	7	1.04	17	1.10	19	0.31	4	1.60	24	0.78	3
G 03	0.79	5	0.86	3	0.92	5	1.01	12	0.56	7	1.43	21	0.76	1
G 04	1.57	23	1.03	16	1.00	11	0.78	4	0.63	8	1.54	23	0.88	7
G 05	0.00	1	0.95	5	0.77	1	0.99	10	1.19	15	1.75	25	0.97	9
G 06	0.91	11	0.82	2	0.81	2	0.78	3	0.25	1	1.03	15	1.07	20
G 07	0.92	13	0.95	4	0.98	10	0.99	11	0.35	6	1.45	22	0.88	6
G 08	0.91	12	0.97	8	1.02	14	1.05	16	1.00	12	1.13	16	1.44	25
G 09	1.12	18	1.08	22	1.08	21	1.05	17	1.19	16	1.26	17	0.98	13
G 10	1.01	15	0.99	9	1.03	16	1.03	13	0.31	5	1.01	14	1.02	16
G 11	0.25	3	0.99	10	0.96	9	1.13	20	1.41	19	0.77	8	1.28	23
G 12	1.09	16	1.05	18	1.07	19	1.10	18	1.49	21	0.40	2	1.11	21
G 13	0.79	7	1.04	17	1.07	20	1.17	23	1.33	17	0.71	5	0.97	11
G 14	1.48	22	1.06	20	1.13	24	1.03	15	1.13	14	0.57	4	0.79	4
G 15	1.24	19	1.15	25	1.23	25	1.19	24	0.28	3	0.13	1	0.76	2
G 16	1.46	21	1.11	24	1.03	15	0.82	6	0.26	2	0.79	9	0.87	5
G 17	1.00	14	0.99	12	0.92	6	0.88	7	1.33	18	0.55	3	1.05	18
G 18	0.79	6	1.02	15	0.95	7	0.98	9	1.49	22	0.95	12	1.00	15
G 19	0.90	9	0.96	6	1.00	12	1.03	14	0.85	10	0.94	11	0.99	14
G 20	0.12	2	1.07	21	0.90	4	1.14	21	0.85	11	1.32	18	1.17	22
G 21	1.76	25	1.10	23	1.01	13	0.71	1	1.07	13	0.72	6	1.06	19
G 22	0.48	4	0.99	11	1.06	18	1.22	25	1.91	23	1.39	20	0.97	10
G 23	1.35	20	1.00	14	0.95	8	0.81	5	1.41	20	1.38	19	1.31	24
G 24	0.90	10	0.99	13	1.10	22	1.16	22	2.68	25	0.86	10	1.04	17
G 25	1.68	24	1.05	19	1.11	23	0.92	8	1.99	24	0.75	7	0.97	12
"S" Range	0.00-1.76		0.77-1.15		0.77-1.23		0.71-1.22		0.25-2.68		0.13-1.75		0.76-1.44	
Stress Intensity	0.063		0.122		0.133		0.262		-0.177		-0.134		-0.273	

A=Days to anthesis; FLS= Flag leaf senescence (day); PM=Physiological maturity (day); GFD=Grain filling duration (day); GC_{35}=Ground coverage at 35 days; CT_{vg}=Canopy temperature at vegetative stage (^oC); CTgf=Canopy temperature at grain filling stage (^oC)

Table 4 Cont'd

	CHLa		CHL_{21}		Bio m^{-2}		Spikes m^{-2}		Grains sp^{-1}		1000-grain wt.		Grain Yield m^{-2}	
Genotype	S_{CHA}	Rank	S_{CH21}	Rank	S_B	Rank	S_{SM}	Rank	S_{GS}	Rank	S_{TGW}	Rank	S_{GY}	Rank
G 01(ck.)	2.02	22	1.99	21	1.05	14	0.16	4	0.10	1	0.31	6	0.92	12
G 02	0.41	7	2.28	23	0.63	7	1.64	19	1.40	18	1.63	23	0.64	5
G 03	0.49	8	3.01	25	1.27	21	0.17	6	0.54	8	1.15	17	1.04	15
G 04	0.19	5	1.13	17	1.61	23	2.26	23	2.26	24	0.18	4	1.50	23
G 05	2.08	23	0.59	10	1.00	12	0.52	11	2.53	25	1.09	15	1.07	16
G 06	0.50	9	1.06	15	0.47	3	2.34	25	1.94	22	0.93	13	0.85	10
G 07	1.05	16	0.24	5	1.11	17	0.00	1	0.16	4	0.62	9	1.70	24
G 08	0.68	12	1.22	18	1.89	25	2.29	24	0.68	11	1.89	24	1.39	21
G 09	0.28	6	2.39	24	0.80	9	0.15	3	2.13	23	0.62	8	0.95	13
G 10	0.76	13	1.32	19	1.26	20	2.24	22	1.67	20	0.04	1	1.10	17
G 11	0.90	14	0.03	1	1.20	18	0.44	10	0.16	3	1.30	20	1.17	19
G 12	0.14	3	0.25	6	0.42	2	1.98	20	0.89	15	0.57	7	0.24	2

G 13	3.30	25	0.69	11	0.48	4	0.23	8	0.44	7	1.05	14	0.50	3
G 14	0.03	2	0.95	14	0.05	1	0.16	5	0.74	13	0.15	3	0.23	1
G 15	1.02	15	1.12	16	1.31	22	1.05	16	0.12	2	0.93	12	1.46	22
G 16	0.03	1	0.21	4	1.23	19	1.04	15	0.28	6	1.24	19	1.17	18
G 17	1.29	18	0.80	12	0.58	6	1.60	18	0.59	9	1.54	22	0.74	8
G 18	0.56	10	0.55	9	0.81	10	0.76	14	0.94	16	0.06	2	0.74	7
G 19	2.76	24	0.36	7	1.06	15	0.22	7	0.75	14	0.19	5	0.87	11
G 20	1.98	21	1.49	20	1.80	24	2.05	21	0.59	10	1.37	21	1.84	25
G 21	0.64	11	0.11	2	1.01	13	0.59	12	0.25	5	3.44	25	1.20	20
G 22	0.15	4	0.83	13	1.06	16	0.34	9	1.92	21	1.23	18	0.98	14
G 23	1.68	20	2.05	22	0.77	8	0.00	2	0.74	12	0.77	10	0.72	6
G 24	1.68	19	0.12	3	0.92	11	1.05	17	1.40	19	1.13	16	0.83	9
G 25	1.17	17	0.38	8	0.53	5	0.59	13	1.30	17	0.77	11	0.51	4
"S" Range	0.03-3.30		0.03-3.01		0.05-1.89		0.00-2.34		0.10-2.53		0.04-3.44		0.23-1.84	
Stress Intensity	-0.039		0.064		0.196		0.092		0.101		0.086		0.225	

CHL_a=Chlorophyll content at anthesis (Spad unit); CHL_{21}=Chlorophyll content at 21 days after anthesis (Spad unit); Bio m^{-2} =Biomass m^{-2}

Based on overall results, G-18, G-19, G-14, G -12, G-13, G-6, G-25, G-23, G-9 and check (G-1) could be categorized as heat tolerance genotypes. Among them, G-18, G-19, G-14, G-12 and G-13 were performed better than the check (G-1). High stability in grain yield under stress condition was associated with poor or moderate grain yield potential (Fischer and Maurer 1978; Bruckner and Frehberg 1987; Ehdaie *et al*. 1988; Bansal and Sinha 1991). In this study, the genotypes G-14, G-12, G-25 and G-13 produced moderate grain yield and found to be highly stable genotypes under heat stress, thus could be recommended for both sowing environments while the genotypes G-2, G-17, G-22, and G-24 might be recommended for optimum sowing condition with relatively high yield as they showed moderate tolerance to heat stress under late sowing condition. Screened genotypes for heat stress tolerance could potentially be used as a genetic stock for further improvements of genotypes for heat stress.

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