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Effect of Heat Stress on Grain Weight in Bread Wheat

KEYWORDS: Wheat, heat stress, heat susceptibility index (HSI), thousand grain weight (TGW).

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ABSTRACT *Heat stress affects a number of physiological and morphological traits in crops. The present study was undertaken to determine the effect of terminal heat stress on a set of 95 bread wheat genotypes. The wheat genotypes were evaluated under normal and late sowing conditions in two different locations. Analysis of variance revealed that location, sowing time and genotype has marked effect on thousand grain weight. Heat Susceptibility Index (HSI) was measured to identify 24 genotypes as highly heat tolerant (HSI<0.5) in one location and 33 genotypes in other location. Ten genotypes were found to be common between groups of genotypes heat tolerant in two locations. The genotypes identified as heat tolerant would form an important resource for the development of high-yielding varieties under heat stress.*

Introduction

Among cereals, wheat is the second most important crop next to rice in production. The average global grain yield of major cereal crops is 2520 million tonnes in 2013-14, of which wheat contributed about 715.5 million tonnes (www.fao.org). Being one of the most important food crops of the world, it occupies one-sixth (17%) of crop acreage world over, feeding nearly half (40%) of the world population and providing one-fifth (20%) of total food calories and protein in human nutrition (http://www.ksu.edu/igrow/IGROW_workshop_report.html). India has also second largest area (26.3 m ha) under wheat cultivation in the world followed by China (22.5 m ha). The total wheat production for 2013-14 in India was approximately 95.85 million tonnes, which was higher than 94.88 and 93.51 million tonnes for 2011-12 and 2012-13, respectively (www.icar.org.in).. This was due to the use of better agricultural practices and improved seed quality during last decade. However, to meet the demand for food of the ever growing Indian population, a significant increase in grain production is required in cereals including wheat. The wheat productivity is affected by a number of factors including biotic and abiotic stresses. To keep productivity levels with the growing demand for food, high yielding varieties under different climatic conditions and stresses needs to be developed.

In wheat, terminal heat stress with ambient temperature > 30˚C, during reproductive development stage has been found to decrease productivity (Hays *et al*. 2007). Accompanied with rising mean temperature as a result of global warming, high temperature at the time of grain filling affects grain production in many environments (Hays *et al.* 2007). It is one of the major causes of yield reduction which affects more than 36 million hectares in temperate environments (Reynolds *et al.* 2001). A significant portion of wheat grown in South Asia is considered to be affected by heat stress, of which the majority is present in India (Joshi *et al.* 2007). In India the losses upto 50% in yield potential have been estimated when crop is exposed to 32-38˚C temperature at crucial grain formation stage (Wardlaw *et al.* 1989).

Both physiological and morphological traits like chlorophyll content, canopy temperature depression, photosynthetic rate, biomass, thousand grain weight, grain yield and yield associated traits are affected by heat stress. Bala *et al.* (2014) showed that high temperature significantly decreased grain yield, number of grains per kernel, plant height, grain filling duration, peduncle length, peduncle weight and 1000 kernel weight. Heat stress during grain filling is responsible for shortening of grain growth period and improper grain filling affects over-all yield of wheat crop (Rane *et al*. 2007). The grain yield per plant, biological yield per plant and grain yield per spike suffer under late sown conditions (Singh *et al.* 2011). The high yielding wheat genotypes under heat stress can be identified by calculating Heat susceptibility index (HSI) following field evaluation for a number of agronomic traits (Kirigwi *et al.* 2007; Mohammadi *et al*. 2008; Mason *et al*. 2010, 2011). Characterization of wheat genotypes for high temperature tolerance identified genotypes with better relative performance in yield components, grain yield and heat susceptibility index (Rahman *et al*. 2009; Khan *et al.* 2014). The use of HSI and performance under late sowing heat stressed conditions has also been reported in a number of studies earlier as well (Mohammadi *et al*. 2008; Pinto *et al.* 2010; Yang *et al.* 2010; Barakat *et al.* 2011; Mason *et al.* 2010, 2011). However, in order to conduct genetic analyses in the form of QTL studies, the genotypes with contrasting characters needs to identified. In view of this, the present study was aimed at identifying heat tolerant wheat genotypes based on HSI for thousand grain weight.

Materials and methods

Planting material and field evaluation

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A set of 95 diverse wheat genotypes, obtained from CCSU, Meerut, U.P (India) were used for heat stress evaluation (Table 1). The wheat genotypes were sown under two regimes of sowing i.e. normal sowing and late sowing, both in replicated trails at two locations viz SKUAST-J, Chatha and SKUAST-J, R.S Pura herein referred to as Chatha and RS Pura. Alpha-lattice experimental design with two replications (each for normal and late sowing) was used. Each genotype was sown in plots of 5.0 m^2 with row-to-row spacing of 0.25cm. All agronomic practices recommended normally for wheat crop were followed. Ten spikes randomly selected from each plot were hand threshed for calculating thousand grain weight.

Statistical analysis

The analysis of variance (ANOVA) was carried out to study the effect of different factors on thousand grain weight. The paired t-test was carried out to understand the effect of late sowing on thousand grain weight. All the data analysis was carried using SPSS statistical package (SPSS 16.0).

Heat Susceptibility Index (HSI)

Heat susceptibility index (HSI) was used to evaluate the effect of heat stress on thousand grain weight (TGW). The formula used for HSI calculation, taken from Paliwal *et al.* (2012), is given below:

HSI of X= $[(1- X_{heat\ stress}/ X_{control})/D]$

Where,

X represents TGW

X_{heat} stress represents phenotypic values of individual genotypes for TGW under late sowing

$X_{control}$ represents phenotypic values of individual genotypes for TGW under normal sowing

D (stress intensity) = $(1- {}_{Yheat\ stress}/ Y_{control})$
$Y_{heat\ stress}$= Mean of $X_{heat\ stress}$ of all genotypes
$Y_{control}$= Mean of $X_{control}$ of all genotypes

Results and Discussion

Phenotypic evaluation of genotypes

The data on 95 wheat genotypes was evaluated for thousand grain weight (TGW) under two regimes of sowing *i.e* normal sowing and late sowing. The TGW was scored at two different locations (Chatha and RS Pura) in the year 2014-15. To estimate the effect of heat on the genotypes, paired t-test was employed on TGW from normal and late sowing conditions (Table 2). Significant differences between normal sowing and late sowing environments were found for TGW. The initial data analysis suggested that there was significant difference in TGW among genotypes between two sowing times. TGW under normal sowing ranged from 14.10 to 46.48 gm (Chatha) and 21.0 to 46.0 gm (RS Pura). For late sowing, TGW ranged from 9.62 to 32.12 gm and 12 to 41.6 gm for Chatha and RS Pura, locations respectively. The mean TGW at Chatha location was 27.35gm and 20.52 gm for early and late sowing, respectively. Similarly, the mean for TGW at RS Pura location was 34.26gm and 28.96gm for early and late sowing, respectively. Thousand grain weight showed significant decrease due to late sowing at both locations as shown in Fig. 1. The results showed that average thousand grain weight decreased by 6.83 gms and 5.30 gms in late sown conditions as compared to early sowing for Chatha and RS Pura locations respectively. Effect of heat stress due to late sowing on grain weight has also been reported in previous studies (Hossain *et al*. 2015; Khan *et al*. 2007; Bala *et al*. 2014 and Shahzad *et al*. 2002).

The ANOVA analysis revealed that location, sowing type and genotype had significant effect on the TGW (Table 3). The main effect interactions (location*sowing, location*genotype, sowing*genotype and location*sowing*genotype) also showed significant differences for thousand grain weight.

Identification of heat stress tolerant genotypes

Heat Susceptibility Index (HSI) was measured for thousand grain weight (TGW) at two locations to identify heat tolerant and susceptible genotypes. HSI estimates for all genotypes showed both resistant and tolerant genotypes. The HSI for TGW ranged from -1.55 to 2.62 for Chatha with mean value of 0.93 and from -1.69 to 3.43 for RS Pura with mean value of 0.96 (Fig. 2). These values were used for identifying heat tolerant genotypes. Low HSI (HSI<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 tolerant (HSI<0.50), moderately heat tolerant (HSI 0.50-1.00) and heat susceptible (HSI>1.00) (Khanna-Chopra and Viswanathan 1999 and Singh *et al*. 2011).

From HSI values for TGW at Chatha, 24 genotypes (C8, C13, C15, C20, C25, C26, C27, C29, C30, C31, C32, C33, C39, C46, C48, C49, C58, C72, C78, C79, C82, C89, C92 and C93) having HSI value <0.5 were identified as highly heat tolerant. Thirty three genotypes (C5, C9, C11, C17, C20, C23, C28, C29, C30, C32, C35, C44, C47, C48, C50, C52, C56, C61, C64, C67, C69, C72, C73, C74, C77, C78, C79, C81, C82, C83, C86, C91 and C93) were identified as highly heat tolerant (HSI<0.5) for RS Pura location (Table 4). Based on HSI values for TGW, a total of 10 highly heat tolerant genotypes (C20, C29, C30, C32, C48, C72, C78, C79, C82 and C93) were identified as common to both locations. Identification of heat stress tolerant wheat genotypes based on HSI values for TGW have also been reported in previous studies as well (Khan *et al*. 2014 and Singh *et al*. 2011).

Table 1. List of ninty-five genotypes with their pedigree

S.No.	Genotype	Pedigree
C1.	PBC Type 11	Not available
C 2.	A115	Not available
C 3.	A90	Not available
C 4.	8A	Not available
C 5.	NP111	Not available
C 6.	NP165	NP 4*Federation
C 7.	C518	PB Type 8B/PB Type 9
C 8.	NP710	NP 52/NP 165
C 9.	NP721	Pusa 52/Pusa 165
C 10.	NP737	Chinese-White/NP111
C 11.	HYB11	A 115/(Kenya-E-220)Kenya-C-10854
C 12.	K65	C 591/NP 773
C 13.	NP809	Democra/C518//Spalding Prolifique/NP114/3/Wisconsin-245
C 14.	NP890	Gaza(TR.DR)/C281//C281
C 15.	MONDHYA3-2	(S)LV-Mondhya
C 16.	K53	Not available
C 17.	C286	Type1(TR.DR)/(TR.DR)Khapli//C591/C250
C 18.	NP792	Kenya-C-10854(Kenya-E-220)/NP-165
C 19.	NP823	NP165/C518//NP799/NP770
C 20.	NP825	NP799/NP770//C518/NP165

C 21.	NP852	KF/2*NP 761
C 22.	SAFED LARMA	Y50//N10B/3/LR 52/3*LR
C 23.	SARBATI SONORA	Sonora 64 Mutant
C 24.	NP824	Wisconsin245(SEL.44-25-7-5)/NP 770//C518/NP 165
C 25.	HD1941 (HIRA)	E 5477 * S64
C 26.	PV18	(FN * K 58-N.TH-N10B)GB55
C 27.	NP884	E1913 * NP755
C 28.	DURGAPURA65	RS31*5//TH./NP165
C 29.	HD2009(Arjun)	LR 64A / NAI 60
C 30.	HD2177	HD1962-E 4870-K65/HD1593
C 31.	HS1097-17	CJ60/3/SPO/MTA//MQ/2*RNW
C 32.	HS1138-6-4	E4870/Sonalika
C 33.	HYB65	GB-AUS/ A115
C 34.	IWP72	E 5606/2*KS
C 35.	J1-7	Selection from J1
C 36.	K78	Janak/K816//K65
C 37.	K816	(CIANO 'S' * (S.64 * KI REND)
C 38.	KSML3	ML 253 RON-CHA*KAL-NOR67 ML 265 ((CNO-SON-KL.REND)*KAL2 ML 277 GTO-KAL*BB-CNO
C 39.	NARMADA195	C306/HY65 (Selection of N-112)
C 40.	NI5439	RFPM 80/3*NP 710
C 41.	NI5643	New Thatch /D221 NI 284-S
C 42.	UP368	LR64 *SON.64
C 43.	WG357	PV 18 * C 273
C 44.	WG377	(WG143 * USA 255)*PV18
C 45.	GW40	INIA66*2/7C
C 46.	HD2329	HD 1962/E 4870/3/K 65/5/HD1553/4/UP262
C 47.	HD2135 (NILGIRI)	H41-3(HD1962*(E4870*K 65))
C 48.	HUW12	NP 876 / CIANO 66
C 49.	HP1102	8156(B) / NAD 63
C 50.	D134	RS31/WIS245'S'
C 51.	VL421	SN 64 / Y 50E/GTO
C 52.	CPAN1796	NAPO/TOB'S' // 8156/3/KAL/BB
C 53.	HB208	SPO/MTA//MQ/2*RNW//3/PJ'S'/P14/KT54B
C 54.	HD2236(Kshipra)	HD 2119 / HD 1981
C 55.	HD2380	HD2225/HD2257
C 56.	HD2501	HD2189/HD2160
C 57.	HS207	KAVKAZ /BUHO // KAL/BB
C 58.	J405	CNO/INIA66//BB/3/CNO//PI/GLL
C 59.	K8027	NP875/4/N10B/Y53//Y50/3/KT54B/5/2*K852
C 60.	MLKS11	IWP 19 E 6254*KS2 IWP 72 E 6056*KS2 IWP 92 S 210*KS3 IWP 98 (NP 875-E 4849-NP 830)*KS2 IWP 123 (NP 875-E 4849-NP 830)*KS2 IWP 106 Norteno 67*KS3 IWP109 V 17-LR 64A*KS3 IWP116 NP 852-E 4871*KS3 IWP 114 HD 1981*KS3
C 61.	PBN142	HD 2189 /NI 917//Agantha
C 62.	PBW154	HD2160-HD 2177
C 63.	PBW65	USA255/K816/3/WL202
C 64.	UP2121	UP 366 / Samaka 68
C 65.	VL616	Sonalika/CPAN 1507
C 66.	RAJ3077	HD 2267/Raj 1482/5/BB/INIA66'S'/NAPO
C 67.	RAJ2184	UP 291/HD 2206
C 68.	SAGARIKA	NP798/KAL
C 69.	RW346	Janak/SA42
C 70.	TAWA267	B B/7C
C 71.	HUW55	E 4870 / HD 1982 // INIA 66 / HD 2189
C 72.	HUW37	Kalyan sona / S 331 // HD 1982
C 73.	HUW213	Norteno / Moti // HD 2160
C 74.	PBW138	Ravi 43/HD 2177
C 75.	DWR16	SKA/70B
C 76.	UP2003	BB/2*7C
C 77.	AKW1071	VEE'S'/ 3FLN/ACC// ANA
C 78.	DL784-3	KAL*4/TR 380 .27*4/3 AG/3/HD 2281
C 79.	DWR195	Bonmara-105-7
C 80.	HP1761	RL 6010/ 6*INIA //3* KAUZ
C 81.	HPW42	VEE"S"/4/PVN"S"/CBB//CNO"S"/3/JAR/ORZ"S"
C 82.	JWS-17(Swapnil)	Selection from HUW 334
C 83.	K88(K8804)	VEERY "S" / WL 711
C 84.	PBW396	CNO 67/MFD//MON "S"/3/SERI
C 85.	PBW373	ND/VG9144 //KAL/BB/3/YCO"S"/4/VEE#5 "S"
C 86.	HD2687	CPAN2009 / HD 2329
C 87.	KRL-1-4	Kharchia65/ WL711
C 88.	HS420	RAJ 3302//CMH 73A-497/3*CNO 79
C 89.	K9162	K 7827/HD 2204
C 90.	K9533	HI 1077/HUW 234
C 91.	NIAW301	SERI 82 /3/ MRS / JUP // HORK 'S'
C 92.	RAJ3777	Raj3160/HD2449
C 93.	RAJ4037	DL 788-2/RAJ 3717
C 94.	VL804	CPAN3018/CPAN3004//PBW65
C 95.	WH711	ALD 'S' HUAC // HD 2285 /3/ HFW-17

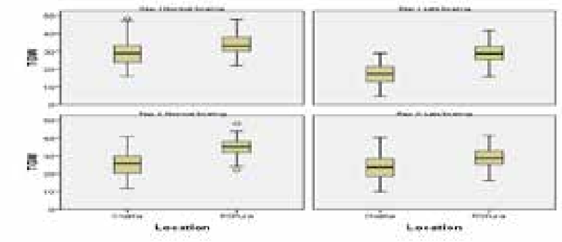


Fig. 1: Thousand grain weight (TGW) under normal and late sowing for two locations (Chatha and RS Pura).

Table 2. Paired t-test for each character using means of early and late sowing.

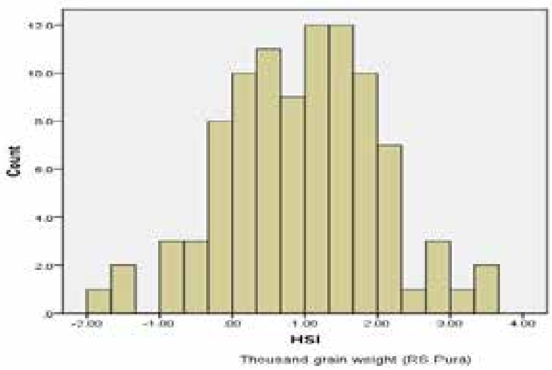
Trait	Mean Difference	Std. Deviation	t-value	95% Confidence Interval of the Difference	
				Lower	Upper
Thousand grain weight	5.96	7.81	14.87*	5.17	6.75

*indicate significant at 0.05 level of probability

Table 3. Analysis of variance (ANOVA) for thousand grain weight under normal and late sowing conditions.

Source of variation	Degree of freedom (df)	Mean square	Significance level
Location	1	10907.62	0.00*
Sowing	1	6762.22	0.00*
Genotype	94	140.81	0.00*
Location * Sowing	1	140.86	0.01*
Location * Genotype	94	55.86	0.00*
Sowing * Genotype	94	31.26	0.005*
Location * Sowing * Genotype	94	32.40	0.002*

*indicate significant at 0.05 level of probability



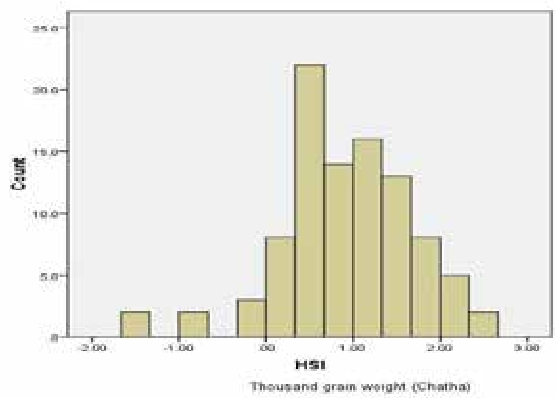


Fig. 2. Graph showing range of HSI for all genotypes for thousand grain weight at Chatha and RS Pura locations.

Table 4: Highly heat tolerant genotypes identified on the basis of Heat Susecptibility Index (HSI) for TGW under two locations.

Genotype	HSI(Chatha)	Genotype	HSI(RS Pura)
C8	-0.79	C5	-0.20
C13	0.22	C9	-1.00
C15	0.42	C11	-1.69
C20	0.41	C17	0.22
C25	0.28	C20	-0.17
C26	-0.16	C23	0.37
C27	-1.38	C28	0.22
C29	0.39	C29	0.44
C30	0.12	C30	0.38
C31	0.47	C32	0.37
C32	0.48	C35	-0.77
C33	-1.55	C44	0.04
C39	0.40	C47	0.09
C46	0.15	C48	-0.48
C48	0.34	C50	0.31
C49	0.44	C52	-0.49
C58	0.10	C56	-1.38
C72	0.23	C61	0.12
C78	0.48	C64	0.03
C79	0.06	C67	-0.29
C82	0.46	C69	-0.74
C89	0.35	C72	-1.66
C92	-0.01	C73	-0.37
C93	-0.02	C74	-0.20
		C77	0.20
		C78	-0.06
		C79	-0.20
		C81	0.31
		C82	0.45
		C83	-0.11
		C86	-0.25
		C91	0.22
		C93	0.45

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