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Screening wheat germplasm for heat tolerance at terminal growth stage

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Abstract

The germplasm comprising of 442 wheat varieties/lines was sown in one meter long row in a plastic sheet tunnel to screen the material for heat tolerance during 2004-05 and 2005-06 at Wheat Research Institute, Faisalabad. A set of the material was sown in the open adjacent to the tunnel. The material was exposed to heat shock (>32^0C) by covering the tunnel with plastic sheet during grain formation for two weeks in 2004-05 and for four weeks in 2005-06. Data was recorded from 25 randomly selected heads from each row for 1000 grain weight, grains per spike and yield per spike during both the years. The data regarding survival (ability to stay green under heat stress) was also recorded. Heat effect was expressed as ratio of stressed / non stressed plants. The effects of heat stress were lesser in shorter period exposure and more drastic in prolonged exposure of the genotypes to heat. The ability of lines to stay green for longer period in heat shock had no direct relationship with seed setting. Three entries CB-367 (BB#2/ PT// CC/ INIA /3/ ALD'S') CB-333 (WL 711/3/KAL/BB//ALD 'S') and CB-335 (WL711/CROW 'S'//ALD#1/CMH 77A. 917/3/HI 666/PVN 'S') showed maximum grain development and survival. This study revealed that these genotypes can be utilized in breeding programs for development of wheat varieties having heat tolerance at terminal growth stage.

***Keywords**:* Bread wheat; Germplasm; Tunnel; Heat stress; Survival

Introduction

Wheat is a winter season crop grown in the tropics and subtropics despite the relatively high temperature that occur during the growth cycle. Heat stress is an important constraint to wheat productivity affecting different growth stages specially anthesis and grain filling. It has already been established that heat stress can be a significant factor in reducing the yield and quality of wheat (Stone & Nicolas 1995). In Pakistan terminal heat stress is a major reason of yield decline in wheat due to delayed planting. Similarly heat stress is a major challenge to wheat productivity in India (Joshi et al., 2007). Late planted wheat suffers drastic yield losses which may exceed to 40-50%. Therefore, there is a dire need to develop genotypes that are either tolerant to terminal heat stress or that mature early without yield losses and thus escape the stress. Terminal heat stress is a common abiotic factor for reducing the yield in certain areas of West Asia and North Africa (Ferrera et al., 1993). Heat tolerance thus should be essential characteristic of wheat cultivars to be developed. Stay green is a trait that has been used to indicate heat tolerance in hot environment (Acevedo et al., 1991, Kohli et al.,1991). Photosynthetic rate is maximum at 20-22^0C and

Table 1. Selected heat tolerant lines and their relative ratios for the characters studied (2004-05) in heat shock for two weeks.

ENTRY No.	Parentage	Grains/spike	1000 grain weight	Yield/ Spikes	Relative value
75	PBW 343	1.14	0.9	1.03	1.02
84	Inqilab/Fink's'	0.61	2.36	1.44	1.47
119	Kauz*2/Yaco//Kauz	0.85	0.9	0.92	0.89
121	PVN//CAR422/ANA/3/Kauz*2/TRAP//Kauz	1.19	0.91	1.08	1.06
124	PVN/YACO/3/Kauz*2/TRAP//Kauz	1.12	0.95	1.06	1.04
128	-DO-	1.02	0.88	0.9	0.93
136	ATTILA/3/HUI/CARC//CHEM/CHTO/4/ATTILA	1.06	0.93	0.98	0.99
149	FRET-1	1.04	0.88	0.91	0.95
198	CNO'S'/PJ62//ON1160.147/3/BB/GALLO	0.85	1.25	1.06	1.05
229	SKA/PRL'S'//YDING	1.28	0.91	0.98	1.06
230	SW 89.3064*2/BORL 95	0.90	1.02	0.92	0.95
232	LU26/3/KWZ/JB 216.67//SIS'S'	0.93	1.03	0.96	0.97
235	HD 2359/3/OVA=/AZ/MUS'S'	0.97	0.86	0.9	0.91
281	MAYA/PVN	0.94	0.96	0.9	0.93
330	KVZ/3/TOB/CTFN//BB/4/BLO'S'/5/VEE#5/6/BOW'S'/3/YDING'S'//BB/CHA	0.94	1.07	0.94	0.98
333	WL711/3/KAL/BB//ALD	1.26	0.93	1.17	1.12
335	WL711/CROW'S'//ALD#1/CMH77A.917/3/HI666/PVN'S	1.06	0.86	0.92	0.95
338	ZHONG 69/PRL'S'	1.06	0.88	0.91	0.95
340	WL711//ALD'S'/PVN'S'	1.71	0.78	1.33	1.27
369	CHIS/ALGER 86//HD2204/3/KVZ/TRM//PTM/INIA	1.0	1.03	1.02	1.02
385	HI 666/PVN'S'	1.1	0.82	0.9	0.94
395	BCN/4/RABI//GS/CRA/3/AENTRYSQ (190)	1.09	0.83	0.91	0.94
400	NEW CHENAB//HD2204/JUN'S'	1.0	0.9	0.9	0.93
402	CHEN/AENTRYSQ (205)//3* KUUZ"'S'	1.07	0.92	0.98	0.99
405	BOW/MOR//BAU	1.21	0.86	1.04	1.04
420	BAV 92//SAP/MOM	1.11	0.83	0.92	0.95
432	TRM//MAYA 74S/MON'S'/3/INQ 91	0.73	1.3	0.94	0.99
437	PND 88/BB'S'/T 0B-66	1.04	0.93	0.96	0.98

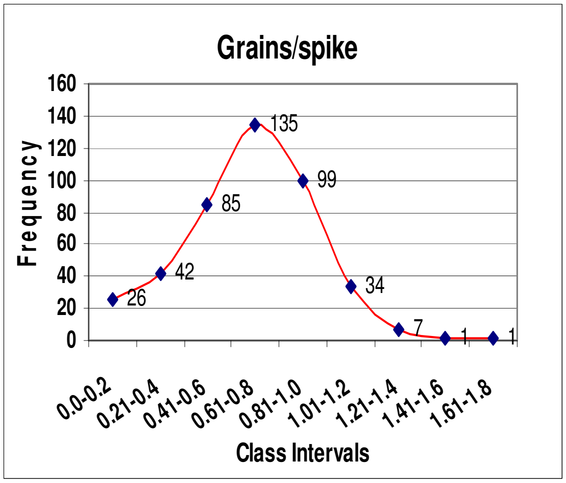

Fig 1a. Frequency Distribution of No. of Grains/spike under heat stress (2004-05).

decreases abruptly at 30-32^{0}C (Al Khatib & Paulsen 1999, Murata & Lyama 1963). Heat stress injuries of the photosynthetic apparatus during reproductive growth of wheat diminish source activity and sink capacity which results in reduced productivity (Harding et al., 1990). Source activity is damaged by heat because both leaf area (Herzog 1982, Slovacek & Hind 1981, Spiertz 1974) and photosynthesis is reduced (Al Khatib & Paulsen 1984, Kuroyanagi & Paulsen 1985). Heat injury limits sink growth potential particularly when stress is imposed during early sink developmental stages (Nicolas et al., 1984).

Grain yield was negatively related to the thermal time accumulated above the base temperature of 31^{0}C (Ferris et al., 1998, Mian et al., 2007). High temperature above 32^{0}C has been reported reducing grain yield and grain weight (Bluementhal et al., 1995, Gibson & Paulsen, 1999, Wardlaw et al., 2002). This study was conducted to find out sources of terminal heat tolerance in bread wheat germplasm for utilization in the breeding program.

Materials and methods

Bread wheat germplasm comprising of 442 varieties/lines was sown in a plastic sheet tunnel at Wheat research institute, Faisalabad during year 2004-05 and 2005-06. One set of the material was sown in the open adjacent to the tunnel. Each entry was sown in a single meter row by maintaining 30cm and 7.5cm inter and intra row spacing. Three seeds per hill were placed at the time of planting and then at two leaf stage, thinned to single seedling. NPK fertilizer was applied @ 100-85-0 kg/hectare. During the 1st year (2004-05) the experiment was sown on 1st December while in the next year (2005-06), the crop was planted on 10th November. All other standard agronomical practices were adopted. In 2004-05, the crop was exposed to heat stress by covering the tunnel with plastic sheet for two weeks (11th to 25th March). However, in 2005-06 the tunnel was covered for four weeks (25th February to 24th March) to expose the material to heat stress. Daily temperature inside and outside the tunnel was recorded and maintained above 32°C inside the tunnel. At maturity twenty five spikes from each entry were randomly selected for data recording and data for the following characters were recorded: 1) Grains/spike 2) 1000-grain weight 3) yield /spike The heat effects for each character were expressed as ratio of stressed/non-stressed (relative ratio) and for each variety/ line as relative value (mean of ratios of all entries for the characters studied). During 2005-06 data for plant survival (ability to stay green) was also recorded after 21 days exposure to heat stress. The capability to set seed/survival under heat stress for a longer period was regarded as heat tolerance.

Results

Population Behavior

As far as population behavior is concerned during the year 2004-05 when the material was exposed to heat stress for two weeks, the relative ratio for the characters studied i.e., grains per spike, 1000 grain weight and yield per 25 spikes showed normal curves (Fig 1a, 1b and 1c). Maximum number of entries (135) showed 0.61-0.80 relative ratio for grains per spike which means that they were able to maintain 61-80% of the grains per spike under heat stress as compared to the normal while the 153 entries produced even less grains per spike as their relative ratio was less than 61% and even there were some entries which had shown no seed formation under heat stress. There were 99 entries which showed 0.80-1.00 relative ratio. Some entries gave higher than 1.00 relative ratios which might be due to experimental error.

When these entries were exposed to heat stress for four weeks after anthesis in 2005-06, the nature of the

Table 2. Selected heat tolerant lines and their relative ratios for the characters studied (2005-06) under prolonged heat shock

ENTRY#	Parentage	Grains/spike	1000 grain weight	Yield/ Spikes	Relative value
17	CHAM 4	0.48	0.54	0.26	0.43
57	MEXIPAK 65	0.31	0.66	0.2	0.39
85	SHALIMAR 88	0.51	0.63	0.32	0.49
159	BAW 898	1.06	0.41	0.43	0.63
190	CMH 76A.912/CMH 76A.769	0.06	2.5	0.15	0.90
221	CHAT'S'	0.71	0.39	0.28	0.46
230	SW 89.3064 *2/BORL 95	0.29	0.44	0.13	0.29
241	CROW'S'/NAC//SA75/3/F3.71/TRM	0.46	0.51	0.24	0.40
281	MAYA/PVN	0.12	0.55	0.06	0.24
333	WL711/3/KAL/BB//ALD	0.32	0.57	0.18	0.36
335	WL711/CROW'S'//ALD#1/CMH77A.917/3/ HI 666 /PVN'S'	0.12	0.67	0.08	0.29
367	BB#2/PT//CC/INIA/3/ALD'S'	0.65	0.7	0.45	0.60
400	NEW CHENAB//HD 2204/JUN'S'	0.61	0.49	0.3	0.47
432	TRM//MAYA 74'S'/MONS/3/INQ 91	0.53	0.54	0.29	0.45
434	ALTAR84/AENTRYSQ(219)//OPATA/3/3*INQ 91	0.5	0.53	0.27	0.43
436	91B 2061/FSD 83	0.94	0.49	0.46	0.63
438	7C/FANG.60	0.63	0.44	0.27	0.45
440	CHENAB//HD 2204/JUN'S'	0.7	0.58	0.4	0.56

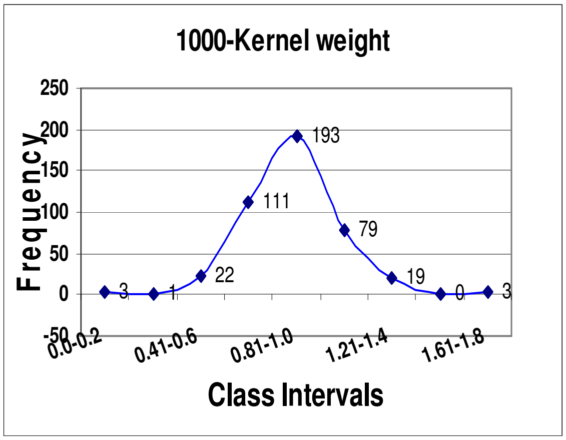

Fig 1b. Frequency Distribution of No. of 1000-grain weight under heat stress (2004-05).

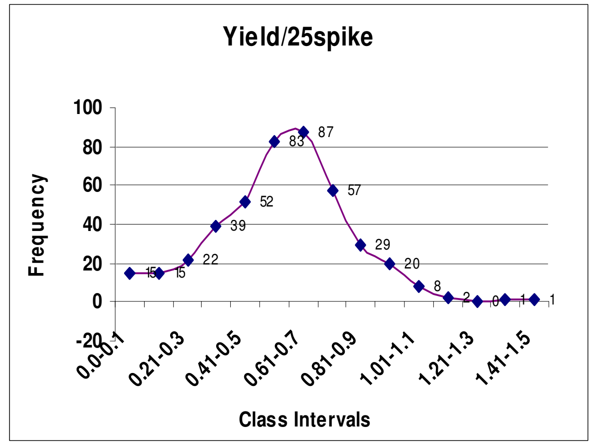

Fig 1c. Frequency Distribution of No. of Yield/25 spike under heat stress (2004-05).

curve was changed and different type of curve was obtained (Fig. 2a, 2b and 2c). Most of the entries had shown no seed formation. Only 57 entries were able to set seed. Out of which 21 entries showed relative ratio 0.0-0.2, 16 entries showed ratio 0.21-0.4, eight entries showed 0.41-0.60, six entries showed 0.61-0.80 and one entry showed greater than 0.80 relative ratio for number of grains per spike.

During 1st year of study when the heat shock was given for shorter period 26 entries showed less than 0.60 relative ratio for 1000 grain weight whereas in 111 entries this character was slightly affected / not affected as the relative ratio was 0.61-1.00 whereas many entries showed higher grain weight which might be due to lesser grain number per spike as compared to normal. None of the entries had shown relative ratio near to the unity for all the traits when the heat stress was applied for four weeks.

Similarly, grain yield was lesser affected under shorter heat stress period and drastically affected under longer heat shock. During shorter exposure 29 entries showed relative ratio near to unity. Whereas under longer exposure only 51 entries were able to give some yield. Only three entries were able to give 40-50% yield as their relative ratio was between 0.40-0.50 followed by 3 other which realized 0.30-0.40.

Staying Green Ability

It was observed that greenness in some lines was affected and some lines maintained this trait during two weeks exposure during 1st year. So, during the second year the data regarding ability to stay green under heat stress was recorded. After three weeks of stress period, seventy two entries were green and after four weeks, thirty seven entries were green while rest of the entries was dried out due to heat shock (Table 3). The comparison of heat susceptible and heat tolerant genotypes were shown in Fig 3.

Individual Line Behavior

Under heat shock some lines showed tolerance as their relative values were near to unity. Among these the especial behavior observed for the line; Entry numbers 84, 198,432 was that in spite of the effect on number of grain per spike (Table 1). They recovered after exposure and improved their grain weight to the level that their yields were near to unity but when exposed to shock for 4 weeks they were not able to recover and hence had shown very poor performance (Table 2). Four entries (Entry No. 333, 335,436, 347) have shown relative value and relative ratio for each character near to unity in shorter exposure and when exposed to heat shock for longer period (Table 4). Entry numbers 367 and 436 have shown better relative ratio for yield and over all relative value by maintaining grain no and grain weight to certain extent. However, the three entries (Entry No. 333,335 and 367) were able to stay green for three weeks under heat stress but entry numbers 436 was not able to remain green under heat shock and thus was forced

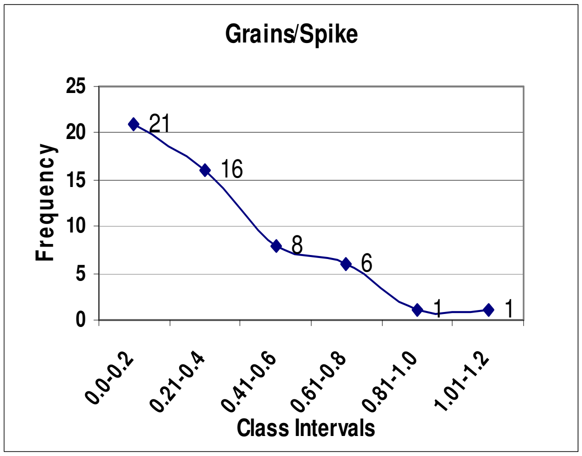

Fig 2a. Frequency Distribution of No. of grains/spike spike under heat stress (2005-06).

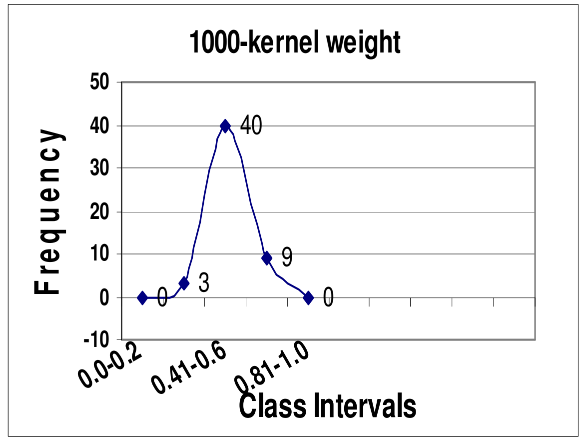

Fig 2b. Frequency Distribution of No. of 1000-grain weight spike under heat stress (2005-06).

to maturity as it is evident from the study that it maintained its grain number. However, its grain weight was reduced more than 50% under prolonged heat shock. This indicated that prolonged exposure to heat shock at grain development phase have severe effects on grain weight (Bluementhal et al.,, 1995; Gibson & Paulsen, 1999; Wardlaw et al., 2002).

Discussion

Population Behavior

Heat shock affected all the three characters when heat stress was applied for shorter period, the effects were less pronounced. When the length of application was extended during the 2nd year of study, only few entries survived and none of these showed normal grain weight. One entry showed exceptionally normal grain weight which might be due to escape. Similarly none of them have normal grain weight under heat stress for longer period. Whereas reasonably good number of entries showed normal grain weight under heat stress for shorter period while some of the entries showed higher grain weight under stress which might be due to component compensation effect (Khan 2003).

However yield was also affected under shorter exposure whereas much affected under heat shock for longer period. During the 1st year, some of the entries have shown better performance under short heat stress period because of heat shock recovery or escape phenomenon. Therefore during the second year, heat stress period was prolonged and there was no chance of recovery or escape. So, the yield in case of all the entries was drastically affected. Similarly, negative effects of heat stress on yield were reported by Ferris et al., (1998) and Mian et al., (2007).

Individual Line/ Variety Affect

Best performing entries under heat stress for two weeks are given in Table 1. These entries showed relative ratio/value near to unity. Relative value for each entry was calculated on the basis of its performance for the three characters. The relative ratio for each character was calculated and then was averaged to get relative value.

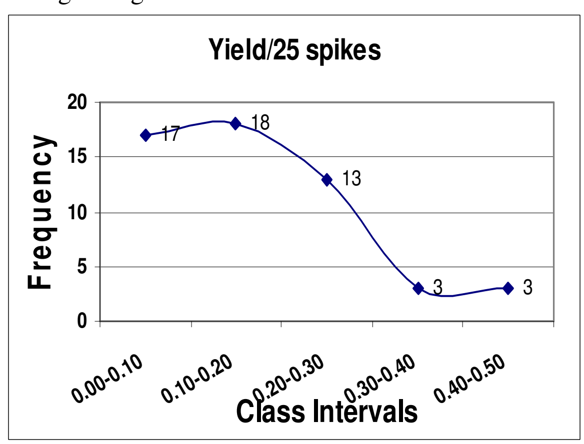

Fig 2c. Frequency Distribution of No. of yield/ 25spike spike under heat stress (2005-06).

Table 3. Lines remained green during heat stress imposed from 25.2.2006 to 24.3.2006

ENTRY#	Varity/ line	17.3.05 After 3 weeks	24.3.05 After 4 weeks
14	Chenab 79	✓	✓
19	CHILERO=CHIL'S'	✓	✓
24	FAISALABAD 85	✓	-
43	IQBAL2000	✓	-
44	KANCHAN	✓	-
46	KASYON/BOW'S'	✓	-
60	MILAN	✓	✓
61	MILAN/HD 832	✓	✓
76	PUNJAB 76	✓	-
80	SA 42	✓	✓
89	WATAN/2*ERA	✓	✓
98	NG8319//SHA4/LIRA	✓	-
101	SKAUZ*2//PRLII/CM65531	✓	-
116	RABE/6/WRM/4/FN/3*TH//K58/2*N/3/AUS-6869/5/PELOTAS-ARTHUR /7/2*RABE/8/LAJ 3302	✓	-
117	RABE/6/WRM/4/FN/3*TH//K58/2*N/3/AUS-6869/5/PELOTAS-ARTHUR /7/2*RABE/8/IRENA	✓	-
131	KAUZ*2/YACO//KAUZ	✓	✓
135	PFAU/WEAVER	✓	-
141	COMARA/TEG//WEAVER/3/ LAJ 3302	✓	✓
147	KAUZ/TSC//2*SKAUZ	✓	✓
157	ACONCHI-89	✓	-
158	MRB589-5	✓	-
162	WH542	✓	✓
165	ATRIS-2	✓	✓
172	HAAMA-11	✓	✓
196	MON'S'/ALD'S'	✓	✓
198	CNO'S'/PJ 62//ON.1160.147/3/BB/ GALLO	✓	✓
199	CONDOR'S'/ANA75//CONDOR'S'/ MUS'S'	✓	✓
200	BOBWHITE'S'	✓	-
201	BUTEO'S'	✓	-
209	KVZ/3/TOB/CFTN//BB/4/BLO'S'/5/ SNB'S'	✓	-
212	PRL'S'/PEW'S'	✓	-
213	SUNBIRD'S'	✓	✓
216	UP 262	✓	-

Table 3. Continued

226	MEISE	✓	✓
229	SKA/PRL'S'//YDING	✓	✓
232	LU26/3/KVZ/JB216-67//SIS'S'	✓	✓
233	BURGUS/SORT-12-13//KAL/BB/3/ PAK.81	✓	-
235	HD 2359/3/GOV/AZ//MUS'S'	✓	✓
243	NAPHAL/CONDOR	✓	✓
252	CH.70/6/KN.83//CH.70/ALD/5/CH.70/4/ INIA/CNO//CAL/3/LR/SON	✓	-
259	HAHN'S'	✓	✓
263	K338/EOCH//KUDIAT 17/KTY/3/ IMREN/4/6CGJ	✓	✓
265	PGO/SERI	✓	-
277	BOW'S'//CMH75A.142/3/CMH74A.487/ HD 2172	✓	-
281	MAYA/PVN	✓	✓
284	SKA/PANILA//YDING	✓	-
296	KAUZ//ALTAR84/AOS	✓	✓
313	VEE/KOEL//HEI/3*CNO79/3/SKAUZ	✓	✓
314	4777//FKN/GB/3/VEE'S'/4/BUC'S'/ PVN'S'	✓	-
317	BUC'S'/FLK'S'//MYNA'S'/VUL'S'	✓	-
319	PRL'S'/VEE#6//MYNA'S'/VUL'S'	✓	-
326	VS73.600/MRL'S'/3/BOW'S'//YR/TRF'S'	✓	✓
327	AMD/HN4/3/GTO/7C//BB/CNO67/5/PVN'S'/4/BB/CNO'S'//JAR/3/ORZ'S'/6/ TAN'S'/SNB'S'	✓	✓
329	CYUS'S'/MESCORIA/5/D68.11/3/GLL*2//T. DIC.V.VERN/4/DWL5023	✓	-
330	KVZ/3/TOB/CTFN//BB/4/BLO'S'/5/VEE#5/6/BOW'S'/3/YDING'S'//BB/CHA	✓	✓
332	VEE'S'/SNB'S'	✓	✓
333	WL711/3/KAL/BB//ALD	✓	-
335	WL711/CROW'S'//ALD#1/CMH77A.917/3/ HI 666/PVN'S'	✓	-
338	ZHONG 69/PRL'S'	✓	✓
346	UP262/PEW'S'//ALD'S'/PVN'S'	✓	✓
366	ALD'S'/PVN'S'	✓	✓
367	BB#2/PT//CC/INIA/3/ALD'S'	✓	-
368	KVZ/3/CC/INIA//CNO/4/EIGAO/SON64	✓	-
385	HI 666/PVN'S'	✓	✓
402	CHEN/AENTRYSQ.(205)//3*KAUZ"S"	✓	✓
415	ALTAR84/4/FG/3/GS/TC60//STK	✓	-
423	GA-2002	✓	✓
424	BLS//F3.71/TRM/3/SKA/PRL’S’//YDING	✓	-
431	CHIL/2*STAR/4/BOW/CROW//BUC/PVN/3/-	✓	✓
435	ZAGLOUL-1	✓	-

Table 4. Selected heat tolerant lines that stayed green and produced seeds

Sr. no.	Es. No.	Parentage	Grains/spike	1000grain weight	Yield	Relative Value
1	333	WL 711/3/KAL/BB//ALD = V-85054	0.79	0.74	0.67	0.73
2	335	WL 711/CROW "S"//ALD #1 / CMH 77A.917/3/HI 666/PVN 'S'	0.59	0.77	0.50	0.62
3	367	BB # 2/PT//CC/INIA/3/ALD 'S'	0.78	0.87	0.62	0.76
4	281	MAYA/PVN	0.53	0.75	0.48	0.59

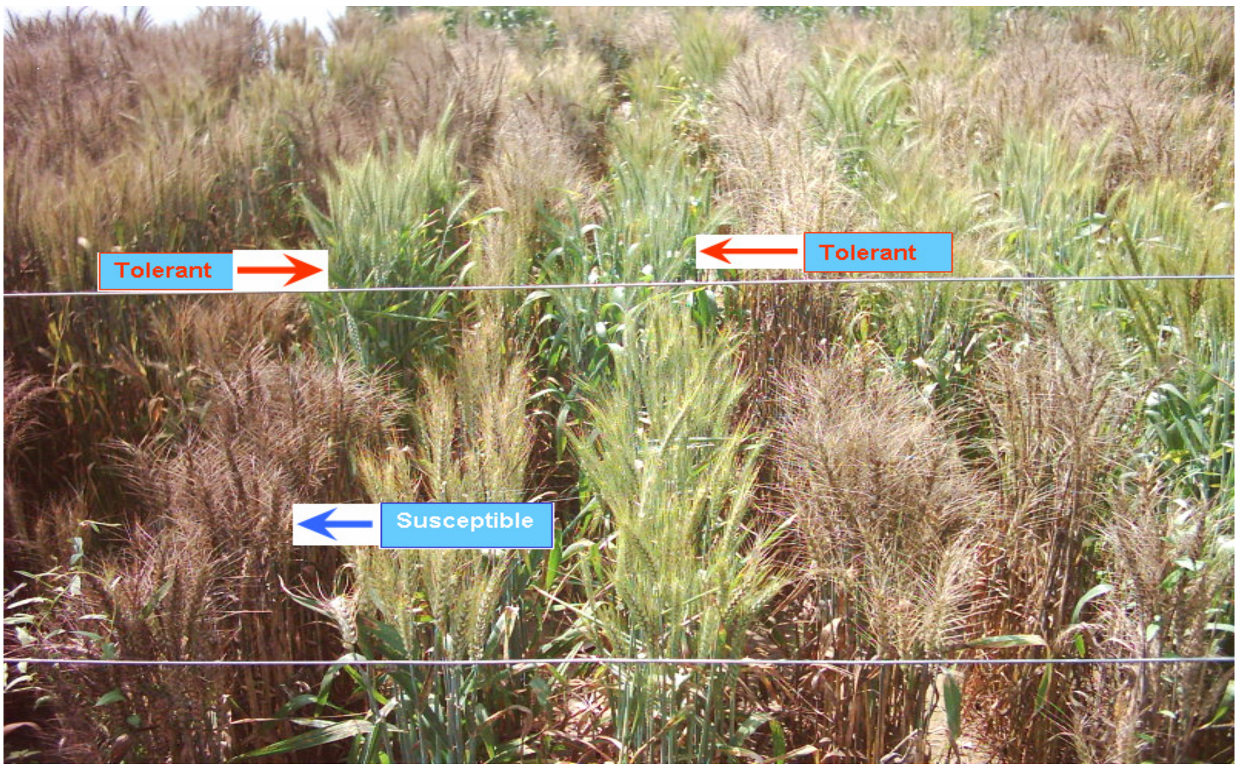

Fig 3. Heat tolerant and susceptible lines inside the plastic sheet tunnel

The lines showed relative ratios near to unity (1.00±0.1) and consequently their relative value near to unity. Some lines have shown unique behavior. Entry numbers 84,198,432 showed lesser number of grains per spike. However, when the heat shock was off, they improved their grain weight due to component compensation effect and ultimately their yield was normal under heat shock treatment. When the heat shock was applied for four weeks, none of the entries showed more than 50% of their yield potential. The relative ratio for yield was less than 0.50 for each entry. Three entries (Entry No. 367, 436) have shown better relative value 0.60-0.63 and relative ratio for yield i.e. 0.43-0.46. This was due to their ability to maintain grain number and grain weight under heat shock. Entry numbers 333 and 335 are not worth mentioning as they produced nominal yield after two and four week's exposure. Stay green had been used as a selection criterion in hot areas (Acevedo et al., 1991, Kohli et al., 1991). Many researchers (Al Khatib et al., 1991, Herzog et al., 1982) had reported negative affect of heat on plant. As far as relationship between the ability of the lines to stay green and their relative value is concerned, none of the lines that stayed green for four weeks were able to set seed in reasonable amount (Table 3). However, some entries (Entry No. 333, 336 and 367) which were able to set some seed also stayed green for three weeks. Many of the entries that produced good yield under heat stress were not able to stay green for three weeks. This might be due to the fact that these lines were forced to maturity after setting as much seed as possible. Therefore, the ability of a line to stay green has no direct relationship with seed setting. To develop heat tolerant lines, selection should be made on the basis of yield, grain weight and grain number per spike. High temperature effects on yield and grain weight had also been reported by Bluementhal et al., (1995), Wardlaw et al., (2002) and Mian et al., (2007).

Conclusion

This study concluded that most of the wheat genotypes were more affected when exposed to heat stress for longer period of time and vise versa. However, the genotypes vary in their ability to tolerate heat stress. Some genotypes had the capability to stay green for longer period under heat stress. There was no direct relationship of the ability of lines to stay green for longer period in heat shock and seed setting. Three entries CB-367 (BB#2/ PT// CC/ INIA /3/ ALD'S') CB-333 (WL 711/3 /KAL/BB//ALD 'S') and CB-335 (WL711/CROW 'S'//ALD#1/CMH 77A. 917/3/HI 666/PVN 'S') displayed the uppermost grain development and survival under the stress. This study revealed that these genotypes can be utilized in breeding programs for development of wheat varieties having heat tolerance at terminal growth stage.

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