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Temperature Regimes on Seeds Germination and Growth Parameters of Wheat (*Triticum aestivum* L.) Genotypes at Early Seedling Stage

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Abstract. To observe the effect of high temperatures stresses i.e., normal (25 °C), high (30 °C) and very high (35 °C) stress, on germination and seedling growth on wheat genotypes a water culture study was conducted under controlled conditions (growth incubators). Eighteen newly developed wheat lines (DH-I, DH-3, DH-4, DH-5, DH-6, DH-7, DH-8, DH-10, DH-11, DH-12, DH-13, DH-14, DH-15, DH-16, DH-18, DH-19, DH-20 and DH-21) were tested along with two local checks i.e., Kiran-95 and LU-26s. There was a gradual reduction in germination and seedling growth at 30 °C and 35 °C. Among the tested genotypes the genotype DH-16 showed least reduction i.e. only 2.27% reduction in germination at 35 °C. On the other hand the genotype DH-6 showed maximum reduction (28.09%) at 35 °C. High temperature stresses also affected on other growth parameters i.e. shoot and root length (cm), fresh and dry matter (g) of shoot and root and the moisture contents. It is based on relative reduction over control in various growth parameters at very high temperature stress (35 °C), four genotypes *viz*., DH-3, DH-5, DH-8 and DH-13 appeared as tolerant, nine genotypes i.e., DH-1, DH-4, DH-7, DH-10, DH-11, DH-14, DH-18, and LU-26s appeared as medium tolerant and two as medium sensitive i.e. DH-6 and DH-16. On the other hand six genotypes *viz*., DH-12, DH-15, DH-19, DH-20, DH-21 and Kiran-95 showed sensitivity 35 °C over 25 °C. It is therefore concluded that the genotypes DH-3, DH-5 and DH-13 can be cultivated on heat prone areas of Pakistan especially in Sindh province.

Keywords: temperature, wheat, germination, early seedling, growth

Introduction

Wheat (*Triticum aestivum* L.) is the most widely cultivated cereal in the World. It is grown in a wide range of environments but thrives best in temperate zones where is adequate rainfall and temperature (Bibinu and Gwadi, 2014). Wheat grains are main cereal which provided protein, energy minerals and vitamins to most of the population (Ahmed and Hassan, 2015). Wheat production can be increased through plantation of productive genotype, which better adjust in an agroclimatic condition.

The selection for grain yield improvement can only be effective, if necessary genetic variability is present in breeding materials (Ali *et al*., 2008). Multifarious types of environmental conditions contribute to big yield losses as they cause change in metabolism, thereby trigging the entire crop physiology (Arshad *et al*., 2008; Monclus *et al*., 2006; Lichtenthaler 1998). The growth and development of wheat is highly affected through high temperature and causes low yield in many regions of the world (Modarresi *et al*., 2010). The environmental stress such as high temperature are major abiotic stresses which seriously affect crop production (Roza *et al*., 2010).

The seed germination is basic component which contributes fluctuation in yield of the crop (Zhixia *et al*., 2014).Germination is depended upon the capability of seeds to utilize reserves extra efficiently (Rao and Sinha, 1993), through mobilization (Penning *et al*., 1979). Temperature is the most important factor for seeds germination, whereas it increases the rate of water absorption and substrates source which are compulsory for growth and development (Essemine

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et al., 2002; Wanjura and Buxtor, 1972). The favourable temperature is excellent for germination, however both low and high temperature directly effect from seeds germination to seeds maturation (Khan *et al*., 2007; Lobell and Monasterio, 2007).

Doubled haploids (DH) wheat plant has complete homozygosity and one generation from hybrid plants, in this process includes two major steps: haploid induction and chromosome doubling. In both steps the plant routinely and successfully performed by using colchicines (Zhixia *et al*., 2014). However in haploid cause crop species varies in success and efficiency but higher plants can occur spontaneously. They can also be artificially induced *in vivo* or *in vitro* by and rogenesis and gynogenesis (Zhixia *et al*., 2014).

The variances of genetic characters in wheat varieties have greater magnitude than environmental variances for most of the traits (Ikramullah *et al*., 2011). Similarly, (Anwar *et al*., 2007) suggested that higher yield productivity could be made through better agronomic strategies and breeding materials, whereas (Cerriet *et al*., 2007) reported that 3 to 5 °C high temperature and 11% increase in precipitation would decrease the productivity of wheat. Keeping in view the above constraints, the present project was initiated with the objective to screen out wheat genotypes as sensitive and tolerant to heat stress conditions based on germination percentage (%) and various allied physiological parameters against different temperature levels (25, 30 and 35 °C) in water culture under controlled laboratory.

Materials and Methods

Eighteen newly developed wheat genotypes (i.e. DH-I, DH-3, DH-4, DH-5, DH-6, DH-7, DH-8, DH-10, DH-11, DH-12, DH-13, DH-14, DH-15, DH-16, DH-18, DH-19, DH-20, DH-21), along with two commercial varieties(Kiran-95 and LU-26s) as local checks were studied for their high temperature tolerance at germination and early seedling stage. The study was conducted in water culture, using 1/4th strength Hoagland nutrient solution (Hoagland and Arnon, 1950) as cultural media in plastic molded bowls having nets (5 cm internal diameter and 2.5 cm depth). The chemical composition of Hoagland nutrient solution is presented in Table 1. Healthy seeds of all the wheat genotypes were surface sterilized for five minutes with 2.0% NaOH (sodium hypochlorite) and then washed thoroughly with distilled water to avoid any contamination. Thirty (30) seeds of each genotype were laid on plastic nets and the bowls were kept in dark in programmed controlled three separate growth incubators (Luminine cube II, ANALIS Model, LM-500), each one is pre adjusted at 25, 30 and 35 °C temperature treatments, respectively. The bowls were arranged in randomized manner using completely randomized design (CRD), with three replicates. The level of nutrient solution maintained regularly throughout the experiment. Germination was recorded after 72 h and then light programme was activated up to the termination of experiment for further seven (7) days and the experiment was terminated at after 10 days. Growth observations were recorded in terms of germination percentage, shoot and root length, fresh and dry weights of shoot and root. Germination percentage (%) was recorded after 24 hours, using the following formula:

$$\text{Germination (\%)} = \frac{\text{no. of seeds germinated}}{\text{total no. of seeds sown}} \times 100$$

The shoot and root length was measured by ruler in centimeter (cm) at the time of termination of experiment. Fresh weight of shoot and root was also recorded immediately in grams using electronic balance. Plant samples (shoot and root) were placed in hot air drying oven (65 ± 5°C) for 72 h to take shoot and root dry weights in gram (g) with electronic digital balance. Relative reduction in different growth parameters were calculated as:

$$\text{Relative reduction (\%)} = \frac{\text{values under optimal condition-values under heat stress condition}}{\text{values under optimal condition}} \times 100$$

$$\text{Shoot and root moisture contents (\%)} = \frac{\text{F. wt.} - \text{D. wt.}}{\text{F. wt.}} \times 100$$

Temperature stress indexes (germination stress index, shoot length stress index and root length stress index) were also calculated according to (Ashraf *et al*., 2008), using following formulas:

$$\text{GSI} = \frac{\text{PI of stress seeds}}{\text{PI of control seeds}} \times 100$$

$$\text{SLSI} = \frac{\text{shoot length of stressed plant}}{\text{shoot length of control plants}} \times 100$$

$$\text{RLSI} = \frac{\text{root length of stressed plant}}{\text{root length of control plants}} \times 100$$

The data was subjected to analysis of variance (ANOVA) and significant difference were measured according to Duncan multiple range test (DMRT), using Statixtic 8.1, computer package.

Results and Discussion

The mean square from analysis of variances showed that genotypes, treatments and genotypes x treatments were significant for all the traits (Table 2a) which indicated that genotypes performed differently across the temperature regimes. Our results are confirmed with Sikder and Paul (2010) they also reported that the wheat genotypes performed differently under different temperature for germination percentage, shoot/root fresh weight, shoot/root dry weight.

Seed germination (%). The present results showed that seed germination under different temperature was significantly reduced (Table 2b, column A). At 25 °C the genotypes like DH-10, DH-11, DH-14 and DH-15 recorded highest that is 100% seed germination and minimum (91.11%) seed germination was given by DH-4. At 30 °C, the maximum seed germination was 98.88% (DH-11 and DH-15), that showed at par response of statistically with DH-1, DH-5, DH-6, DH-14, DH-19 and DH-21 which had 97.77% seed germination, respectively. The minimum (86.66%) seed germination was observed in DH-4. At 35 °C the maximum seed germination was recorded in genotype DH16 i.e., 95.55%, while minimum seed germination was observed in genotype DH-6 i.e., 71.11%. The mean seed germination was observed to be 98.00% at 25 °C (95.44%) followed by 300C (95.44%) and 35 °C (85.12%). It is evident from the result that a significant decreasing trend in germination percenage was observed as the temperatures increased (Table 2b, Column A, last row). The present findings can partially be compared with Buriro *et al*. (2011) who reported more than 90% germination at 10-30 °C. The maximum percentage reduction in seed germination was 28.09% at 35 °C over 25 °C in DH-6 followed by DH-13, DH-7, DH-21, DH-12, DH-15, and DH-1 with 26.13, 21.35, 20.23, 19.10, 16.67 and 15.73% reduction, respectively. The present findings can be compared safely with those of Sikder and Paul (2010) who evaluated three temperature levels (16, 26 and 36 °C) on germination rate in wheat cultivars and reported an increasing trend in germination at 16 to 26 °C and respiration loss increased at higher temperatures (26-36 °C).

Shoot fresh weight (g). The shoot fresh weight was reduced significantly at 30 °C and 35 °C as compared to 25 °C in all the genotypes. The temperature effect on cumulative basis revealed significant difference (Table 2b, column B). Mean shoot fresh weight was recorded as 4.01 g in 25 °C whereas, the lowest 1.81 g in 35 °C treatment. At 25 °C the genotype DH-5 showed maximum shoot fresh weight i.e. 4.83g; however the genotype DH-18 showed minimum shoot fresh weight i.e. 3.45 g and was statistically at par with DH-15 i.e. 3.48 g. At 30 °C the shoot fresh weight was recorded as maximum in DH-4 (3.39 g) while minimum

Table 1. Chemical composition of Hoagland nutrient solution

Compound	Formula	Stock solution (g/L)	Stock solution (cc) (mL)
A. Macro nutrients			
Potassium nitrate	KNO_3	101	12
Calcium nitrate	$Ca\ (NO_3)_2\ 4H_2O$	236	08
Ammonium phosphate	$NH_4H_2PO_4$	115	04
Magnesium sulphate	$MgSO_47H_2O$	246	02
B. Micronutrients			
Potassium chloride	KCl	0.37	2
Boric acid	H_3BO_3	0.15	2
Manganese sulphate	$MnSO_4H_2O$	0.03	2
Zinc sulphate	$ZnSO_47H_2O$	0.06	2
Copper sulphate	$CuSO_4\ 5H_2O$	0.01	2
Molybalic acid	MO_4	0.01	2
Iron sulphate	$FeSO_4\ 7H_2O$	0.05	2

value was observed in genotype DH-7 (1.82 g). At 35 °C the shoot fresh weight was recorded as maximum in DH-5 (2.87 g), while minimum value was observed in genotype Lu-26s (1.11 g). The maximum percentage reduction in shoot fresh weight was 73.25% in LU-26s at 35 °C over 25 °C whereas showed minimum shoot fresh weight was i.e. 37.09% in DH-4. The present findings can be compared in broader sense with those of Cerri *et al*. (2007) who reported that increase in temperature above threshold would cause decline in agricultural production. The present research achievements are in close conformity with Khajam *et al*. (2011), Akbar and Jaime (2012) and Lack *et al*. (2013) who reported that heat stress conditions exerted adverse effects on the biological growth of wheat.

Shoot dry weight (g). It is evident from the results (Table 2b. column C) the shoot dry weight was significantly affected under different temperature levels. The mean shoot dry weight was recorded high value in 25 °C (0.38g) followed in 30 °C (0.33g) and 35 °C (0.26g), respectively. At 25 °C that DH-3 showed maximum shoot dry weight i.e. 0.46 g, while the genotype DH-20 had minimum shoot dry weight i.e. 0.29 g and did not show significant difference with those of found on DH-7, DH-12 and DH-21 with 0.31 g shoot dry weight in each. At 30 °C the genotype DH-3 was recorded maximum shoot dry weight i.e. 0.45 g, while DH-7 showed minimum shoot dry weight i.e. 0.25 g. At 35 °C the maximum shoot dry weight was recorded in DH-5 (0.38g), whereas LU-26s and Kiran-95 showed minimum shoot dry weight (0.10 g each). The minimum reduction in shoot dry weight was recorded as 6.45% in DH-12, whereas maximum i.e. 51.28% in Kiran-95 at 35 °C over 25 °C treatment. The present findings are not in conformity with those of Tahir *et al*. (2008) who stated that shoot growth was not affected at high root zone temperature. According to Sikder and Paul (2010) they reported that shoot dry weight increased at 16 to 26 °C as compared to 26-36 °C.

Root fresh weight (g). Based on interactional response, among genotypes and temperatures, the root fresh weight decreased significantly on increasing temperature (Table 2c, column D), the on an average mean effect of various temperatures revealed significant differences. The maximum (2.65 g) root fresh weight was recorded in 25 °C, whereas minimum (0.75 g) root fresh weight was noted in 35 °C. Among the genotypes, DH-19 exhibited maximum (3.77g) root fresh weight observed

Table 2a. Analyses of variance of the data regarding various growth parameters in genotypes of wheat at different temperature regimes at early seedling stage

SOV	DF	Germination (%)		Shoot fresh weight (g)		Shoot dry weight (g)		Root fresh weight (g)		Root dry weight (g)		Shoot moisture content (%)		Root moisture content (%)	
		MS	FR	MS	FR	MS	FR	MS	FR	MS	FR	MS	FR	MS	FR
Temperatures (T)	2	2791.359	1323.12**	73.188	113862.16**	0.231	1736.95**	55.713	275504.06**	0.151	1331.43**	447.934	1530.24**	1158.273	1384.89**
Genotypes (G)	19	64.878	30.75	1.494	2323.62	0.024	180.64	0.751	3715.59	0.013	117.90	16.353	55.86	62.365	72.63
G X T	38	53.964	25.58	0.170	264.31	0.003	24.36	0.448	2212.92	0.006	49.39	9.68	33.06	16.321	18.90
Error	120	2.11	0.001	0.00016	0.00016	0.00008	0.293	0.859							

SOV	DF	Shoot length (cm)		Root length (cm)		Shoot length stress index (%)		Root length stress index (%)		
		MS	FR	MS	FR	MS	FR	MS	FR	
Temperatures (T)		2	231.293	1117.30**	847.185	2850.97**	156375.989	28116.03**	99168.567	6439.09**
Genotypes (G)	19	43.117	208.29**	18.038	60.70**	95.455	17.16**	216.51	14.06**	
G X T	38	3.131	15.12**	3.573	12.03**	74.296	13.36**	140.310	9.11**	
Error	120	0.207		0.297		5.562		15.401		

** = significant at P < 0.01; DF = degrees of freedom; MS = mean square; FR = fractional ratio.

in 25 °C, and fluctuated significantly in all other genotypes and temperature treatments whereas, the genotype DH-7 showed minimum root fresh weight i.e. 2.02 g in 25 °C treatment and also differed significantly from other treatments as well as genotypes. The maximum reduction of 86.14% in root fresh weight was recorded in LU-26s at 35 °C over 25 °C, while DH-3 showed minimum (44.19%) reduction in root fresh weight at 35 °C over 25 °C. Present result is suggested that increase in temperature which resulted significant decrease in root fresh weight. Our findings are in conformity with Anwar *et al*. (2000) and Tahir *et al*. (2008) who observed that maximum reduction in root length and weight was noted under high root zone temperature.

Root dry weight (g). The different temperature regimes cause significant reduction in root dry weight (Table 2c column E). Based on interactional responses, among the genotypes, the mean wise maximum (0.21 g) root dry weight was recorded at 25 °C which is significantly reduced in 30 °C and 35 °C with 0.14 and 0.12 g in root dry weight, respectively. DH-16 showed maximum root dry weight of 0.34 g at 25 °C which is fluctuate statistically in all the other genotypes in same treatment as well as in other treatments like 30 °C and 35 °C. The minimum (0.12 g) root dry weight was noted in DH-7 at 25 °C, while other genotypes like DH-10, DH-12, DH-13, DH-4 and DH-3 they did not show significant differences at 30 °C treatment their root dry weight ranged from 0.13 to 0.15 g. The root dry weight was significantly reduced at 35 °C in all the genotypes. DH-15 showed maximum reduction in root dry weight i.e. 70.97% at 35 °C over 25 °C. The minimum reduction of 15.38% in root dry weight was recorded in genotypes DH-10 and DH-13. The present findings are in conformity with Sikder and Paul (2010) who reported that at higher temperature like 26-36 °C, root dry weight was dramatically reduced. Camacho and Caraballo (1994) reported that root dry weight was identified as

Table 2b. Temperatures effect on plant growth parameters in various genotypes of wheat under water culture experiment from column A to C

Genotypes	Seed germination (%) (A)				Shoot fresh weight (g) (B)				Shoot dry weight (g) (C)			
	Interactional response (LSD at 5% = 2.34)			(%) Reduction	Interactional response (LSD at 5% =0.05)			(%) Reduction	Interactional response (LSD at 5% =1.445E-02)			(%) Reduction
	25 °C	30 °C	35 °C	at 35°C over 25°C	25 °C	30 °C	35 °C	at 35°C over 25°C	25 °C	30 °C	35 °C	at 35°C over 25°C
DH-1	98.89 AB	97.77 ABC	83.33 M	15.73	4.61 B	2.90 OP	2.25 W	51.19	0.42 C	0.37 GH	0.32 MNO	23.81
DH-3	95.55 CDE	94.44 DEF	89.99 HIJ	5.82	4.66 B	3.39 K	2.65 S	43.13	0.46 A	0.45 AB	0.37 HI	19.57
DH-4	91.11 GHI	86.66 KL	83.33 M	8.54	4.26 C	3.09 M	2.68 RS	37.09	0.40 EF	0.40 DEF	0.37 HI	7.50
DH-5	98.89 AB	97.77 ABC	86.67 KL	12.36	4.83 A	3.34 L	2.87 P	40.58	0.45 AB	0.41 CDE	0.38 GH	17.78
DH-6	98.89 AB	97.77 ABC	71.11 O	28.09	4.15 D	2.53 T	1.33	67.95	0.44 B	0.35 JK	0.29 PQR	34.09
DH-7	98.88 AB	92.22 FGH	77.77 N	21.35	3.75 H	1.82	1.39	62.93	0.31 NOP	0.25 T	0.21UVW	32.26
DH-8	97.77 ABC	95.55 CDE	85.55 LM	12.50	3.58 I	2.38 V	1.90 Z	46.93	0.37 GH	0.29 QR	0.25 T	32.43
DH-10	100.00 A	92.22 FGH	91.11 GHI	8.89	3.92 F	2.95 O	2.45 U	37.50	0.39 F	0.33 L	0.30 OPQ	23.08
DH-11	100.00 A	98.88 AB	85.55 LM	14.45	4.23 C	3.03 N	2.06 Y	51.30	0.37 GH	0.37 GHI	0.33 LM	10.81
DH-12	98.88 AB	96.66 BCD	79.99 N	19.10	3.70 H	2.78 Q	1.74	52.97	0.31 NOP	0.30 PQR	0.29 PQR	6.45
DH-13	97.77 ABC	94.44 DEF	72.22 O	26.13	3.82 G	2.87 P	2.18 X	42.93	0.39 F	0.32 LMN	0.29 QR	25.64
DH-14	100.00 A	97.77 ABC	91.11 GHI	8.89	3.58 I	2.47 U	1.26 a	64.80	0.36 HIJ	0.27 S	0.21WX	41.67
DH-15	100.00 A	98.88 AB	83.33 M	16.67	3.48 J	2.13 X	1.39	60.06	0.45 AB	0.31 OPQ	0.22 U	51.11
DH-16	97.77ABC	96.66 BCD	95.55 CDE	2.27	4.07 E	2.72 R	1.63	59.95	0.39 FG	0.32MNO	0.21 UV	46.15
DH-18	96.77BCD	92.22 FGH	89.99 HIJ	7.01	3.45 J	2.27 W	1.12 b	67.54	0.34 KL	0.29 QR	0.21 Y	37.62
DH-19	98.88AB	97.77 ABC	88.88 IJK	10.11	4.25 C	2.88 P	1.77	58.35	0.41 CD	0.30 OPQ	0.20 VWX	51.22
DH-20	97.77 ABC	96.66 BCD	86.66 KL	11.36	3.57 I	2.46 U	1.33	62.75	0.29 PQR	0.28 RS	0.17 Y	41.38
DH-21	98.88 AB	97.77 ABC	78.88 N	20.23	3.90 F	2.44 U	1.53	60.77	0.31 NOP	0.29 PQR	0.20 VWX	35.48
LU26s	94.44 DEF	91.11 GHI	87.99 JKL	6.83	4.15 D	2.68 RS	1.11 b	73.25	0.36 IJ	0.32 LMN	0.19 WX	47.22
Kiran-95	98.88 AB	95.55 CDE	93.33 EFG	5.61	4.18 D	2.81 Q	1.63	61.00	0.39 FG	0.29 PQR	0.19 X	51.28
Means	98.00 A	95.44 B	85.12 C		4.01 A	2.70 B	1.81C		0.38 A	0.33 B	0.26 C	
(LSD at 5%)		0.52				1.14				3.23E-03		

The mean in the same column and the same rows sharing the same letters did not differ significantly.

the major criterion for selection of wheat genotypes under temperature stress conditions.

Shoot moisture content (%). The Table 2c. of column F, showed that different temperature regimes caused lower in shoot moisture content. Further results revealed at room temperature i.e.25 °C showed highest (90.48%) shoot moisture contents whereas minimum (85.01%) shoot moisture contents was recorded at 35 °C. The genotype like DH-21 showed maximum (92.16%) shoot moisture content which was at par statistically with DH-7, DH-20, LU-26s and DH-12 having 91.74, 91.65, 91.44 and 91.61% moisture contents in 25 °C, respectively. The minimum shoot moisture content was 81.92% in DH-15 and differed significantly in all other genotypes at 25 °C. A significant reduction in shoot moisture content was recorded in 30 °C and 35 °C treatments in all the genotypes with more or less variation. The shoot moisture content percentage reduction decreased as the temperature increased. DH-6 showed maximum reduction i.e. 14.36% in 35 °C over 25 °C. The minimum reduction of shoot moisture content i.e., 1.64% was observed in DH-19 in 35 °C over 25 °C treatments. Okçu *et al*. (2005) reported that temperature stresses depressed the shoot growths of the cultivars rather than their root growth. Walters (1998) reported that temperature and moisture play a significant role in determining the storage longevity of seeds.

Root moisture contents (%). Based on interactional response among genotypes and various temperatures, the Table 2d. column G, showed that on an average mean of all the genotypes under various temperature treatment like 25 °C, 30 °C and 35 °C, the treatment one (25 °C) showed maximum (92.10%) root moisture content whereas in treatment three (35 °C) the root moisture content was reduced in minimum i.e. 83.49%. The treatment two (30 °C) showed intermediate trend having 89.32% root moisture contents and differed significantly from other treatment. It is evident that maximum root moisture content was observed on DH-5 i.e. 94.46% and did not differ significantly with DH-1, DH-3, DH-4, DH-7, DH-8, DH-11, DH-12 and DH-13 having 93.44, 93.01, 92.70, 94.23, 93.40, 93.26, 93.15 and 93.02% root moisture contents, respectively in 25 °C. The minimum root moisture content was 90.30% in DH-16 and differed significantly in all other genotypes at 25 °C. The percentage reduction in root moisture at 35 °C over 25 °C revealed that the genotype DH-18 possessed maximum root moisture (22.12%) followed by DH-14, LU-26s and Kiran-95 with 15.47, 13.83 and 13.41%, respectively. Sikder and Paul (2010) also reported higher root moisture contents percentage at optimum temperature in wheat. Mahan *et al*. (1995) observed that thermal stress influence morphology and physiology of the root system which may influence water movement through the plant.

Shoot length (cm). The shoot length was reduced significantly at 30 °C and 35 °C as compared to 25 °C in all the genotypes (Table 2d. column H). Mean shoot length at 25 °C was recorded as 18.43 cm and was reduced to 17.50 and 14.66 cm at 30 °C and 35 °C, respectively. The genotype LU-26s possessed maximum shoot length 22.02 cm in 25 °C and the minimum shoot length was found to be 14.43 cm in DH-8. In 30 °C the minimum shoot length was 11.51 cm in DH-7 and the maximum is 21.68 in LU-26s. In 35 °C which showed minimum 10.89 cm shoot length and the maximum is 19.71 in LU-26s. Based on percentage reduction in 35 °C over 25 °C, it is evident that the genotype DH-6 and DH-3 showed maximum reduction in shoot length i.e. 36.83 and 30.86%, respectively. The present findings can be compared in big sense with those of Hasan *et al*. (2004) also reported that from a low temperature to high temperature (15 to 30 °C), the shoot length of wheat seedlings showed an increasing tendency.

Root length (cm). The results regarding the effect of different temperature on the root length (Table 2d. column I) revealed that maximum average mean root length was recorded in 25 °C treatment (15.72 cm), while it was minimum in 35 °C treatment i.e. 8.24 cm. the root length was 12.64 cm in 30 °C and all the treatments differed significantly with one another. At 25 °C, genotype DH-21 showed maximum root length i.e. 17.22 cm, while the genotype DH-6 and DH-10 possessed minimum root length showing 13.73 and 13.60 cm. All other genotypes were found intermediate between maximum and minimum. The effect of 35 °C on the root length was more pronounced as compared to 30 °C and 25 °C treatments. The maximum percentage reduction in root length was recorded to be 62.00% in genotype DH-6 in 35 °C over 25 °C. The minimum root length reduction was recorded to be 37.35% in DH-14 in 35 °C over 25 °C. The present findings support the results of present experiment with Sikder and Ahmed (2007) also found that root length of different wheat genotypes failed to increase under higher temperature (32 °C).

Table 2c. Temperatures effect on plant growth parameters in various genotypes of wheat under water culture experiment from column D to F

Genotypes	Root fresh weight (g) (D)				Root dry weight (g) (E)				Shoot moisture contents (%) (F)			
	Interactional response (LSD at 5% = 7.3029E-03)			(%) Reduction at 35°C	Interactional response (LSD at 5% =1.4459E-02)			(%) Reduction at 35°C	Interactional response (LSD at 5% =0.905)			(%) Reduction at 35°C
	25 °C	30 °C	35 °C	over 25°C	25 °C	30 °C	35 °C	over 25°C	25 °C	30 °C	35 °C	over 25°C
DH-1	2.57 J	1.71 T	0.80 DE	68.87	0.17 HIJ	0.15 JKLMN	0.12 QRSTU	29.41	90.97 BCDEFG	86.97 RSTUVWX	85.84 YZ	5.64
DH-3	2.15 L	1.59 U	1.20	44.19	0.15 JKLMN	0.14 MOPQR	0.12 QRTU	20.00	90.20 FGHIJ	86.66 UVWXYZ	86.00 XYZ	4.67
DH-4	2.14 LM	1.69 T	0.91 B	57.48	0.14 KMNO	0.14 MOPQR	0.11 STUV	21.43	90.70 CDEFGH	86.98 RSTUVWX	86.23 WXYZ	4.93
DH-5	3.12 F	1.84 Q	1.08	65.38	0.17 HI	0.16 IJKL	0.13 OPQRS	23.53	90.62 DEFGH	87.64 QRSTU	86.78 TVWXY	4.24
~~DH-6~~	~~1.75 S~~	~~0.86 C~~	~~0.54 I~~	~~69.14~~	~~0.14 MOPQ~~	~~0.12 PQRSTU~~	~~0.09 YZ~~	~~35.71~~	~~89.33 JKLM~~	~~85.93 XYZ~~	~~76.50~~	~~14.36~~
DH-7	2.02 N	1.05	0.49 J	75.74	0.12 RSTUV	0.11 TUVW	0.08	33.33	91.74 AB	84.54	84.25	8.16
DH-8	2.13 M	1.47 X	0.78 E	63.38	0.14 LNOP	0.12 RSTUV	0.11UVWX	21.43	89.55 IJKL	87.74 PQRST	86.63 UVXYZ	3.26
DH-10	1.97 O	1.46 X	0.72 F	63.45	0.13 NPQR	0.12 QRSTU	0.11 STUV	15.38	90.05 GHIJ	88.52 LMNOPQ	87.59 QRSTUV	2.73
DH-11	2.27 K	1.69 T	0.97 A	57.27	0.15 JKLM	0.14 LMNOP	0.12RSYUV	20.00	91.09 BCDEF	87.76 PQRST	84.08	7.70
DH-12	1.91 P	1.46 X	0.56 I	70.68	0.13 OPQRS	0.12 QRSTU	0.08 Z	38.46	91.61 ABCD	89.31 JKLM	82.39	10.06
DH-13	1.81 R	1.30 Z	0.57 I	68.51	0.13 OPQRS	0.12 QRSTU	0.11 UVWX	15.38	89.67 HIJK	88.71 KLMNOP	86.43 WXYZ	3.61
DH-14	2.88 H	1.25	0.65 G	77.43	0.27 EF	0.20 G	0.15JKLM	45.12	89.95 GHIJ	88.93 KLMN	83.29	7.41
DH-15	3.28 E	1.35 Y	0.65 G	80.18	0.31 BC	0.16 JKL	0.09 YZ	70.97	86.92 STVWX	85.65 Z	84.33	2.98
DH-16	3.47 B	1.21	0.93 B	73.20	0.34 A	0.14 LMNOP	0.12 RSTUV	64.71	90.57 EFGHI	87.99 OPQR	87.06 RSUVW	3.80
DH-18	2.61 I	1.03	0.50 J	80.84	0.27 F	0.18 H	0.15JKLMN	44.44	90.25 EFGHIJ	87.24RSTUVW	81.61	9.58
DH-19	3.77 A	1.60 UV	1.14	69.76	0.30 CD	0.17 HIJ	0.16 IJK	46.67	90.34 FGHIJ	89.36 JKLM	88.86 KLMNO	1.64
DH-20	3.08 G	1.29 Z	0.64 G	79.22	0.29 D	0.13 OPQRST	0.10 WXYZ	65.52	91.65 ABC	88.36 MNOPQ	86.88 STVWX	5.20
DH-21	3.36 C	1.61 U	0.60 H	82.14	0.31 BC	0.17 HIJ	0.10 WXYZ	67.74	92.16 A	87.85 OPQRS	86.56VWXYZ	6.08
LU26s	3.32 D	1.08	0.46 K	86.14	0.29 DE	0.21 G	0.17 HI	40.70	91.44 ABCDE	88.06 OPQRS	82.88	9.36
Kiran-95	3.34 D	1.52 W	0.82 D	75.45	0.32 B	0.12 QRSTU	0.09 XYZ	58.62	90.70 CDEFGH	89.44 JKL	88.37 MNOPQ	2.57
Means	2.65 A	1.41 B	0.75 C		0.21 A	0.14 B	0.12 C		90.48 A	87.67 B	85.01 C	
(LSD at 5%)		4.572E-03				3.2332E-03				0.195		

The mean in the same column and the same rows sharing the same letters did not differ significantly.

Table 2d. Temperature effect on plant growth parameters in various genotypes of wheat under water culture experiment from column G to I

Genotypes	Root moisture contents (%) (G)				Shoot length (cm) (H)				Root length (cm) (I)			
	Interactional response (LSD at 5% = 1.498)			(%) Reduction at 35°C over 25°C	Interactional response (LSD at 5% =0.735)			(%) Reduction at 35°C over 25°C	Interactional response (LSD at 5% =0.881)			(%) Reduction at 35°C over 25°C
	25 °C	30 °C	35 °C		25 °C	30 °C	35 °C		25 °C	30 °C	35 °C	
DH-1	93.44 AB	91.13 EFGHI	84.88 STU	9.16	14.61 PRST	14.10STUV	13.04 WX	10.75	16.76 AB	13.61 IJK	9.69 QRS	42.22
DH-3	93.01 ABCD	90.98 EFGHI	89.00 JKLMN	4.31	19.73 E	18.34 GHI	13.64 VW	30.86	16.61 AB	11.96 N	6.82 V	58.93
DH-4	92.70 ABCDE	92.07 BCDEF	87.14 OPQR	6.00	18.73 FG	18.32 GHI	15.13OPQR	19.24	15.22 DEF	13.97 HIJ	7.32 UV	51.52
DH-5	94.46 A	91.50 CDEFG	88.07 LMNOP	6.76	18.20 GHIJ	17.71 IJK	14.85 PQRS	18.39	13.29JKLM	10.13 OPQR	7.02 V	47.17
~~DH-6~~	~~91.80 BDEFG~~	~~85.63 RST~~	~~83.75 UV~~	~~8.77~~	~~19.88 E~~	~~18.20 GHIJ~~	~~12.56 X~~	~~36.83~~	~~13.73 IJK~~	~~7.33 UV~~	~~5.22 W~~	~~62.00~~
DH-7	94.23 A	87.15 OPQR	83.41 UV	11.48	14.68PRST	11.51 Y	10.89 Y	25.81	14.89 FGH	11.02 O	8.47 T	43.12
DH-8	93.40 AB	92.02 DEF	86.16 QRS	7.75	14.43RTUV	12.77 X	12.64 X	12.41	14.53 FGHI	12.34 MN	9.06 ST	37.63
DH-10	93.19 BCD	91.72 BCEFG	84.11 TUV	9.74	20.73 CD	20.15 DE	14.90 PQRS	28.14	13.60 IJK	9.15 RST	6.63 V	51.24
DH-11	93.26 ABC	91.58 CDEFG	87.96 LMNO	5.68	20.08 DE	19.66 E	14.79 PRST	26.35	14.81 FGH	13.44 JKL	9.68 QRS	34.62
DH-12	93.15 ABCD	91.64 BCEFG	84.29 TUV	9.51	21.64 B	21.26 ABC	15.48 OP	28.47	14.94 FGH	12.07 N	5.65 W	62.21
DH-13	93.02 ABCD	90.99 EFGHI	80.27 W	13.71	16.64LMN	15.94 NO	14.66PQRST	11.88	16.16 BCD	10.70 OP	9.76PQRS	39.58
DH-14	90.53FGHIJ	84.26 TUV	76.53 Y	15.47	14.93 PQRS	13.96 TUV	13.14 WX	12.01	16.33 ABC	14.09 GHIJ	10.23OPQ	37.35
DH-15	90.58 FGHIJ	88.45 KMNO	86.18 QRS	4.86	17.85 HIJK	17.11 KLM	14.50 QSTU	18.75	16.79 AB	15.50 CDEF	9.04 ST	46.18
DH-16	90.30 FGHIJ	88.42 KMNO	87.60 NOPQ	2.99	21.11 BC	19.81 E	16.69 LMN	20.94	16.26 ABC	15.10 EFG	9.18RST	43.55
DH-18	89.66HIJKL	82.80V	69.82 Z	22.12	19.70 E	17.37 JKL	16.47 MN	16.40	16.65 AB	13.25JKLM	9.18 RST	44.86
DH-19	92.05 BCDEF	89.50 IJKLM	86.64 PQR	5.88	19.48 EF	19.38EF	15.93 NO	18.21	16.69 AB	12.51 LMN	8.33 T	50.07
DH-20	90.60 FGHIJ	90.11GHIJK	83.29 UV	8.07	18.12 GHIJ	17.85 HIJK	15.10 PQR	16.68	16.06BCDE	12.74KMN	6.88 V	57.17
DH-21	90.87 FGHI	89.67 HIJKL	83.73 UV	7.89	17.34 JKL	16.72 LMN	13.73 UVW	20.81	17.22 A	15.50 CDEF	8.23 TU	52.20
LU26s	91.41DEFGH	87.77 MNOPQ	78.76 X	13.83	22.02 A	21.68 AB	19.71 E	10.49	17.11 AB	13.54 FGH	10.29 M	39.85
Kiran-95	90.41 FGHIJ	89.01 JKLMN	78.28 X	13.41	18.60 GH	18.19 GHI	15.32 OPQ	17.67	16.77 AB	14.83IJK	8.18 OPQ	51.19
Means	92.10 A	89.32 B	83.49 C		18.43 A	17.50 B	14.66 C		15.72 A	12.64 B	8.24 C	
LSD at 5%		0.335				0.164				0.197		

The mean in the same column and the same rows sharing the same letters did not differ significantly.

Shoot length stress index (%). The Table 3, of column A, showed that if the temperature increases that causes significantly reduction in shoot length stress index (SLSI) further it was evidence from the mean results which showed that 30 °C showed SLSI i.e. 94.59% whereas minimum i.e. 80.60% SLSI in 35 °C treatment. The genotype DH-20 had maximum SLSI i.e. 98.49% and the minimum SLSI was 78.38% in DH-7 in 30 °C. The results obtained in 30 °C fluctuated significantly from 35 °C for all the genotypes with more or less variation. In 35 °C minimum SLSI was 63.29% in DH-6 and differed significantly from all other genotypes. The reduction percentage in SLSI in 35 °C over 30 °C revealed that the maximum reduction of 30.96% was found in DH-6 followed by DH-12, DH-10, DH-3 and DH-11 showing 27.28, 26.01, 25.65 and 24.79% in SLSI, respectively. The minimum reduction was 1.01% in DH-8. The (%) reduction in SLSI was ranged from 4.87 to 17.88 in other genotypes. According to Guedes *et al*. (2011), higher temperature (35 °C) can cause disintegration of protein structures and along with the toxic effect and physiological drought, led to reduction in shoot.

Root length stress index (%). The average mean performance (Table 3 column B) regarding the root length stress index (RLSI) under different temperatures treated as treatments showed that the mean RLSI at 30 °C was 80.15% which was reduced to 51.54 at 35 °C, respectively. It is evident that the maximum RLSI (92.97%) was observed in DH-16 at 30 °C and the minimum RLSI was recorded to be 53.50% in DH-6 and had significant difference from all other genotypes. The RLSI at 35 °C treatment varied significantly among genotypes and was significantly lower than 30 °C treatment in all the genotypes. The minimum RLSI at 35 °C was found to be 37.80% in DH-12 and the maximum value was observed in DH-14 i.e., 62.72% RLSI. The (%) reduction in RLSIs for each genotype of wheat in 35 °C over 30 °C revealed that the genotype DH-12 showed maximum reduction i.e., 53.22% followed by 47.66, 46.87, 45.99, 44.79 and 43.02% in

Table 3. Stress indices for shoot and root length in different genotypes of wheat under different temperature treatments

Genotypes	Shoot length stress index (%) (A) Interactional response (LSD at 5% = 3.812)			(%) Reduction at 35 °C over 30 °C	Root length stress index (%) (B) Interactional response (LSD at 5% =6.344)			(%) Reduction at 35 °C over 30 °C
	25 °C	30 °C	35 °C		25 °C	30 °C	35 °C	
DH-1	0 S	96.48 ABCD	91.96 EFGH	7.63	0 Q	81.24 CD	57.85 IJKL	28.79
DH-3	0 S	93.02 CDEFG	69.16 Q	25.65	0 Q	72.03 EFG	41.04 P	43.02
DH-4	0 S	97.80 AB	81.44 KLMN	17.41	0 Q	91.88 AB	48.09 NO	47.66
DH-5	0 S	97.34 ABC	82.95 KLM	16.10	0 Q	76.21 DE	52.86 LMN	30.64
DH-6	0 S	91.67 EFGH	63.29 R	30.96	0 Q	53.50 MNOP	38.06 P	28.87
DH-7	0 S	78.38 NO	74.19 P	5.35	0 Q	74.08 DEF	57.13 IJKLM	22.88
DH-8	0 S	88.47 HI	87.58 HIJ	1.01	0 Q	84.95BC	62.42 HIJ	26.52
DH-10	0 S	97.17 ABCD	73.73 P	26.01	0 Q	67.43 FGH	48.78 NO	27.65
DH-11	0 S	97.88 AB	74.61 OP	24.79	0 Q	91.03 AB	56.26 IJKLM	38.20
DH-12	0 S	98.26 AB	71.55 PQ	27.28	0 Q	80.82 CD	37.80 P	53.22
DH-13	0 S	95.84 ABCDE	88.99 GH	8.03	0 Q	66.23 GH	60.53 HIJK	8.60
DH-14	0 S	92.80 DEFG	88.03 HI	5.14	0 Q	86.31 ABC	62.72 HI	27.33
DH-15	0 S	95.88 ABCDE	81.89 KLMN	15.27	0 Q	92.48 A	53.85 KLMN	41.77
DH-16	0 S	93.79 BCDEF	79.06 MN	15.70	0 Q	92.97 A	56.42 IJKLM	39.31
DH-18	0 S	87.88 HI	83.60 JKL	4.87	0 Q	79.62 CD	55.20 IJKLMN	30.68
DH-19	0 S	97.80 AB	83.34 KLM	16.37	0 Q	75.04 DE	49.96 LMNO	33.42
DH-20	0 S	98.49 A	84.33 IJK	15.41	0 Q	79.34 CD	42.85 OP	45.99
DH-21	0 S	96.14 ABCD	79.72 LMN	17.88	0 Q	90.04 AB	47.84 NO	46.87
LU26s	0 S	98.48 A	90.15 FGH	9.09	0 Q	79.27 CD	60.33HIJK	23.89
Kiran-95	0 S	97.82 AB	82.33 KLMN	15.84	0 Q	88.44 AB	48.83 NO	44.79
Means	0.00 C	94.59 A	80.60 B		0.00 C	80.15 A	51.94 B	
(LSD at 5%)		0.8525				1.418		

The mean in the same column and the same rows sharing the same letters did not differ significantly.

DH-4, DH-21, DH-20, Kiran-95 and DH-3, respectively. The minimum reduction in RLSI was observed in DH-13 i.e., 8.60%. The other genotypes had intermediate trend with a range of 28.87 to 41.77% reduction in RLSIs. The present findings can compared with Leishman and Westoby (1994) the root length is an important trait against temperature stress in plant varieties; in general, variety with longer root growth has resistant ability for temperature.

Categorization of wheat genotypes based on <50% reduction in variables Studied at 35 °C over 25 °C. The results (Table 4 and 5) obtained from the variables already studied in Table 2 a,b,c is summarized based on <50% reduction at 35 °C over 25 °C reveal that out of 20 genotypes, four genotypes *viz*., DH-3, DH-5, DH-8 and DH-13 appeared as tolerant in which these genotypes showed <50% reduction in 10 variables. The nine genotypes i.e., DH-1, DH-4, DH-7, DH-10, DH-11, DH-14, DH-18 and LU-26s were medium tolerant as these showed <50% reduction in nine variables. The genotypes *viz*., DH-6 and DH-16 were medium sensitive because there were eight variables which showed <50% reduction in these genotypes. Finally, there were six genotypes *viz*., DH-12, DH-15, DH-19, DH-20, DH-21 and Kiran-95 which had sensitive response as 6 to 7 variables showed <50% reduction in these genotypes to 35 °C over 25 °C.

All the genotypes showed good performance on 25 °C as compared 30 and 35 °C. These findings are in conformity with Modarries *et al*. (2010) who reported that temperature stress adversely affected wheat development and growth. Similar finding are also reported by (Essemine *et al*., 2002; Parera and Cantliffe 1994; Rao and Sinha, 1993; Penning *et al*., 1979; Wanjura and Buxtor, 1972). The present findings cannot be compared with those of Khajam *et al*. (2011) and Mukhtar and Hassan (2011) who studied the effect of temperature and solar radiation on the yield components causes significantly reduction in yield and yield related traits rather than plant growth parameters. The present findings can partially be compared with those of Akbar and Jaime (2012) who reported that wheat varieties when sown late (December 27) faced severe temperature stress and significantly affected phenology, growth and yield.

Table 4. Wheat genotypes categorized on the bases of < 50% reduction at low temperature levels

Genotypes	G %	SFW	SDW	RFW	RDW	SMC	RMC	SL	RL	SLSI	RLSI	No. of variables
DH-1	+	-	+	-	+	+	+	+	+	+	+	9
DH-3	+	+	+	+	+	+	+	+	-	+	+	10
DH-4	+	+	+	-	+	+	+	+	-	+	+	9
DH-5	+	+	+	-	+	+	+	+	+	+	+	10
DH-6	+	-	+	-	+	+	+	+	-	+	+	8
DH-7	+	-	+	-	+	+	+	+	+	+	+	9
DH-8	+	+	+	-	+	+	+	+	+	+	+	10
DH-10	+	+	+	-	+	+	+	+	-	+	+	9
DH-11	+	-	+	-	+	+	+	+	+	+	+	9
DH-12	+	-	+	-	+	+	+	+	-	+	-	7
DH-13	+	+	+	-	+	+	+	+	+	+	+	10
DH-14	+	-	+	-	+	+	+	+	+	+	+	9
DH-15	+	-	-	-	-	+	+	+	+	+	+	7
DH-16	+	-	+	-	-	+	+	+	+	+	+	8
DH-18	+	-	+	-	+	+	+	+	+	+	+	9
DH-19	+	-	-	-	+	+	+	+	-	+	+	7
DH-20	+	-	+	-	-	+	+	+	-	+	+	7
DH-21	+	-	+	-	-	+	+	+	-	+	+	7
LU26s	+	-	+	-	+	+	+	+	+	+	+	9
Kiran-95	+	-	-	-	-	+	+	+	-	+	+	6

G % = germination % age; SFW = shoot fresh weight; SDW = shoot dry weight; RFW = root fresh weight; RDW = root dry weight; SMC = shoot moisture content; RMC = root moisture content; SL = shoot length; RL = root length; SLSI = shoot length stress index; RLSI= root length stress index; + = genotypes showing < 50% reduction in variables; - = genotypes showing > 50 % reduction in variables.

Table 5. Catagorization of wheat genotypes based on tolerance levels at <50% reduction in growth parameters at early seedling stage

Categories	Based on	Genotypes
Tolerant	< 50 % reduction in 10 variables	DH-3, DH-5, DH-8, DH-13 (04)
Medium Tolerant	< 50 % reduction in 9 variables	DH-1, DH-4, DH-7, DH-10, DH-11, DH-14, DH-18, Lu26s (08)
Medium Sensitive	< 50 % reduction in 8 variables	DH-6, DH-16 (02)
Sensitive	< 50 % reduction in 7&6 variables	DH-12, DH-15, DH-19, DH-20, DH-21, Kiran-95 (06)

Wheat genotypes tested for temperature tolerance based on <50% reduction at 35 °C (early seedling studies); Genotypes tested = 20; Tolerant genotypes = 04; Medium Tolerant = 08; Medium sensitive = 02; Sensitive = 06.

Conclusion

The present results based on the genotypes like DH-3, DH-5, DH-8 and DH-13 were categorized as heat tolerant and other genotypes such as DH-1, DH-4, DH-7, DH-10, DH-11, DH-14, DH-18 and LU-26s were medium tolerant, these genotypes could be grown under high temperature with minimum yield losses.

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