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EFFECT OF WATER STRESS ON YIELD AND YIELD COMPONENTS OF SEMI-DWARF BREAD WHEAT (*TRITICUM AESTIVUM*, L.)

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Abstract

Twenty-one drought-tolerant genotypes of wheat developed through hybridization and mutation breeding were evaluated along with four drought-tolerant check varieties viz., Chakwal-86, Margalla-99, Thori (awnless) and Sarsabz under water stress conditions. Four experiments having 4 different irrigation treatments viz., single, two, three and four were conducted at NIA, Tando Jam. Observations on morphological (plant height, 1000-grain weight, grain yield), phenological (days to heading, days to maturity, grain filling period) and meteorological parameters were recorded. Genotype NIA-8/7 produced significantly the highest 1000-grain weight (37.9, 41.7, 42.0, 45.5g) at single, two, three and four irrigations respectively than other genotypes including check varieties; hence more tolerant to water stress conditions. Ten genotypes viz., BWM-3, NIA-8/7, 25/1, MSH-14, MSH-17, MSH-36, BWS-77, BWS-78, BWM-47 and Khirman produced higher grain yield (>3500 kg/ha) with two irrigations; indicated tolerance to water stress environments.

Introduction

Wheat (*Triticum aestivum*, L.) is the staple food crop of Pakistan and is grown under a wide range of climatic conditions (Mirbahar *et al*., 2009). In Pakistan, it covers around 8.5 million hectares with annual production of 23.5 million tones (Anon., 2008). It is the staple food of nearly 35 % of the world population and demand for wheat will grow faster than for any other major crop. Water stress is the main environmental constraint for the wheat crop besides high temperature and salinity (Savin & Nicolas, 1999; Richards *et al.*, 2001; Reynolds *et al*., 2001; Kimarto *et al*, 2003; Najafian *et al.*, 2004; Sial *et al.*, 2007). This stresses the need to increase the productivity of wheat crop under available limited water resources. It is estimated that to feed the increasing population, 40% more food would be required by the year 2025. Drought stress from anthesis to maturity, especially if accompanied by high temperatures, hastens leaf senescence; reduce mean kernel weight (Royo *et al.*, 2000). Grain yield in wheat is dependent on assimilates produced by current photosynthesis in the post-anthesis period, post-anthesis carbohydrates stored temporarily in vegetative organs before being re-translocated to the grain, and assimilates translocated from stored carbohydrates in the vegetative plant parts produced during the pre-anthesis period (Regan *et al.*, 1993).

The ability to effectively translocate assimilates from stems and leaves to the developing grain is desirable for maximizing grain yield production in water-limited environments (Turner & Begg, 1981). Midseason drought, experienced under rainfed conditions, reduced mainly the number of spikes per square meter and kernels per spike, traits that develop during the period most sensitive to drought stress i.e., from double

ridge to anthesis (Shpiler & Blum, 1991). The breeding efforts were therefore, undertaken to evolve wheat genotypes, which possess tolerance to water stress and produce higher yields with one or two irrigations.

Materials and Methods

Twenty-one wheat genotypes evolved through conventional and mutation breeding techniques were evaluated along with four drought-tolerant check varieties viz., Chakwal-86, Margalla-99, Thori (awnless) and Sarsabz under water stress conditions. Four experiments having 4 different irrigation treatments viz., single, two, three and four were conducted at NIA, Tando Jam. Trials were conducted in RCBD with 3 replicates; each trial was surrounded with 2.5 meter buffer zone. Experiments were sown on 13th November at NIA, Tando Jam. Each genotype was sown with 4 rows 3m long in 3.6m^2 plots. Observations on phenological and meteorological parameters were recorded. The studies were conducted on phenological (days to heading, days to maturity and grain filling period), morphological (plant height, spike length, spikelets/spike, number of grains/spike, number of grains/spikelet, main spike yield, 1000-grain weight and grain yield) and meteorological (minimum and maximum temperatures and humidity) data.

Details of irrigation treatments

Experiment-1

No. of irrigation applied	Irrigation applied after:	Growth stage of crop
Single irrigation	14 days of sowing	Tillering

Experiment-2

No. of irrigation applied	Irrigation applied after:	Growth stage of crop
1st irrigation	14 days of sowing	Tillering
2nd irrigation	28 days of sowing	Pre-anthesis (Tillering)

Experiment-3

No. of irrigation applied	Irrigation applied after:	Growth stage of crop
1st irrigation	14 days of sowing	Tillering
2nd irrigation	28 days of sowing	Pre-anthesis (Heading)
3rd irrigation	94 days of sowing	Post-anthesis(milky-dough)

Experiment-4

No. of irrigation applied	Irrigation applied after:	Growth stage of crop
1st irrigation	14 days of sowing	Seedling/Tillering
2nd irrigation	28 days of sowing	Pre-anthesis (heading)
3rd irrigation	87 days of sowing	post-anthesis (milky)
4th irrigation	113 days of sowing	post-anthesis (dough)

Results and Discussions

The results indicated the significant effects of water stress on various yield and yield associated traits. Genotypes, treatments and genotype x treatment interaction were highly significant ($p<0.01$) for different traits. A significant decrease in various agronomic traits

was recorded in severe water stress trial (single irrigation treatment) as compared to other treatments. The overall comparison between various traits as affected by different treatments are presented in Tables 1-11. Meteorological data recorded during season is given in Table 13. Favorable temperatures were observed during entire wheat season. Physiological studies are under progress.

Days to heading: The number of days to heading reduced (74.4 days) at single irrigation treatment followed by two irrigation (75.9 days); however the difference between two treatments was non-significant (Table 1). The linear increase was observed in days to heading of all genotypes at three and four irrigations treatments as compared with single and two irrigation levels. The mean number of days to heading at 3 irrigation was 78.9 days and 80.4 days at four irrigations. From the overall performance, it is obvious that water stress to wheat genotypes induced earliness in heading. Seven advance lines and two checks varieties Thori and Chakwal-86 took overall more days to heading (>80 days) as compared to overall four irrigation treatments. Fifteen genotypes took significantly more days to heading (>72) than two check varieties Sarsbz and Margalla-99 with severe stress (single irrigation).

Table 1. Phenological traits of wheat genotypes as affected by different water stress conditions (2005-06).

Genotypes	Days to heading				Mean
	Single irrigation	Two irrigation	Three irrigation	Four irrigation	
BWM-3	67.0 op	70.7 l	74.7 hi	74.0 ok	71.6
NIA-8/7	70.0 mn	72.0 k	72.7 ij	75.3 o	72.5
NIA-9/5	74.7 hij	79.0 dc	82.7 c	83.0 fgh	79.8
NIA-37/6	77.0 fgh	80.0 cd	80.3 cde	83.3 efg	80.1
NIA-10/8	81.3 bc	81.3 b	85.3 b	86.7 bc	83.6
NIA-25/1	80.7 bcd	75.3 I	82.0 cd	87.0 b	81.2
NIA-28/4	72.3 klm	76.3 hi	81.0 cde	85.3 bcd	79.4
NIA-30/5	78.3 def	79.0 de	85.7 b	85.3 bcd	82.0
NIA-25/5	79.0 cde	79.3 cde	85.3 b	85.0 cde	82.1
ESW-9525	77.7 efg	80.3 bc	85.0 b	85.3 bcd	82.0
SI-91195	74.7 hij	75.3 i	77.7 fg	81.3 hi	77.2
SI-9590	80.0 cde	76.3 hi	82.7 c	84.7 def	80.9
MSH-14	75.0 hij	76.7 gh	82.0 cd	83.0 fgh	79.2
MSH-17	78.7 def	76.7 gh	80.7 cde	83.7 def	79.9
MSH-36	64.0 q	68.7 n	69.3 k	68.3 m	67.6
MSH-22	74.0 ijk	78.7 ef	69.7 def	82.0 ghi	75.6
BWQ-4	76.0 ghi	77.7 fg	79.3 ef	82.0 ghi	78.7
BWS-77	72.7 jkl	75.3 i	80.3	81.0 i	77.3
BWM-84	69.7 n	69.3 m	72.3 j	73.0 kl	71.1
BWS-78	70.7 lmn	72.0 k	76.7 gh	73.0 kl	73.1
BWM-47	61.3 r	65.3 n	64.7 l	67.7 m	64.7
Sarsabz	69.0 no	73.3 j	74.7 hi	71.7 l	72.2
Thorhi	83.0 b	81.3 b	88.0 a	86.7 bc	84.7
Margalla-99	66.3 p	71.0 kl	72.0 o	72.0 l	70.3
Chakwal-86	88.7 a	86.7 a	89.7 a	89.3 a	88.3
Mean	**74.4**	**75.9**	**78.9**	**80.4**	**----**

Table 2. Phenological traits of wheat genotypes as affected by different water stress conditions (2005-06).

Genotypes	Days to maturity				Mean
	Single irrigation	Two irrigation	Three irrigation	Four irrigation	
BWM-3	108.3 e	118.7 abc	111.0 h	121.0 abc	114.7
NIA-8/7	109.0 e	112.3 ghi	116.7 g	120.7 abc	114.7
NIA-9/5	115.7 bcd	121.3 ab	121.3 bc	122.0 ab	120.0
NIA-37/6	118.3 bc	120.0 abc	120.3 cde	124.3 a	120.7
NIA-10/8	118.0 bcd	122.7 a	123.7 ab	122.7 a	121.8
NIA-25/1	114.3 b	111.3 ghi	121.3 bcd	123.0 a	117.5
NIA-28/4	115.0 cd	109.0 ijk	118.0 efg	122.0 ab	116.0
NIA-30/5	115.0 cd	119.7 abc	122.0 bcd	123.7 a	120.1
NIA-25/5	109.0 e	116.7 cde	122.3 abc	123.7 a	117.9
ESW-9525	115.7 bcd	118.0 bcd	123.3 ab	124.3 a	120.3
SI-91195	117.3 bcd	117.3 bcd	119.7 def	121.0 abc	118.8
SI-9590	117.7 bcd	113.0 fgh	121.0 bcd	121.0 abc	118.2
MSH-14	118.0 bcd	107.3 kl	119.7 def	118.0 cd	115.7
MSH-17	115.3 bcd	117.3 bcd	122.3 abc	118.7 bcd	118.4
MSH-36	114.7 cd	108.7 jkl	118.0 efg	116.3 de	114.4
MSH-22	116.0 bcd	114.7 def	122.7 abc	123.3 a	119.1
BWQ-4	107.7 e	114.0 efg	118.3 efg	122.7 a	115.7
BWS-77	115.3 bcd	122.7 a	122.7 abc	123.7 a	121.1
BWM-84	107.7 e	108.3 jkl	116.3 g	113.3 e	111.4
BWS-78	107.7 e	115.0 def	116.7 g	113.3 e	113.2
BWM-47	108.0 e	110.3 hij	108.0 i	108.0 f	108.6
Sarsabz	107.7 e	106.0 l	110.0 hi	108.0 f	107.9
Thorhi	118.7 b	121.0 ab	122.0 bcd	123.0 a	121.2
Margalla-99	107.0 e	114.0 efg	117.3 fg	107.3 f	111.4
Chakwal-86	122.7 a	122.3 a	125.0 a	123.3 a	123.3
Mean	**113.6**	**115.3**	**119.8**	**119.5**	**----**

Days to maturity: The overall results indicated that the average maturity period of all genotypes including local checks was significantly decreased under severe water stress (single irrigation) as compared to other treatments. With the availability of water, the maturity was delayed and it was 115 days at two irrigations, 120 days at 3 and 4 irrigations (Table 2). Seven genotypes including high yielding genotypes NIA-8/7 and Margalla-99 took medium duration (111-115 days) to maturing when means of all treatments were compared. Genotypes BWM-84, BWS-78, BWQ-4, 25/5, NIA-8/7 and BWM-3 took significantly less days (107-109) and considered as early maturing at single irrigation. At two irrigations, 28/4, MSH-14, MSH-36, BWM-84 and Sarsabz matured earlier (106-109 days) than other genotypes, whereas, the duration to maturity varied among different genotypes ranging from 106 (Sarsabz) to 123 days (NIA-10/8, BWS-77 and Chakwal-86). Twelve genotypes matured earlier (<120 days) at three irrigations.

Table 3. Phenological traits of wheat genotypes as affected by different water stress conditions (2005-06).

Genotypes	Grain filling period				Mean
	Single irrigation	Two irrigation	Three irrigation	Four irrigation	
BWM-3	41.3 cde	48.8 a	36.3 ghi	47.0 a	43.1
NIA-8/7	39.0 cde	40.3 b	44.0 b	45.4 ab	42.2
NIA-9/5	41.7 cde	42.3 b	38.6 efg	39.0 cde	40.4
NIA-37/6	41.3 cde	40.0 b	40.0 cde	41.0 cd	40.5
NIA-10/8	36.7 fgh	41.4 b	38.4 fgh	36.0 ghi	38.1
NIA-25/1	33.6 hij	36.0 b	39.3 def	36.0 ghi	36.2
NIA-28/4	42.6 l	32.7 b	37.0 ghi	36.7 efg	37.3
NIA-30/5	36.7 fgh	40.7 b	36.3 ghi	38.4 cde	38.0
NIA-25/5	30.0 j	37.4 b	37.0 ghi	38.4 cde	35.7
ESW-9525	38.0 def	37.7 b	38.3 fgh	39.0 cde	38.2
SI-91195	42.7 j	41.7 b	42.0 bcd	39.7 cde	41.5
SI-9590	37.7 def	36.7 b	38.3 fgh	36.3 fgh	37.2
MSH-14	43.0 c	30.6 b	37.7 ghi	35.0 hi	36.6
MSH-17	36.6 def	40.6 b	41.6 bcd	35.0 hi	38.4
MSH-36	50.7 a	40.0 b	48.7 a	48.0 a	46.8
MSH-22	42.0 cd	36.0 b	43.0 bcd	41.3 cd	40.6
BWQ-4	31.7 ij	36.3 b	39.0 efg	40.7 cde	36.9
BWS-77	42.6 c	47.4 a	42.4 bcd	42.7 bc	43.8
BWM-84	38.0 def	39.0 b	44.0 b	40.3 cde	40.3
BWS-78	37.7 efg	43.0 ab	40.0 cde	40.3 cde	40.2
BWM-47	46.7 g	45.0 b	43.3 bc	40.3 cde	43.8
Sarsabz	38.7 cde	32.7 b	35.3 hi	36.3 fgh	35.1
Thorhi	35.7 ghi	39.7 b	34.0 i	36.3 fgh	36.4
Margalla-99	40.7 cde	43.0 b	45.7 b	35.3 hi	41.2
Chakwal-86	34.0 hij	35.6	36.3 ghi	34.3 I	35.0
Mean	**39.2**	**39.4**	**39.9**	**39.1**	**----**

Grain filling period: Grain filling period of all genotypes under all four treatments did not show any significant differences (Table 3). It ranged from 39.1-39.9 days (three and four irrigation treatments respectively), which was non-significantly different from each other. Ten advance lines and a check variety Margalla-99 utilized more days to grain filling (>40 days) than all other genotypes at various irrigation treatments. Ten advanced genotypes utilized more days to grain filling (41 days) than the highest check Margalla-99 (40.7 days) and Sarsabz (38.7 days) at single irrigation. Genotypes 25/5, 25/1, BWQ-4 took short period to fill the grains (30-33.7 days), however it was at par with check varieties Thori and Chakwal-86. The period for grain filling ranged from 30.6-48.8 days with two irrigations. Eight genotypes including check variety Margalla-99 took more than 40 days to grain filling period with two irrigations.

Plant height: The plant height was adversely affected by the genotypes when subjected to severe water stress conditions (Table 4). With one irrigation, the mean plant height was 73.7cm which increased to 96.9 at 2 irrigations and 102.1 cm at 3 irrigations. The 4th irrigation applied at post-anthesis (dough) stage did not enhance the plant height (99.1cm) Two advance lines BWS-77 and BWM-84 had significantly the highest plant height (114.6 and 108 cm) and ranked in tall group.

Table 4. Agronomic traits of wheat genotypes as affected by different water stress conditions (2005-06).

Genotypes	Plant height (cm)				Mean
	Single irrigation	Two irrigation	Three irrigation	Four irrigation	
BWM-3	85.3 ab	101.3 bcd	99.3 bcd	81.3 m	91.8
NIA-8/7	76.3 abc	92.0 ghi	97.7 cde	85.0 lm	87.7
NIA-9/5	77.7 abc	96.0 def	94.3 de	92.7 jk	90.1
NIA-37/6	69.3 def	101.3 bcd	106.7 bcd	99.7 efg	94.2
NIA-10/8	76.3 abc	105.0 bc	107.3 bcd	100.3 efg	97.2
NIA-25/1	70.0 def	95.3 efg	93.7 de	85.7 l	86.2
NIA-28/4	67.3 efg	96.0 def	93.0 de	91.0 k	86.8
NIA-30/5	83.7 abc	107.3 ab	112.3 b	106.0 cd	102.3
NIA-25/5	68.3 efg	92.3 fgh	95.3 de	95.0 ijk	87.7
ESW-9525	60.3 g	87.3 ij	95.0 de	95.0 ijk	84.4
SI-91195	65.7 efg	102.0 bcd	105.7 bcd	99.7 fgh	93.3
SI-9590	64.3 fg	93.7 efg	96.7 cde	96.0 hij	87.7
MSH-14	72.3 cde	101.0 bcd	100.0 bcd	103.0 def	94.0
MSH-17	65.3 efg	93.0 efg	100.3 bcd	99.3 fgh	89.5
MSH-36	65.0 fg	76.3 k	92.0 e	95.3 ijk	82.1
MSH-22	73.0 cde	96.7 cde	96.0 cde	93.3 jk	89.7
BWQ-4	82.3 abc	95.3 efg	101.3 bcd	97.3 ghi	94.0
BWS-77	88.0 a	114.7 a	129.0 a	126.7 a	114.6
BWM-84	83.3 ab	106.3 b	124.7 a	117.7 b	108.0
BWS-78	76.0 abc	95.0 efg	100.7 bcd	98.7 fgh	92.6
BWM-47	85.7 ab	100.0 bcd	107.3 bcd	104.7 de	99.6
Sarsabz	81.0 abc	93.7 efg	104.0 bcd	102.0 def	95.2
Thorhi	74.0 bcd	104.7 bcd	110.7 bc	109.0 c	99.6
Margalla-99	67.7 efg	84.7 j	94.3 de	93.7 jk	85.1
Chakwal-86	65.3 efg	91.3 hij	96.7 cde	110.0 c	90.8
Mean	**73.7**	**96.9**	**102.16**	**99.1**	**---**

Thousand-grain weight: Highly significant effects of water stress were observed on 1000-grain weight (Table 5). It was significantly decreased (28.) at single irrigation treatment. The linear increase was recorded in this trait as number of irrigation increased. Approximately 24.8% reduction was recorded at severe water stress trial as compared to normal (four irrigations) treatment. Similarly, 13% and 7.7% reduction was observed in 1000-grain weight at two and three irrigations as compared to four irrigation treatment. Genotype NIA-8/7 produced significantly the highest mean 1000-grain weight (41.8g) under various irrigation treatments than all other genotypes; hence posses more tolerance to water stress conditions. Same genotype also produced significantly the highest 1000-grain weight (37.9 and 41.7g respectively) than all other genotypes including local check varieties at single, two and three irrigations. Eleven genotypes (BWQ-4, BWM-3, NIA-9/5, NIA-10/8, 25/1, MSH-14, MSH17, BWQ-4, BWS-78 and BWM-47) including Sarsabz produced significantly higher 1000-grain weight (>30.0g) than others, hence posses more tolerance to water stress conditions. Thousand grain weight at single irrigation ranged from 22.4 to 37.9g. At two irrigations, 20 genotypes produced 1000-grain weight above 30g. At four irrigations, thousand-grain weight of genotypes varied from 31.3g in Chakwal-86 to 45.5g in NIA-8/7.

Table 5. Agronomic traits of wheat genotypes as affected by different water stress conditions (2005-06).

Genotypes	1000-grain weight (g)				Mean
	Single irrigation	Two irrigation	Three irrigation	Four irrigation	
BWM-3	31.3 cd	34.7 bcd	34.9 de	38.7 cde	34.9
NIA-8/7	37.9 a	41.7 a	42.0 a	45.5 a	41.8
NIA-9/5	33.4 b	32.9 cd	36.0 de	40.9 bcd	36.0
NIA-37/6	25.4 hi	35.3 bc	34.0 efg	39.1 bcd	31.9
NIA-10/8	30.4 def	35.0 bcd	35.5 def	39.4 cde	35.1
NIA-25/1	32.2 bc	33.5 cde	35.0 def	37.7 efg	34.6
NIA-28/4	25.4 hi	27.6 I	32.1 hi	33.6 hi	29.7
NIA-30/5	29.5 ef	35.0 bc	36.3 de	39.0 bcd	34.9
NIA-25/5	22.4 j	33.3 de	33.9 ef	36.3 efg	31.5
ESW-9525	22.4 j	28.2 kl	32.4 hi	34.8 gh	29.4
SI-91195	26.5 h	33.8 cd	35.2 de	38.7 cde	33.6
SI-9590	24.8 i	32.2 gh	33.5 fg	37.2 efg	31.9
MSH-14	30.3 def	31.9 hi	36.4 de	40.8 bcd	34.8
MSH-17	31.6 cd	32.3 de	36.1 de	38.6 cde	34.9
MSH-36	26.1 hi	33.5 cde	34.8 def	38.3 def	33.2
MSH-22	22.7 j	29.7 j	32.3 hi	35.6 fgh	30.1
BWQ-4	30.5 de	34.5 bcd	34.9 de	37.7 efg	34.4
BWS-77	29.2 fg	31.5 i	32.7 gh	34.1 h	31.9
BWM-84	29.3 fg	34.8 bcd	39.4 b	41.5 bc	36.2
BWS-78	31.0 cd	32.3 fg	38.6 bc	41.9 b	35.9
BWM-47	32. bc	31.9 hi	35.7 de	38.9 bcd	34.7
Sarsabz	30.5 de	36.0 b	35.3 de	38.5 cde	35.1
Thorhi	24.7 i	32.9 efg	33.3 fg	34.3 h	31.3
Margalla-99	28.6 g	33.9 cde	36.7 cd	38.6 cd	34.5
Chakwal-86	26.5 h	32.4 fg	30.7 I	31.3 i	30.2
Mean	**28.6**	**33.07**	**35.i**	**38.0**	**---**

Grain yield (Kg/ha): The overall mean grain yield of genotypes showed significant linear response to different irrigation treatments (Table 6). Grain yield decreased significantly at single irrigation and ranged from 1057 to 2721 kg/ha. Genotypes NIA-8/7, NIA-10/8, MSH-14, BWS-78 and MSH-36 produced the highest grain yield (2144-2721 kg/ha) than all other entries at single irrigation. It increased by 56% at two irrigations (3419 kg/ha), 86% at three (3953 kg/ha) and 81% at four irrigations (4845 kg/ha). Genotypes MSH-14 produced the highest grain yield (4199 kg/ha) than all other genotypes in various irrigation treatments. Six genotypes including NIA-8/7 had the higher grain yield (3900 kg/ha). Genotype NIA-8/7 produced the highest yield and ranked first among all genotypes, whereas the same genotype had the highest 1000-grain weight under single irrigation. The results suggested that the genotype NIA-8/7 posses more drought tolerance as compared to other entries in this comparison. Grain yield at two irrigations varied from 1888 kg/ha to 4015 kg/ha. Ten advance genotypes produced significantly the highest yield (>3500 kg/ha) than all other genotypes including local checks. These genotypes could be selected as drought tolerant genotypes for further

breeding. With three irrigations, grain yield ranged from 2588 to 4581 kg/ha; fourteen genotypes produced yield more than 4000 kg/ha. In well-watered experiments, grain yield ranged between 2173 kg/ha (Thori) and 5985 kg/ha (MSH-17) genotype. Genotypes MSH-17, ESW-9525, MSH-14, BWM-3, NIA-10/8, 25/1, NIA-9/5, NIA-8/7 and Khirman produced significantly the highest grain yield (>5000 kg/ha) with four irrigations.

Spike length: The average spike length of all genotypes indicated significant reduction at single irrigation. The overall spike length of genotypes increased at two, three and four irrigations (Table 7). Five genotypes viz., NIA-9/5, NIA-10/8, SI-91195, BWM-3 and Sarsabz showed overall increase in spike length at various irrigation treatments than other genotypes. Four genotypes BWM-3, NIA-9/5, NIA-10/8 and MSH-14 possessed comparatively longer spikes (>9.0 cm) compared to other entries at single irrigation treatment.

Table 6. Agronomic traits of wheat genotypes as affected by different water stress conditions (2005-06).

Genotypes	Grain yield (kg/ha)				Mean
	Single irrigation	Two irrigation	Three irrigation	Four irrigation	
BWM-3	2116 abc	3904 ab	4426 ab	5482 ab	3982
NIA-8/7	2721 a	3774 abc	4174 a	5233 abc	3976
NIA-9/5	2031abc	3184 cde	4118 abc	5293 ab	3657
NIA-37/6	1517 cde	3253 bcd	3221 f	4496 bc	3122
NIA-10/8	2316 ab	3384 abc	4059 abc	5430 ab	3797
NIA-25/1	2060 abc	4015 a	4137 abc	5400 ab	3903
NIA-28/4	1948 bcd	2738 f	3546 ef	4374 bc	3127
NIA-30/5	1903 bcd	3421 abc	3664 cde	4959 ab	3487
NIA-25/5	1829 bcd	3209 cde	3618 cde	4911 ab	3392
ESW-9525	2105 abc	3296 abc	4026 cde	5822 a	3812
SI-91195	2118abc	3907 ab	4274 abc	5026 ab	3831
SI-9590	1546 cde	3412 abc	4170 abc	4819 ab	3487
MSH-14	2707 a	3759 abc	4519 a	5811 ab	4199
MSH-17	1894 bcd	3837 abc	4111 abc	5985 a	3957
MSH-36	2144 abc	3811 abc	4526 a	5330 ab	3953
MSH-22	1968 bcd	3307 bcd	3996 abc	4540 bc	3453
BWQ-4	2019 abc	3322 bcd	4048 abc	4811 bc	3550
BWS-77	1712 bcd	3807 abc	3733 cde	4341 bc	3398
BWM-84	1578 bcd	3472 abc	3785 bcd	4522 bc	3372
BWS-78	2243 abc	3690 abc	4504 a	4285 ab	3681
BWM-47	2094 abc	3575 abc	3974 abc	4311 bc	3488
Sarsabz	1575 bcd	3094 def	3447 bcd	4307 c	3106
Thorhi	1292 de	2854 ef	2588 g	2173 d	2227
Margalla-99	1804 bcd	3436 abc	4581 a	4204 bc	3506
Chakwal-86	1057 e	1888 g	3591 def	4284 bc	2695
Mean	**1928**	**3419**	**3953**	**4845**	**3536**

Table 7. Agronomic traits of wheat genotypes as affected by different water stress conditions (2005-06).

Genotypes	Spike length (cm)				Mean
	Single irrigation	Two irrigation	Three irrigation	Four irrigation	
BWM-3	10.1 a	10.9 ab	11.8 ab	10.9 a	10.9
NIA-8/7	8.1 cde	9.5 bcd	10.6 abc	9.4 cde	9.4
NIA-9/5	9.3 ab	10.9 ab	10.7 abc	10.4 abc	10.3
NIA-37/6	8.6 bcd	9.1 cd	10.4 abc	9.5 bcd	9.4
NIA-10/8	9.0 bc	10.9 ab	11.9 a	10.9 a	10.7
NIA-25/1	8.5 bcd	9.9 abc	10.7 abc	9.5 cde	9.6
NIA-28/4	8.9 bcd	9.6 bcd	11.4 abc	10.4 abc	10.1
NIA-30/5	7.7 ef	8.9 cd	9.1 e	9.0 def	8.7
NIA-25/5	7.9 cde	8.9 cd	9.8 bcd	8.7 efg	8.8
ESW-9525	8.2 bcd	9.1 cd	9.2 de	8.1 h	8.7
SI-91195	8.9 bcd	10.8 ab	10.4 abc	10.0 abc	10.0
SI-9590	7.8 def	9.0 cd	9.7 bcd	9.2 cde	8.9
MSH-14	9.0 bc	9.5 bcd	10.9 abc	8.6 fgh	9.5
MSH-17	8.5 bcd	10.1 abc	10.7 abc	9.0 def	9.6
MSH-36	7.6 f	9.1 cd	10.5 abc	8.9 def	9.0
MSH-22	7.9 cde	10.2 abc	10.6 abc	9.7 abc	9.6
BWQ-4	8.7 bcd	9.7 bcd	9.1 abc	8.6 efg	9.0
BWS-77	8.6 bcd	10.7 ab	10.4 abc	9.9 abc	9.9
BWM-84	8.4 bcd	9.6 bcd	11.0 abc	10.4 abc	9.8
BWS-78	8.8 bcd	11.2 a	10.0abc	9.7 abc	9.9
BWM-47	8.4 bcd	9.6 bcd	9.6 cde	9.2 cde	9.2
Sarsabz	7.9 cde	10.1 abc	11.3 abc	10.7 ab	10.0
Thorhi	7.6 f	8.7 d	9.0 e	8.3 h	8.4
Margalla-99	8.2 bcd	9.9 abc	9.6 cde	8.3 gh	9.0
Chakwal-86	8.3 bcd	10.2 abc	9.3 de	10.0 abc	9.5
Mean	**8.44**	**9.84**	**10.31**	**9.49**	**---**

Spikelets/spike: The number of spikelets per spike is dependent on spike length of that genotype. The number of spikelets was minimum (16.35) when genotypes were exposed to severe drought (one irrigation). Other treatments showed similar performance for spikelets per spike as to severe drought (one irrigation) (Table 8). Genotypes BWS-78, SI-91195, MSH-14, MSH-17, 37/6 and NIA-8/7 possessed more number spikelets per spike than other genotypes at single irrigation.

Table 8. Agronomic traits of wheat genotypes as affected by different water stress conditions (2005-06).

Genotypes	Spikelets per spike				Mean
	Single irrigation	Two irrigation	Three irrigation	Four irrigation	
BWM-3	15.7 cde	19.2 a	20.6 abc	20.4 abc	18.9
NIA-8/7	16.8 bcd	20.1 a	20.2 abc	19.6 abc	19.2
NIA-9/5	15.0 ef	20.1 a	20.4 abc	20.9 abc	19.2
NIA-37/6	17.1 bcd	19.5 a	20.5 abc	20.3 abc	19.3
NIA-10/8	16.4 cde	20.6 a	21.0 abc	22.1 a	20.0
NIA-25/1	16.4 cd	20.5 a	20.9 abc	21.0 abc	19.7
NIA-28/4	16.7 bcd	20.1 a	21.2 abc	21.7 ab	19.9
NIA-30/5	15.5 def	17.8 ab	18.4 cde	18.6 bcd	17.6
NIA-25/5	14.9 ef	19.5 a	18.9 bcd	19.1 abc	18.1
ESW-9525	16.5 cde	19.8 a	20.1 abc	20.1 abc	19.12
SI-91195	18.8 ab	21.4 a	20.3 abc	22.4 a	20.7
SI-9590	15.3 ef	18.8 a	19.5 abc	19.8 abc	18.3
MSH-14	17.7 abc	13.8 a	20.5 abc	18.4 bcd	17.6
MSH-17	16.9 bcd	21.9 a	20.4 abc	21.2 abc	20.1
MSH-36	16.0 cde	17.0 ab	19.4 abc	17.5 e	17.5
MSH-22	16.1 cde	20.9 a	21.0 abc	20.5 abc	19.6
BWQ-4	15.3 ef	21.0 a	17.9 ef	17.6 de	17.9
BWS-77	15.9 cde	22.1 a	20.1 abc	21.7 ab	19.9
BWM-84	15.6 def	21.2 a	21.6 ab	20.8 abc	19.8
BWS-78	19.5 a	22.2 a	18.9 bcd	21.0 abc	20.4
BWM-47	16.9 bcd	18.9 a	18.9 bcd	19.2 abc	18.5
Sarsabz	15.9 cde	20.1 a	17.3 f	21.6 ab	18.7
Thorhi	13.8 f	17.7 ab	18.3 def	17.9 cde	16.9
Margalla-99	17.9 abc	20.9 a	22.0 a	18.4 bcd	19.8
Chakwal-86	16.2 cde	21.2 a	19.5 abc	22.2 a	19.8
Mean	**16.35**	**19.74**	**19.91**	**20.16**	**---**

Grains per spike: The minimum number of grains per spike (37.8) were recorded at single irrigation treatment. Then there has been a gradual increase at two, three and four irrigation treatments (48.9, 50.0 and 48.0 respectively) (Table 9). At single irrigation, mean grains per spike ranged from 26.9 (Thori) to 45.5 (ESW-9525). Twenty genotypes had more grains per spike than check varieties. At medium water stress experiment, 13 genotypes had more mean number of grains per spike (>50). Five genotypes 28/4, BWM-84, NIA-8/7, NIA-10/8 and 25/1 had more grains per spike as compared to other genotypes under moderate water stress conditions.

Table 9. Agronomic traits of wheat genotypes as affected by different water stress conditions (2005-06).

Genotypes	Grains per spike				Mean
	Single irrigation	Two irrigation	Three irrigation	Four irrigation	
BWM-3	40.1 abc	42.3 abc	51.2 abc	46.3 abc	45.0
NIA-8/7	37.3 abc	44.1 abc	55.8 ab	48.9 ab	46.5
NIA-9/5	39.0 abc	46.9 abc	52.7 abc	51.3 a	47.5
NIA-37/6	38.5 abc	42.5 abc	48.3 abc	47.1 ab	44.1
NIA-10/8	38.7 abc	54.5 a	54.8 abc	53.5 a	50.4
NIA-25/1	38.5 abc	49.7 abc	55.5 ab	45.8 abc	47.7
NIA-28/4	39.4 abc	52.5 ab	57.1 a	53.5 a	50.6
NIA-30/5	36.1 abc	42.8 abc	39.8 ef	45.1 abc	40.9
NIA-25/5	35.2 bcd	45.0 abc	46.5 abc	44.7 abc	42.8
ESW-9525	45.5 a	57.9 a	52.9 abc	52.1 a	52.1
SI-91195	37.3 abc	53.5 ab	52.0 abc	48.1 ab	47.7
SI-9590	36.7 abc	47.0 abc	51.1 abc	52.3 a	46.8
MSH-14	43.4 abc	50.7 abc	53.9 abc	52.2 a	50.0
MSH-17	39.9 abc	53.9 abc	52.8 abc	51.3 a	49.5
MSH-36	40.6 abc	53.9 abc	51.2 abc	48.7 ab	48.6
MSH-22	36.6 abc	53.5 abc	53.5 abc	52.1 a	48.9
BWQ-4	40.5 abc	57.7 a	43.4 cde	45.9 abc	46.9
BWS-77	36.1 abc	50.2 abc	44.7 bcd	47.9 ab	44.7
BWM-84	38.9 abc	36.4 bc	57.1 a	48.8 ab	45.3
BWS-78	41.6 abc	54.1 a	54.1 abc	44.1 abc	48.5
BWM-47	38.3 abc	52.3 ab	49.7 abc	51.2 a	47.9
Sarsabz	33.7 cde	43.1 abc	47.5 abc	49.7 ab	43.5
Thorhi	26.9 e	34.7 c	32.5 f	33.7 c	31.5
Margalla-99	35.4 bcd	58.5 a	51.3 abc	37.8 bc	45.7
Chakwal-86	30.1 de	46.6 abc	41.6 def	49.3 ab	41.9
Mean	**37.77**	**48.98**	**50.04**	**48.06**	**----**

Grains per spiklets: Mean number of grains per spikelet of all genotypes showed significant increase at two and three irrigation treatments as compared to single and four irrigations (Table 10). Grains per spikelets had also significant increase in newly evolved genotypes as compared to local check varieties. Thirteen genotypes possess significantly more grains per spikelet than check varieties (> 2.4) under severe water stress (single irrigation).

Table 10. Agronomic traits of wheat genotypes as affected by different water stress conditions (2005-06).

Genotypes	Grains per spikelet				Mean
	Single irrigation	Two Irrigation	Three irrigation	Four irrigation	
BWM-3	2.55 ab	2.20 bcd	2.56 abc	2.27 bcd	2.39
NIA-8/7	2.22 bcd	2.13 bcd	2.76 abc	2.50 abc	2.40
NIA-9/5	2.59 ab	2.27 bcd	2.58 abc	2.45 abc	2.47
NIA-37/6	2.25 bcd	2.18 de	2.36 bcd	2.32 abc	2.28
NIA-10/8	2.36 abc	2.65 abc	2.57 abc	2.42 abc	2.50
NIA-25/1	2.35 abc	2.42 bcd	2.65 abc	2.18 cde	2.40
NIA-28/4	2.36 abc	2.61 abc	2.72 abc	2.47 abc	2.54
NIA-30/5	2.31 bcd	2.41 bcd	2.16 def	2.42 abc	2.32
NIA-25/5	2.36 abc	2.31 bcd	2.49 abc	2.27 abc	2.36
ESW-9525	2.76 a	2.92 ab	2.63 abc	2.52 abc	2.71
SI-91195	1.98 def	2.50 abc	2.56 bcd	2.15 ef	2.30
SI-9590	2.40 abc	2.50 abc	2.62 abc	2.64 abc	2.54
MSH-14	2.46 abc	3.67 a	2.63 abc	2.83 a	2.90
MSH-17	2.36 abc	2.46 abc	2.59 abc	2.41 abc	2.45
MSH-36	2.54 ab	3.17 a	2.64 abc	2.79 ab	2.78
MSH-22	2.27 bcd	2.56 abc	2.55 abc	2.54 abc	2.48
BWQ-4	2.64 ab	2.75 abc	2.42 abc	2.61 abc	2.60
BWS-77	2.27 bcd	2.21 bcd	2.16 cde	2.20 cde	2.21
BWM-84	2.49 abc	1.72 e	2.64 abc	2.35 abc	2.30
BWS-78	2.13 cde	2.43 abc	2.86 ab	2.10 def	2.38
BWM-47	2.26 bcd	2.76 abc	2.63 abc	2.67 abc	2.58
Sarsabz	2.12 cde	2.13 cde	2.74 a	2.30 bcd	2.32
Thorhi	1.95 efg	1.96 e	1.78 f	1.88 f	1.89
Margalla-99	1.97 fg	2.81 abc	2.33 ef	2.05 ef	2.29
Chakwal-86	1.86 g	2.20 bcd	2.13 def	2.22 ef	2.10
Mean	**2.31**	**2.48**	**2.51**	**2.38**	**---**

Main spike yield: The main spike yield at single irrigation was the lowest (1.29g) as compared to other (two, three and four irrigation) treatments (1.52, 1.62 and 2.08g respectively). Genotypes 25/5, Thori and Chakwal-86 had the lowest main spike yield overall the treatments. At severe water stress, NIA-8/7, NIA-9/5 and 30/5 produced significantly higher main spike yield than other genotypes. Genotypes NIA-10/8 produced higher main spike yield (2.2g) followed by MSH-14, NIA-8/7 and ESW-9525 at two irrigations. Seven genotypes showed increase in main spike yield under moderate water stress.

Table 11. Agronomic traits of wheat genotypes as affected by different water stress conditions (2005-06).

Genotypes	Main spike yield (g)				Mean
	Single irrigation	Two irrigation	Three irrigation	Four irrigation	
BWM-3	1.38 ab	1.47 abc	1.44 abc	1.71 b	1.50
NIA-8/7	1.60 a	1.81 abc	1.89 ab	2.51 ab	1.95
NIA-9/5	1.58 a	1.74 abc	2.03 a	2.82 a	2.04
NIA-37/6	1.32 ab	1.48 abc	1.81 ab	2.02 ab	1.66
NIA-10/8	1.31 ab	2.22 a	1.52 abc	2.01 ab	1.76
NIA-25/1	1.33 ab	1.10 c	1.77 abc	2.19 ab	1.60
NIA-28/4	1.41 ab	1.06 c	1.78 abc	2.08 ab	1.58
NIA-30/5	1.56 a	1.26 bc	1.31 bc	2.08 ab	1.56
NIA-25/5	1.30 ab	1.35 bc	1.45 abc	1.85 b	1.49
ESW-9525	1.29 ab	1.81 abc	1.28 bc	2.27 ab	1.67
SI-91195	1.39 ab	1.65 abc	1.53 abc	2.32 ab	1.72
SI-9590	0.97 b	1.12 bc	1.62 abc	2.48 ab	1.55
MSH-14	1.35 ab	1.92 ab	1.70 abc	2.19 ab	1.79
MSH-17	1.26 ab	1.49 abc	1.89 ab	1.92 ab	1.64
MSH-36	1.24 ab	1.28 bc	1.60 abc	1.88 ab	1.50
MSH-22	1.15 ab	1.40 bc	1.77 abc	2.24 ab	1.64
BWQ-4	1.28 ab	1.49 abc	1.39 abc	1.89 b	1.51
BWS-77	1.18 ab	1.56 abc	1.68 abc	1.94 ab	1.59
BWM-84	1.29 ab	1.61 abc	1.85 ab	2.34 ab	1.77
BWS-78	1.38 ab	1.69 abc	1.75 abc	2.01 ab	1.71
BWM-47	1.31 ab	1.79 abc	1.69 abc	1.83 b	1.65
Sarsabz	1.08 b	1.40 bc	1.64 abc	2.11 ab	1.56
Thorhi	0.96 b	1.31 bc	1.10 c	1.78 b	1.29
Margalla-99	1.34 ab	1.49 abc	1.52 abc	1.94 ab	1.57
Chakwal-86	1.04 b	1.44 abc	1.40 abc	1.69 b	1.39
Mean	**1.29**	**1.52**	**1.62**	**2.08**	**---**

Conclusion

Ten wheat genotypes viz., BWM-3, NIA-8/7, NIA-10/8, 30/5, 25/5, ESW-9525, SI-91195, MSH-14, MSH-36 and BWS-78 out of 21 indicated more tolerance to water stress conditions and produced the highest (>3000 kg/ha) overall mean grain yield under various locations in Sindh during third year of evaluation. Ten genotypes had the highest 1000-grain weight (>30.0g) than others at severe water stress; hence possess more tolerance to water stress. It is concluded that the appropriate yields could be achieved from drought-tolerant wheat genotypes by applying at least two irrigations during critical growth stages i.e., at tillering and pre-anthesis or post-anthesis stage of wheat crop.

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