Crop Breeding Journal, 2011, 1(1)

Adaptive traits related to terminal drought tolerance in hexaploid wheat *(Triticum aestivum* L.*)* genotypes under field conditions

G. Najafian[a*], A. Jafarnejad[b], A. Ghandi[c] and R. Nikooseresht[d]

[a]Seed and Plant Improvement Institute, Karaj, Iran
[b]Agricultural and Natural Resources Research Center of Khorasan Razavi Province, Neishabour, Iran.
[c]Agricultural and Natural Resources Research Center of Isfahan Province, Isfahan, Iran.
[d]Agricultural and Natural Resources Research Center of Kermanshah Province, Kermanshah, Iran.
[*]Corresponding author. E-mail: Goodarzn@yahoo.co.uk

Received: July 2010 Accepted: October 2010

Abstract

Najafian, G., A. Jafarnejad, A. Ghandi and R. Nikooseresht. 2011. Adaptive traits related to terminal drought tolerance in hexaploid wheat *(Triticum aestivum* L.*)* genotypes under field conditions. **Crop Breeding Journal 1(1):** 57-73.

To identify and characterize bread wheat *(Triticum aestivum* L.*)* genotypes adapted to terminal water deficit conditions, 51 superior hexaploid wheat genotypes together with commercial check cultivars were studied, in a two stages screening practice, for drought tolerance in Karaj, Kermanshah, Isfahan, Neishabour and Varamin filed stations under terminal water deficit conditions in 2002-2005 growing seasons. At the first stage grain yield was the main criteria for screening, but several other traits including 1000 grain weight, number of tillers m^{-2}, number of grains $spike^{-1}$, spike and peduncle length were also measured. Glaucousness of leaves and stems (covered by grayish or bluish waxy coating) was assessed and recorded, two week after anthesis, in the second step. Results of the first step revealed 16 genotypes as superior as compared to the checks. In the second stage of evaluation 10 genotypes with grain yield of equal to or greater than 6 t ha^{-1} were identified where *cv.* Pishtaz had 5.7 t ha^{-1}. Water productivity for some of the superior genotypes identified in the second stage was also measured in a separate experiment. The best genotype with good grain yield stability and high grain weight was WS-82-9 which also showed higher water productivity and is morphologically characterized between irrigated and rainfed adapted cultivars. This genotype had glaucousness on its leaves, in grain filling stage, which is a positive characteristic for tolerance to terminal moisture. It is concluded that growing of such cultivars with intermediate features (between rainfed and irrigated adapted cultivars), the yield gap between rainfed and irrigated wheat, to some extent, reduces and leads to enhancement of the average wheat grain yield in terminal drought prone areas.

Key Words: Grain yield, Glaucousness, Moisture stress, Grain yield, Stability and Water productivity

Introduction

Iran is one of the major wheat growing countries in west Asia. From 14.3 million tons of wheat produced in 2005, in Iran, 4.3 million tons was harvested from rainfed (4.3 mha) and 10 million tons from irrigated (2.6 mha) wheat growing areas (Anonymous, 2008; Jalal Kamali *et al.*, 2009). These statistics indicate that 2/3 of wheat growing areas suffer severe drought and moisture stress. Rainfed wheat growing areas are completely dependant on precipitation, and the average wheat grain yield in these areas is 1004 Kg ha^{-1} (Anonymous, 2005; Jalal Kamali *et al.,* 2009). The long term average of annual rainfall in Iran is 252 mm and reduced to 127.3 mm in 2007-2008, which was a severe dry season (Islamic Republic of Iran Meteorological Organization, 2010).

The average grain yield of irrigated wheat is 3786 Kgha^{-1}. Considerable proportions of 2.4 mha of irrigated wheat growing areas suffer from the shortage of irrigation water, particularly, in post anthesis stage (Jalal Kamali *et al.*, 2009 Anonymous, 2008). Records of up to 12 t ha^{-1} wheat have been reported from irrigated wheat in temperate agro-climatic zone in Iran, however, average grain yield in a great proportion of the irrigated wheat growing areas in this zone does not exceed 3-4 th^{-1}, due mainly to shortage of irrigation water in grain filling stage (Jalal Kamali *et al*., 2009). Hence, the average grain yield of irrigated wheat is less than 4 t ha^{-1} (Jalal Kamali *et al*., 2009; Anonymous, 2008). Drought seasons have frequently occurred in the last decade have intensified crop failure and economic loss to farmers. Since farmers have no access to adequate underground water resources, agricultural production including wheat has declined (Mohammadi and Karimpour Reihan, 2008).

National wheat breeding programs in Iran have been oriented for either irrigated or rainfed cropping systems. However, screening practices, in temperate agro-climatic zone, have been initiated to develop suitable and adapted bread wheat cultivars for wheat growing areas suffering from shortage of irrigation water in pos-anthesis stages (Najafian, 2009). Large numbers of hexaploid wheat were grown in two moisture conditions; normal and deficit irrigation. Cluster analysis was performed using stress tolerance index (STI), introduced by Fernandez (1992), for grain yield. These practices led to selection of 51 promising lines to be evaluated in this study (Najafian, 2009).

Traits and scheme of a breeding program addressing drought tolerance depend upon the level and timing of stress in target areas (Araus *et al.*, 2002). They reported that water use efficiency (WUE) and harvest index are desirable traits to be used for increasing grain yield under water stress conditions. However, they emphasized more on WUE, particularly, in areas where no additional irrigation water is available to the crop. Esmaeilzadeh *et al.* (2005) reported disagreements between genetic diversity determined by AFLP analysis and agronomic performance under drought conditions. Their study showed that drought tolerance as a complex trait is the output of different mechanisms controlled by different genetic backgrounds. Olivares-Villegas *et al.* (2007) reported that canopy temperature (CT) was the single most drought adaptive trait contributing to a higher performance, highly heritable, and consistently associated with grain yield phenotypically and genetically. Ghodsi *et al.* (2008) tested WUE and radiation use efficiency (RUE) in four bread wheat cultivars under different irrigation regimes. They found fast growing stages and grain filling as the most sensitive stages to moisture stress. Based on their report *cv.* Chamran was the most adapted cultivar to water stress conditions.

The main objective of this study was to screen, characterize and identify adaptive traits for post-anthesis drought tolerance in hexaploid wheat genotypes.

Materials and Methods

This study included two steps:

Step 1 (2002-2003 experiments):

Plant materials in this step were 51 bread wheat lines/cultivars which had been screened and advanced from a previous study carried out in 2001-2002 cropping season (Najafian, 2009). These 51 genotypes have been selected for their superior grain yield and grain plumpness under post-anthesis water deficit conditions (Najafian, 2009). Genotypes were divided into three groups based on phenology, (group 1 included early maturity, and the other two groups consisted of late maturity genotypes). Each group consisted of 17 genotypes and grown in three locations; Kermanshah, Isfahan and Varamin field stations, in temperate agro-climatic zone of Iran, in three experiments designated as water stressed$_1$ (WS$_1$), water stressed$_2$ (WS$_2$) and water stressed$_3$ (WS$_3$) using randomized complete block design (RCBD) with four replications in 2002-2003 cropping season. Three check cultivars; Marvdasht Cross Alborz and Azar-2, were included in each experiment. Plot No. 1-20, 21-40 and 41-60 belonged to WS$_1$, WS$_2$ and WS$_3$, respectively. Azar-2 and Cross Alborz that have been recommended as suitable genotypes for rainfed and supplementary irrigation condition were included as check cultivars.

Plot size was 6 × 1.2 = 7.2 m^2. Seed rate for each genotype was calculated based on 1000 grain weight and seed density of 400 seed m^{-2}. 250 kg ha^{-1} nitrogen as urea applied in three equal proportions at planting, stem elongation and heading. 100 kgha^{-1} triple super phosphate and 100 kgha^{-1} potassium sulfate, as base fertilizers were also applied before planting. Water stress was applied to all three experiments in spring from heading stage (when heading observed in 50% of wheat genotypes in each experiment). To do so, experiments were irrigated at heading stage and received no irrigation afterward.

Grain yield and 1000 grain weight (TGW) were measured for all genotypes in three experiments. Grain yield was harvested and weighed from 5 × 1.2 = 6 m^2 plot area. For TGW, 1000 grains were counted and weighed. Some other agronomic and morphological traits including; number of tillers m^{-2}, number of grains spike^{-1}, length of spike and peduncle, on 10 randomly selected stems were also measured in each plot. Considering large number of genotypes, the collected data for these traits will not be reported for all genotypes. Glaucousness on upper half of plants in each genotype was visually assessed and recorded as strong, medium or poor, in the second week following anthesis. Combined analysis of variance for grain yield was performed and means comparison was carried out using Duncan’s Multiple Range Test at the 5% probability level.

Step 2 (2003-2005 experiments):

Sixteen selected genotypes from step 1 experiment and four check lines/cultivars; Pishtaz, Cross Alborz, Azar-2 and Sardari, as recognized drought tolerant, were further studied in an adaptation trial grown in Karaj, Kermanshah, Isfahan and Neishabour under water deficit conditions from heading stage in two 2003-04 and 2004-05 cropping seasons (Table 3). The justification for inclusion of Azar-

2 and Sardari in the experiment was that these two cultivars are widely adapted cultivars in rainfed wheat areas and posses adaptive traits for drought stress conditions. Since one objective of this study was identification of adaptive traits for water deficit conditions in intermediate type (between rain-fed and irrigated wheat) lines, these cultivars as well as Pishtaz (adapted to irrigated conditions) were used.

Plot size and field management practices were similar to experiments in step 1. Grain yield was measured and combined analysis of variance was performed for 8 environments and mean comparison carried out using Duncan's Multiple Range Test at the 5% probability level. Grain yield stability and adaptation were tested using additive main effects and multiplicative interaction (AMMI) method (Gauch 1992). For AMMI analysis, means of two cropping seasons were used; therefore, four environments were analyzed.

Based on results of the first cropping season, genotypes WS-82-6, WS-82-7, WS-82-9, WS-82-13, WS-82-14 and WS-82-16, *cv.* Pishtaz and a breeding line AR-DT-7 from advanced trial were examined for water productivity in a separate experiment in 2004-05 cropping season. Three irrigation regimes were applied; T1: well-irrigated treatment with application of 3940 m^3 ha^{-1} for irrigation in spring when there was no more rainfall and irrigation was necessary up to the maturity; T2: water deficit irrigation treatment defined as irrigation up to 50% of the plots were at heading stage with application of 1830 m^3 ha^{-1}; and T3: severe drought stress treatment defined as irrigation up to the jointing stage of the plots with application of 840 m^3 ha^{-1}, water for irrigation. To calculate water productivity, grain yield was divided by water used for irrigation. Rainfall received before application of irrigation treatments was not considered in calculations of water productivity, because it was received in all treatments.

Results and Discussion

Step 1 (2002-2003 experiments):

Combined analysis of variance showed that effects of location, genotype and G × L interaction on grain yield were highly significant, in all three experiments, implying differences among the environments, genotypes and the response of genotypes to different environments (Data not shown). Mean comparisons has been presented in Table 1. Summary of result for each experiment is presented and discussed as follows.

Experiment WS1 (early maturity group):

Mean comparison, for this experiment, showed that entries; WS$_1$-7, WS$_1$-19, WS$_1$-5, WS$_1$-18 and WS$_1$-16 with grain yield of greater than 6 t ha^{-1} performed well under terminal moisture stress (Table 1). *cv.* Marvdasht a high yielding cultivars adapted to well irrigated conditions (Saidi *et al.* 2005) could not compete with other lines and showed low grain yield. *cv.* Marvdasht is relatively late maturity and was affected more than the other genotypes by terminal water stress, hence, its grain yield drastically reduced to 4.9 t ha^{-1} under the condition of this experiment (Table 1 and 2).

Table 1. Mean of grain yield (t ha^{-1}) for bread wheat genotypes in WS$_1$, WS$_2$ and WS$_3$ experiments in step 1 in the 2002-2003 cropping season.

WS$_1$		**WS$_2$**		**WS$_3$**	
Genotype No.	**Grain yield**	**Genotype No.**	**Grain yield**	**Genotype No.**	**Grain yield**
7	6.596^{a}	36	6.273^{a}	45	6.262^{a}
19	6.316^{ab}	27	6.190^{a}	52	6.171^{ab}
5	6.150^{abc}	26	5.987^{ab}	51 (Bahar)	6.014^{abc}
18	6.045^{abc}	30	5.683^{ab}	46	5.948^{abcd}
16	6.004^{abc}	33	5.761^{abc}	60	5.748^{abcde}
20	5.878^{abc}	34	5.755^{abc}	47	5.734^{abcde}
11	5.865^{abc}	25	5.639^{abc}	48	5.710^{abcde}
17 (Zagross)	5.851^{abc}	28	5.626^{abc}	41 (Marvdasht)	5.671^{abcde}
13	5.801^{abc}	21 (Marvdasht)	5.602^{abc}	53	5.667^{abcde}
10	5.757^{abc}	31	5.507^{abcd}	56	5.584^{abcde}
8	5.733^{abc}	35	5.486^{abcd}	54	5.583^{abcde}
15	5.700^{abc}	39	5.427^{abcd}	50	5.426^{abcde}
14	5.645^{abc}	37	5.417^{abcd}	44	5.370^{abcdef}
9	5.636^{abc}	32	5.408^{abcd}	55	5.331^{abcdef}
4	5.516^{abcd}	38	5.356^{abcd}	49	5.262^{bcdef}
6	5.457^{abcd}	29	5.332^{abcd}	42 (Cross Alborz)	5.199^{cdef}
12	5.245^{bcd}	40	5.154^{bcd}	57	5.046^{def}
1 (Marvdasht)	4.948^{cde}	24	4.896^{cde}	58	4.988^{ef}
2 (Cross Alborz)	4.379^{de}	22 (Cross Alborz)	4.529^{de}	59	4.507^{fg}
3 (Azar-2)	3.959^{e}	23 (Azar-2)	4.166^{e}	43 (Azar-2)	4.129^{g}

Means, in each column, followed by at least one letter in common are not significantly different at the 5% probability level-using Duncan's Multiple Range Test.

WS$_1$, WS$_2$ and WS$_3$: water stress 1, water stress 2 and water stress 3, respectively.

Cross Alborz line and *cv.* Azar-2 adapted to rainfed cropping system did not show high grain yield (Table 1). Azar-2 as an adapted cultivar to rainfed conditions with thin and weak stems (Najafian *et al.*, 2008) could not stand pre-anthesis irrigation and lodged in all experiments. From this set of genotypes, WS_1-5, WS_1-7, WS_1-10, WS_1-13, WS_1-15, WS_1-17, WS_1-18 and WS_1-19 were selected and considered for being studied in the second step. The average of days to maturity in this experiment was shorter than the other two experiments (Table 2). One of the spring bread wheat cultivars, Zagross, adapted to rainfed conditions performance satisfactory under conditions of this study, due mainly to its earliness (Table 1 and 2). Najafian (2009) also reported of satisfactory performance of Zagross under terminal drought stress conditions.

Experiment WS2:

Mean comparison showed that genotypes WS_2-36, WS_2-27 and WS_2-26 as the high yielding entries (Table 1). *cv.* Marvdasht, check cultivar, had greater grain yield in this experiment as compared to its grain yield in WS_1 experiment, but lesser than some of the other new lines (Table 1 and 2). From experiment WS_2, genotypes WS_2-27, WS_2-31, WS_2-32, WS_2-34 and WS_2-36 were selected genotypes for the second step in this study considering some characteristics such as grain yield, grain plumpness and higher 1000GW.

Experiment WS_3:

Mean comparison showed that WS_3-45, WS_3-52, WS_3-51 and WS_3-46 were the top high yielding genotypes (Table 1). The genotypes in this experiment were also late maturity (Table 2). Therefore, *cv.* Marvdasht as an adapted cultivar in well irrigated and Cross Alborz as a suitable line for supplementary irrigation conditions showed higher grain yield as compared to experiment SW_1, however, their grain yields were lower than some of the other new lines (Table 1). From this set of entries, WS_3-46, WS_3-54 and WS_3-60 were selected and considered to be included in to the second step in this study using desirable agronomic concerned traits.

Table 2. Days to heading (DHE) and days to maturity (DMA) for bread wheat genotypes in WS_1, WS_2 and WS_3 experiments in step 1 in the 2002-2003 cropping season.

WS1	DHE	DMA	WS2	DHE	DMA	WS3	DHE	DMA
1 (Marvdasht)	167	206	21 (Marvdasht)	168	207	41 (Marvdasht)	167	207
2 (Cross Alborz)	166	202	22 (Cross of Alborz)	167	203	42 (Cross Alborz)	165	201
3 (Azar-2)	166	202	23 (Azar-2)	166	202	43 (Azar-2)	165	202
4	160	200	24	167	204	44	166	204
5	163	203	25	166	205	45	165	205
6	159	202	26	164	204	46	166	205
7	162	203	27	166	205	47	166	205
8	161	203	28	165	205	48	167	206
9	160	203	29	167	204	49	165	205
10	162	201	30	164	203	50	166	205
11	160	202	31	164	204	51 (Bahar)	168	203
12	161	201	32	166	205	52	168	203
13	159	201	33	163	203	53	167	204
14	159	199	34	164	203	54	167	205
15	160	200	35	166	205	55	166	205
16	162	203	36	167	206	56	166	204
17 (Zagross)	160	200	37	168	206	57	166	205
18	161	203	38	167	205	58	167	206
19	164	203	39	167	206	59	165	204
20	164	204	40	166	205	60	167	205
Mean	**162**	**202**	**-**	**166**	**204**	**-**	**166**	**204**

WS_1, WS_2 and WS_3: water stress 1, water stress 2 and water stress 3, respectively.

Step 2 (2003-2005 experiments):

Combined analysis of variance for grain yield showed significant genotype, year × location and year × location × genotype interactions (Table 3). Entries WS-82-12, WS-82-13, WS-82-7, WS-82-16, WS-82-14, WS-82-8, WS-82-6, WS-82-9, WS-82-10 and WS-82-18 had grain yield equal or greater than 6 t ha^{-1} which is a desirable grain yield under moisture stress conditions (Table 4). AMMI analysis showed significant genotype and G × E interaction effects on grain yield. Interaction Principal Components; IPC1 and IPC2 were also significant (Table 5). There was significant effect of location on grain yield which shows the climatic homogeneity of field stations. Plotting of interaction effects for grain yield of genotypes and locations based on IPC1 and IPC2 showed a general stability for genotypes WS-82-5, WS-82-16, WS-82-19, WS-82-13, WS-82-20, WS-82-6, WS-82-9, WS-82-12 and WS-82-15, as their IPC1 and IPC2 values were close to zero at the cross point of the two axes (Fig. 1). Lower IPC value shows less interaction, therefore, greater stability (Gauch, 1992; Najafian *et al.*, 2010).

Water productivity for the experimental lines is presented in Fig. 1. WS-82-9 had highest water productivity (4.3 kg m^{-3}) under the third irrigation regimes which was the severe moisture stress condition (Fig. 1). Therefore, WS-82-9 was considered as the drought tolerant genotype. T2 is better corresponded to the water deficit conditions in target areas (Fig 2). WS-82-9 better adapted to the T2 and T1 irrigation regimes (Fig. 1).

Some of the agronomic characteristics of check cultivars in step 1 were compared with the selected line, WS-82-9 (Table 6). Higher 1000 grain weight, longer peduncle and lower number of grains spike^{-1} in WS-82-9 were comparable with rainfed adapted cultivars, and key adaptive attributes for terminal drought tolerant genotypes. These are desirable features of adapted wheat genotypes to rainfed cropping systems, where drought is the main reducing factor of grain yield.

Discussion

The genetic variation in bread wheat genotypes for response to different water deficit regimes was translated in differences in their grain yield.

Table 3. Summary of combined analysis of variance for grain yield in 2003-2005 cropping seasons.

S. O. V.	d. f.	SS	MS
Year (Y)	1	25.756	25.756
Location (L)	3	2.606	0.870^{ns}
Y × L	3	122.449	40.817**
Replication (Y × L)	16	27.688	1.730
Genotype (G)	19	138.529	7.291**
G × L	57	74.692	1.310^{ns}
G × Y	19	24.854	1.308^{ns}
G × L × Y	57	58.126	1.020**
Error	304	101.306	0.333
C. V. (%) = 9.95			

**: Significant at the 1% probability level.

ns: Non-significant

Table 4. Mean of grain yield (t ha^{-1}) for bread wheat genotypes in step 2 experiments in 2003-2005 cropping seasons.

Genotype code	Grain yield	Rank
WS-82-1 (Pishtaz)	5.703^{ab}	15
WS-82-2 (Cross Alborz)	5.166^{b}	18
WS-82-3 (Azar-2)	4.554^{c}	19
WS-82-4 (Sardari)	4.240^{c}	20
WS-82-5	5.722^{ab}	14
WS-82-6	6.107^{a}	7
WS-82-7	6.231^{a}	3
WS-82-8	6.123^{a}	6
WS-82-9	6.089^{a}	8
WS-82-10	6.070^{a}	9
WS-82-11	5.885^{a}	12
WS-82-12	6.286^{a}	1
WS-82-13	6.272^{a}	2
WS-82-14	6.144^{a}	5
WS-82-15	5.681^{ab}	17
WS-82-16	6.159^{a}	4
WS-82-17	5.999^{a}	11
WS-82-18	6.011^{a}	10
WS-82-19	5.850^{a}	13
WS-82-20	5.685^{ab}	16

Means, in each column, followed by at least one letter in common are not significantly different at the 5% probability level-using Duncan’s Multiple Range Test.

Table 5. AMMI analysis for means of grain yield in step 2 experiments in 2003-2005 cropping seasons.

S. O. V.	d.f.	SS	MS	F-value	Probability	Variation defined (%)	Cumulative variation defined (%)
ENV	3	1.3046	0.43488	1.305	0.27288	-	-
GEN	19	69.2617	3.64535	10.939	0.00000	-	-
G×E	57	37.3499	0.65526	1.9663	0.00016	-	-
IPC1	21	21.4433	1.02111	3.06416	0.00001	57.41	57.41
IPC2	19	10.9663	0.57717	1.73198	0.03040	29.36	86.77
IPC3	17	4.9403	0.2906	0.87205	0.60783	13.23	100.00

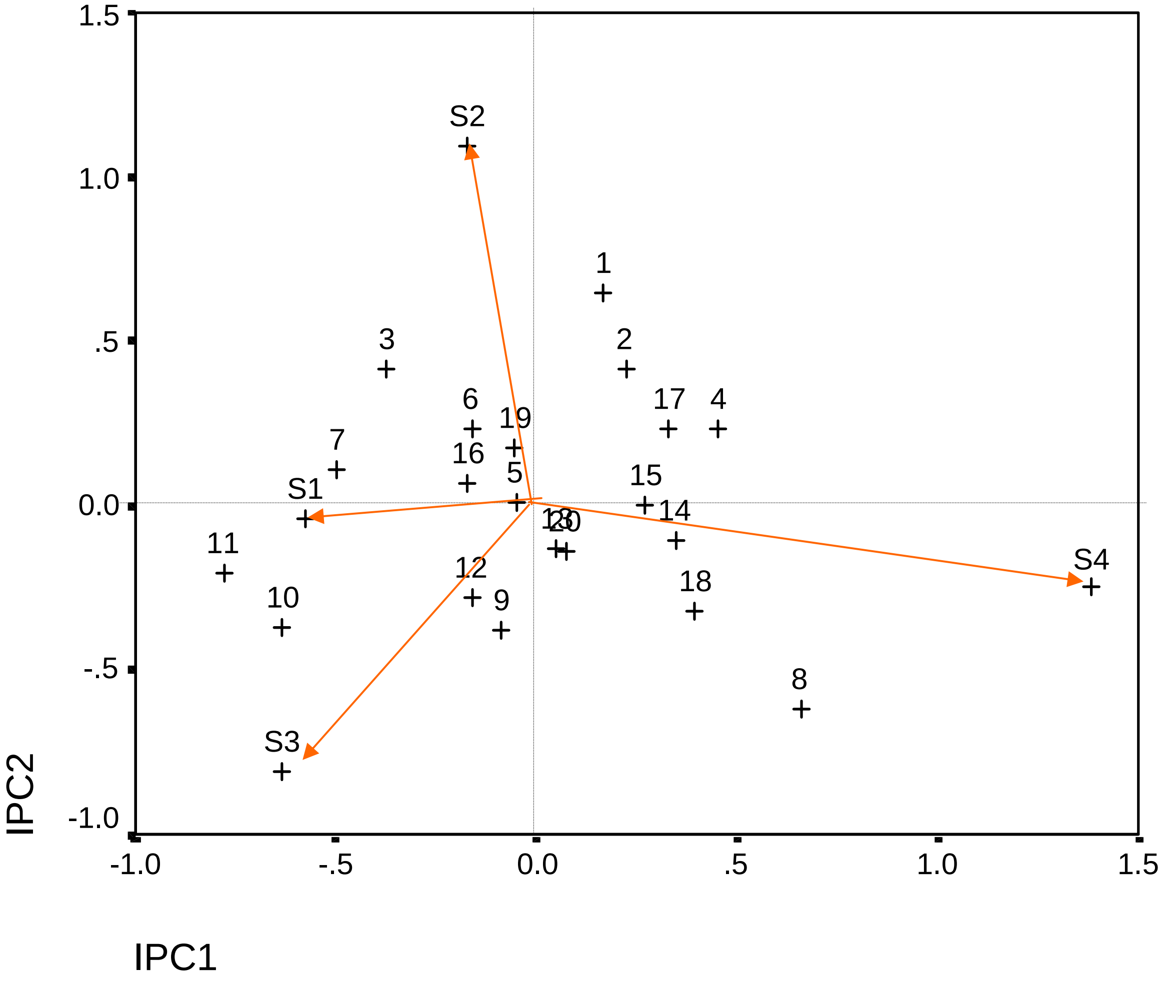

Fig. 1. AMMI biplot for grain yield for genotypes and four locations in step 2 based on IPC1 and IPC2 in step 2. S1: Karaj, S2: Kermanshah, S3: Isfahan, S4: Neishabour.

Table 6. Mean of some agronomic characteristics for some genotypes in step 2 experiments in 2003-2005 cropping seasons.

Cultivar/Line	TGW (g)	No. Tillers m^{-2}	Grain No. $spike^{-1}$	Spike length (cm)	Peduncle length (cm)
Marvdasht	25	950	62	8.7	34
Cross Alborz	31	850	38	8.1	45
Azar-2	37	1125	31	7.8	41
WS-82-9	36	925	44	8.8	42

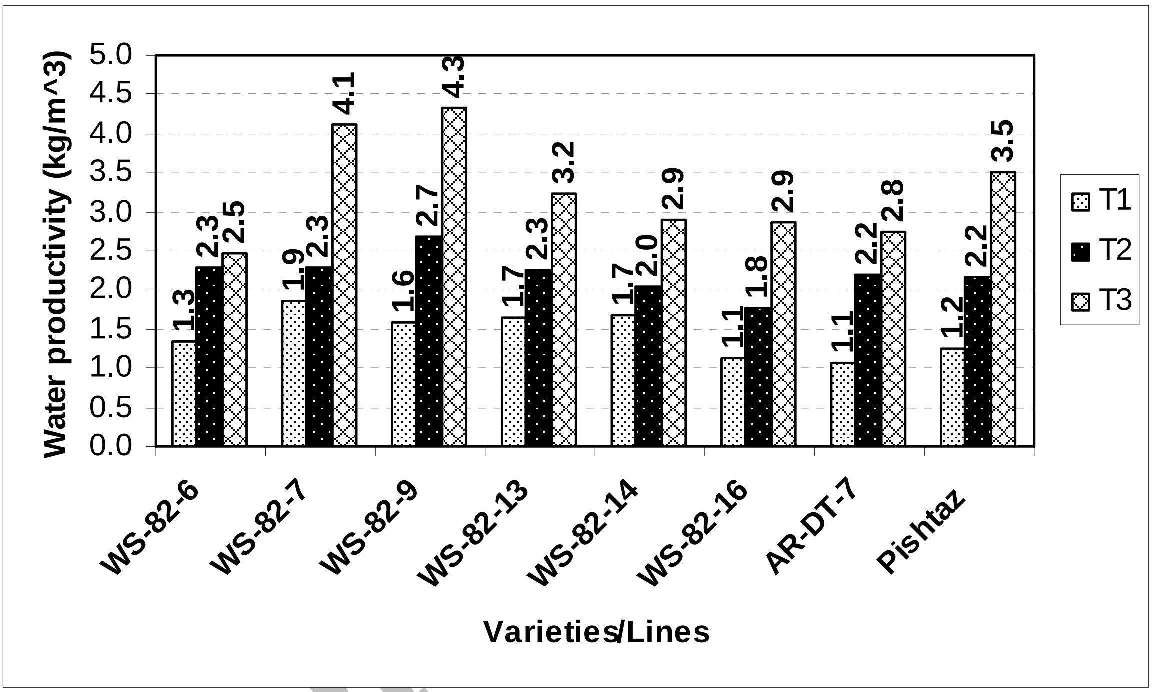

Fig. 2. Water productivity for some wheat genotypes and *cv.* Pishtaz.
T1: 3940 m^{-3} ha^{-1}; T2: 1830 m^{-3} ha^{-1} and T3: 840 m^{-3} ha^{-1} irrigation water up to physiological maturity, 50% heading and jointing stages, respectively.

Earliness is one of the key adaptive attributes in terminal drought tolerant genotypes which lead to escape from adverse effects of terminal moisture deficit stress. Most of the lines in WS_1 experiment in step 1 were early maturity genotypes which escaped from applied terminal moisture deficit stress and developed their grain very fast. Van Ginkel *et al.* (1998) also reported earliness as a desirable attributes in terminal drought stress prone environments. Genotype WS_2-27 was an advanced breeding line which also showed a reasonable performance in normal condition. This implies that adaptation to terminal drought and high yield potential in normal conditions could be combined in development of new cultivars adapted to terminal drought conditions. Rajaram (2000) also emphasized on incorporation of adaptive traits and high grain yield in wheat breeding programs. In WS_3 experiment, entry WS_3-51 (Bahar), which has been released as adapted cultivar for irrigated conditions in temperate agro-climatic zone of Iran, had also reasonable performance in well irrigated conditions. Analyzing the parentage of the selected lines from all three experiments in step 1 including; WS_1-7, WS_1-10, WS_1-15, WS_2-27 and WS_3-46 revealed that they have “Veery” genotype in their parentage (Table 7). This genotype is one of the derivatives of spring × winter crosses made in International Maize and Wheat Improvement Center (CIMMYT), which is recognized as a widely adapted genotype with good performance in favorable as well as in drought, heat and salinity prone conditions (Najafian and Jalal Kamali, 2004; Rajaram 2000; Rajaram and van Ginkel, 1996; Villareal and Rajaram, 1984). This attributes in “Veery” has been associated with the 1B/1R translocation (Najafian and Jalal Kamali, 2004; Rajaram and van Ginkel, 1996). It can be concluded that some of the selected genotypes in this study have acquired some genetic attributes from this widely adapted genotype (Table 7).

The second step experiment showed that the grain yield stability as a desirable attribute for drought tolerant genotypes. Some genotypes such as WS-82-7 had high water productivity and yield stability, but were susceptible to shattering. Considering desirable agronomic traits, water productivity and grain yield stability, WS-82-9 was identified as the superior genotype well adapted genotype to terminal drought stress condition. This genotype with grain yield of 6.089 t ha^{-1}, good grain quality, resistance to shattering and lodging (data not shown), and higher water productivity stood out among other genotypes in this study. This is in agreement with Araus *et al.* (2002) who emphasized on water use efficiency and water productivity as preferred selection criteria in water deficit prone conditions. Three check cultivars: "Cross Alborz", "Azar-2" and "Sardari" are adapted cultivars to drought prone and rainfed areas of Iran. Marvdasht cultivar is adapted to high input and well irrigated conditions and this was reflected in its peduncle length and grain weight in terminal water deficit conditions (Table 7).

However, WS-82-9 is an intermediate genotype between *cv.* Marvdasht and other two checks. Long peduncle in wheat which has been postulated source of stem reserve for remobilization in WS-82-9 was identical to Cross Alborz and Azar-2. Grain weight of WS-82-9 was also significantly heavier than Marvdasht, but similar to Azar-2. Lower grain no. spike^{-1} is also associated with terminal drought tolerance, as it implies that available assimilates easily met demands of fewer grains under water stress conditions. Grains spike^{-1} in WS-82-9 showed very similar with the other rainfed adapted cultivars (Table 7).

The glaucousness of leaves and stems was visually assessed in pos-anthesis phase in step 2 experiment, showed strong glaucousness in WS-82-9, medium for WS-82-19 and WS-82-20, while most of other genotypes had weak glaucousness on leaves and stems (data not shown). The strong glaucousness on leaves and stems in WS-82-9 during grain filling stage is also an adaptive attribute which reflects radiation. Consequently, cooler canopy temperatures as well as preservation of plant water content which otherwise are lost in transpiration. Richards *et al.* **(**1986) also reported that wheat genotypes with strong glaucousness on leaves and stems had cooler canopy temperatures and lost less water in transpiration in drought prone environments. It is postulated that WS-82-9 has inherited this trait from Iranian wheat landraces used in development of Maroon, Azadi and Alvand cultivars which have been designated as Mrn, Azd and Avd in its parentage (Table 7). Using landraces in development of new germplasm is to be considered as a key strategy for bread wheat breeding for marginal areas.

Table 7. Name and parentage for 16 superior genotypes selected from step 1 experiments in 2002-2003 cropping season.

Code of genotype in step 1 experiments	Name/Parentage	Code of genotype in step 2 experiment
-	Pishtaz	WS-82-1
-	Cross Aloborz	WS-82-2
-	Azar-2	WS-82-3
-	Sardari	WS-82-4
WS$_1$- 5	Shi#4414/Crow"S"//Fow-1	WS-82-5
WS$_1$- 7	WW33G/Veery "S"//Mrn/3/Attila/Tjn	WS-82-6
WS$_1$- 10	Shi#4414/Crow"S"//Veery "S"/Nac	WS-82-7
WS$_1$- 13	Cham-4/Dovin-2	WS-82-8
WS$_1$- 15	WW33G/Veery "S"//Mrn/4/HD2172/Bloudan//Azd/3/San/Ald"S"//Avd	WS-82-9
WS$_1$- 17	Zagross	WS-82-10
WS$_1$- 18	Azd/HD2172//Kayson/Glenson/3/1-70-28/Ning8201	WS-82-11
WS$_1$- 19	Tevee 'S'/Karawan 'S'	WS-82-12
WS$_2$- 27	WW33G/Veery "S"//Mrn/3/Attila/Tjn	WS-82-13
WS$_2$- 31	Cham-6/Mayon "S"	WS-82-14
WS$_2$- 32	Ns732/Her//Darab	WS-82-15
WS$_2$- 34	T. aestivum./Sprw "S"//CA8055/3/Bacanora 86	WS-82-16
WS$_2$- 36	Tevee"S"/Karawan "S"	WS-82-17
WS$_3$- 46	Ures/3/Fury//Sln/Aldan "S"/4/NS732/Her	WS-82-18
WS$_3$- 54	T. aestivum./Sprw "S"//CA8055/3/Bacanora 86	WS-82-19
WS$_3$- 60	Azd/HD2172//Pitoma/Cucurp 86	WS-82-20

References

Anonymous. 2005. Agricultural statistics, Vol. I, Field and Horticultural Crops. Ministry of Jihad-e-Agriculture, Tehran, Iran. (www.maj.ir). (In Persian).

Anonymous. 2008. Agricultural statistics, Vol. I, Field and Horticultural Crops. Ministry of Jihad-e-Agriculture, Tehran, Iran. (www.maj.ir). (In Persian).

Araus, J. L., G. A. Slafer, M. P. Reynolds, and C. Royo. 2002. Plant breeding and drought in C3 cereals: what should we breed for? Ann. of Bot. 89: 925-940.

Esmaeilzadeh Moghadam, M., R. M. Trethowan, H. M. William, A. Rezaei, A. Arzani, and A. F. Mirlohi. 2005. Assessment of genetic diversity in bread wheat genotypes for tolerance to drought using AFLPs and agronomic traits, Euphytica. 141: 147-156.

Fernandez, G. C. 1992. Effective selection criteria for assessing plant stress tolerance. In: Proceeding of Symposium on Adaptation of Vegetables and other Food Crops in Temprature and Water Stress Environment. 13-16 Aug. 1992. AVRDC, Taiwan.

Gauch H. G. 1992. Statistical analysis of regional trials: AMMI analysis of factorial designs. Elsevier, Amsterdam, Netherlands.

Ghodsi, M., M. R. Jalal Kamali, D. Mazaheri, and M. R. Chaichi. 2008. Water and radiation use efficiency in different developmental stages in four bread wheat cultivars under moisture stress conditions. Desert 12: 129-137.

Islamic Republic of Iran Meteorological Organization, 2010. Comparison of average annual rainfall of 2008-2009 crop season with long term and last crop season. http://www.irimo.ir/upload/publication/mountly/averagecompare/gadostanshahrivar88.pdf. Accessed on 02 March 2010 (In Persian).

Jalal Kamali, M. R., H. Asadi and T. Najafi Mirak. 2009. Irrigated and dryland wheat research strategic program. Agricultural Research, Education and Extension Organization. 345pp. (In Persian).

Mohammadi, H, and M. Karimpour Reihan. 2008. The effect of 1991-2001 droughts on ground water in Neishabour plain. Desert 12: 185-197. (In Persian).

Najafian, G. and M. R. Jalal Kamali. 2004. Wide adaptation of “Veery” genotypes and its derivatives an example of homeostasis in wheat. Pp. 175-191. In: Key papers of the 8th Iranian Crop Production and Breeding Congress. The University of Guilan, Rasht, Iran. (In Persian).

Najafian, G. 2009. Drought tolerance indices, their relationships and manner of application to wheat breeding programs, Middle Eastern and Russian Journal of Plant Science and Biotechnology 3 (Special Issue 1): 25-34.

Najafian, G., M. R. Jalal-Kamali And J. Azimian. 2008. Description of Iranian grown wheat cultivars and promising lines based on standards of international union for the protection of new variaties of plants. Nashr-e-Amoozesh-e-Keshavarzi, Karaj, Iran. 208 pp. (In Persian).

Najafian, G., A. K., Kaffashi, and A. Jafarnezhad**.** 2010. Analysis of grain yield stability in hexaploid wheat genotypes grown in temperate regions of Iran using additive main effects and multiplicative interaction. J. Agric. Sci. Tech. 12: 213-222. (In Persian).

Olivares-Villegas, J. J., M. P. Reynolds, and G. K. McDonald. 2007. Drought-adaptive attributes in a Seri/Babax hexaploid wheat population, Functional Plant Bio. 34:189-203.

Rajaram, S. 2000. International wheat breeding: past and present achievements and future directions. Warren E. Kronstad Honorary Symposium, Oregon State University Extension Service, Special Report 1017.

Rajaram, S., and M. Van Ginkel. 1996. Yield potential debate: Germplasm vs. Methodology, or Both. Pp. 11-18. In: Reynolds, M.P., S. Rajaram and A. McNab, (eds.). Increasing yield potential in wheat: Breaking the barriers. Mexico, D.F.: CIMMYT.

Saidi, A., A. Akbari-Haghighi, F. Bakhtiar, M. R. Mehrvar, and Z. Nategh. 2005. Characteristics of improved bread wheat, durum wheat, barley, triticale and rye cultivars released in Iran during 1930-2003. Nashr-e-Amoozesh-e-Keshavarzi, Karaj, Iran. 105pp.

Van Ginkel M., D. S. Calhoun, G. Gebeyehu, A. Miranda, C. Tain-You, R. Pargas Lara, R. M. Trethowan, K. Sayre, J. Crossa, and S. Rajaram. 1998. Plant traits related to yield of wheat in early, late or continuous drought conditions. Euphytica. 100: 109-121.

Villareal R., and S. Rajaram. 1984. Semi-dwarf bread wheat. Names: parentage; pedigrees; origin. Mexico, D.F.: CIMMYT.

Richards, R. A., H. M. Rawson, and D. A. Johnson. 1986. Glaucousness in wheat: its development and effect on water-use efficiency, gas exchange and photosynthetic tissue temperatures. Aust. J. Plant Physiol. 13: 465-473.