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Introduction of New Landrace Varieties Adapted to Drought Stress

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Authors' contributions

This work was carried out in collaboration between all authors. Author BH designed and supervised the framework of the study and edited manuscript file. Author LGR wrote the manuscript and author AD was adviser of the work. All authors read and approved the final manuscript.

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ABSTRACT

Screening and introducing landrace varieties (as useful cultigens) is important for cultivation under abiotic stresses in temperate regions with low precipitations. To evaluate the response of wheat (*Triticum aestivum* L.) landraces to post-heading drought stress, two types of cultigens including commercial cultivars and landrace varieties were cultivated under drought stress and fully irrigated conditions in 2010/11 and 2011/12. Drought stress reduced grain yield by 22 and 19% compare to fully irrigated conditions in the first and second year respectively. Regression models indicated that genotypes with higher grain yield under fully irrigated had higher grain yield under drought conditions. Thousand- grain weight and harvest index strongly affected by drought stress although plant height and heading date were less affected. Under drought condition, the highest grain yield (5.8-8.1 ton ha^{-1}) was found in the landrace varieties KC4557, KC4633, KC4542, KC4862, KC3891 and KC4551 in both years. Grain yield of Shiraz and Cross-Boolani were 4.7 and 5.5 ton ha^{-1} respectively. Significant correlations of grain yield in fully irrigated (Yp) and drought (Ys) conditions with the indices of mean productivity (MP) and stress tolerance index (STI) support the idea that these indices are able to discriminate genotypic differences under drought conditions. Heading was

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not significantly correlated with grain yield. Therefore, selection for earliness does not affect grain yield under drought stress. Analysis of principal components indicated that the landrace varieties numbers KC4557 and KC4551 in 2010/11 and KC4633, KC4537, KC4862 and KC3891 in 2011/12 had higher grain yield under drought conditions. Results showed that landrace varieties had better performance than commercial cultivars under drought and KC4557, KC4633, KC4542, KC4862, KC3891 and KC4551 were more tolerant to drought conditions.

Keywords: Cultigens; drought; heading; landrace; wheat.

1. INTRODUCTION

Drought stress restricts normal growth and the productivity of wheat cultivations. Increasing global climate changes makes the situation more serious in arid and semi-arid regions [1,2]. In the most areas of Iran, wheat cultivations encounter serious drought stresses especially after heading and anthesis stages that result in reduced grain yield [3].

Evaluating plant responses to drought are highly focused due to grain yield losses under post-anthesis water deficit conditions [4,5]. Indentifying productive wheat for drought conditions is a major objective of research works and plant breeding programs [6,7]. Breeding plants for dried regions is complicated due to the lack of fast and reproducible screening techniques and the inability to routinely create precise and repeatable water deficit conditions where a large amount of genotypes can be evaluated [8]. Genetic variation and raw germplasms provide new opportunities for effective screening of stable and high yielding genotypes under different climatic conditions [9]. Screening various germplasms is the first step of a basic program for selection of candidate genotypes for targeted regions. One of the rich genetic resources are the local landraces harboring valuable genes against adverse effects of biotic and abiotic stresses [10]. The features of landrace varieties can be incorporated into commercial cultivars and inbred lines by under-field hybridizations or transformation methods.

A landrace is a local variety of a domesticated plant species which has developed largely by natural processes, by adaptation to the natural and cultural environment in which it lives. It differs from a formal breed which has been selectively bred deliberately to conform to a particular formal, pure breed standard of traits. Landraces are usually more genetically and physically diverse than formal breeds. Landraces are varieties with high capacity to tolerate biotic and abiotic stress, resulting in high yield stability and an intermediate yield level under a low input agricultural system [10]. Landraces are grown from seeds which have not been systematically selected and marketed by seed companies or developed by plant breeders. Landraces refer to all those cultigens that are highly heterogeneous, but with enough characteristics in common to permit their recognition as a group. This includes all cultigens cultivated without any specific nomenclature and value. A landrace identified with a unique feature and selected for uniformity over a period of time for maintenance of the characteristic features of the population can evolve into a farmers' variety or even a modern cultivar as in many crops. The genetic structure of wheat landraces shows that they have undergone an evolutionary event to survive under various conditions of environments. The combined effects of natural and human selections have led to architecture of genotypes representing different combinations of traits, such as cold, heat or drought tolerance, early growth vigor, time to heading and maturity [11].

Screening genotypes for cultivation under stressed environments is based on stress-adaptive properties [12]. Stress tolerance (TOL) index was defined as the difference in grain yield of genotypes between stress (Ys) and non-stress (Yp) conditions but mean productivity (MP) is the average of Ys and Yp [13]. As defined by Fernandez [14], stress tolerance index (STI) is efficient in discriminating high yielding genotypes under both stress and normal conditions. Geometric mean productivity (GMP) is one of the other statistical indices, which is often used for screening tolerant genotypes dealing with water deficit conditions [8]. Mohammadi et al. [15] screened durum wheat cultivars for drought tolerance and found high variations in stress sensitivity index (SSI). The index MP has been used to identify high yielding genotypes in both stressed and non-stressed environments [16]. An efficient selection criterion is supposed to distinguish the genotypes that express uniform superiority in both stressed and non-stressed environments from the genotypes that are favorable only in one of environments [17].

Given the importance of genetic variation in better screening of genotypes under stressed environments and natural and cultural adaptation of landrace cultigens to environmental conditions, the main purposes of this study were to evaluate the response of wheat landrace varieties and commercial cultivars under water deficit conditions and to determine the efficacy of different statistical indices for more precise screening of genotypes under drought condition. The meteorology data show that the site of study faces with high temperature and low and/or no precipitations from April to June, a period that is coincident with the reproductive stages of wheat. Therefore, it is very important to evaluate landrace cultigens and screen genotypes for involving in breeding and hybridization programs for drought tolerance.

2. MATERIALS AND METHODS

2.1 Plant Materials and Field Condition

The present study was conducted during 2010/11 and 2011/12 growing seasons in the Research Farm of College of Agriculture, Shiraz University, Shiraz, Iran. Two commercial cultivars (Shiraz and Cross-boolani) as control and thirty three landrace varieties were selected for drought tolerance screening (Table 1). The landrace varieties collected from different regions of Iran and are highly variable morphologically. The name of landraces preceded with KC (Table 1) that shows these genotypes are collected by the Karaj Center for Agricultural Researches, Karaj, Iran.

In each year, the experiment was arranged as a split plot based on randomized complete block design with three replications. One of main plots allocated to fully irrigated and the other assigned to drought stress condition. Genotypes were allocated to the sub plots. In plots that allocated to drought stress, plants were fully watered (100% field capacity) until the time that 50% of genotypes headed and from that time irrigation stopped until plants were harvested. Genotypes in normally irrigated trial fully watered (100% field capacity) throughout growing season.

Prior to sowing, the field was fertilized with 50 kg N ha^{-1} and 110 kg triple superphosphate ha^{-1}. Each experimental plot was 3 × 2 m. On November 2010/11 and 2011/12, the seeds of the genotypes were sown at a depth of 5 cm with plant density of 400 seed m^{-2}. Amount of 50 kg N ha^{-1} was used at each of the stem elongation and heading stages. The soil texture was sandy clay with pH 7. Weeding was performed by using the herbicide Total (40 g ha^{-1} at tillering stage) and manually in all stages. The meteorology data at the experimental station is presented in Table 2.

2.2 Data Collection and Statistical Analyses

Number of day to heading (NDH) was calculated as the difference of sowing date and the time that spike emerged in 50% of plants in each plot. Plant height (PH) was measured from the ground level to the tip of spike during grain filling.

Table 1. Number and name of the wheat commercial cultivars and landrace varieties

Number	Genotype name	Number	Genotype name	Number	Genotype name
1	KC4565	13	KC4557	25	KC4543
2	KC4568	14	KC4495	26	KC3885
3	KC4818	15	KC3893	27	KC2165
4	KC4500	16	KC4633	28	KC4929
5	KC4548	17	KC4604	29	KC4595
6	KC4864	18	KC2177	30	KC3878
7	KC4617	19	Cross Boolani	31	KC3891
8	KC2194	20	KC4619	32	Shiraz
9	KC3892	21	KC4618	33	KC4512
10	KC4847	22	KC4537	34	KC4492
11	KC4567	23	KC4542	35	KC4551
12	KC2172	24	KC4862		

The initial KC in nomenclature of landraces shows that these genotypes are collected by the Karaj Center for Agricultural Researches, Karaj, Iran. Cross Boolani and Shiraz are the commercial wheat cultivars

Table 2. The meteorology data for the Research Farm of College of Agriculture, Shiraz, Iran

Month	Temperature (℃)				Relative humidity (%)		Precipitation (mm)	
	2010		2011					
	Max	Min	Max	Min	2010	2011	2010	2011
November	18.20	- 6.94	12.47	- 3.50	30.85	52.67	31.0	79.5
December	12.30	- 5.79	12.88	- 4.11	42.93	58.28	48.5	61.0
January	10.26	- 1.30	10.48	- 2.52	48.98	55.45	107.5	127.0
February	16.27	0.89	13.43	- 1.72	49.47	42.82	76.8	27.0
March	20.31	3.32	19.06	3.17	50.02	43.35	30.5	45.0
April	27.50	7.83	26.82	7.51	48.27	35.05	0.00	0.00
May	34.10	12.39	31.43	11.58	24.47	26.15	0.00	0.00
June	35.77	15.30	35.23	14.08	20.92	22.19	0.00	0.00
Total							262.8	339.5

In each plot, 10 plants were selected for counting number of spikelet per spike (SPS) and grain number (GN) per spike. A number of thousand grains weighed (TGW) for each genotype. Grain yield (GY) and biological yield (BY) as per square meter were also measured after harvesting plants from the field. Harvest index (HI) was calculated by using the following formula:

$$HI = \frac{GY}{BY} \times 100$$

Correlation analysis was performed for traits and statistical indices under both fully irrigated and drought stress treatment. Drought tolerance indices were calculated using the following formulas:

- SSI=1-(Ys/Yp))/SI where SI=1-(Ys/Yp), Ys and Yp are the mean yield of each genotype under drought and fully irrigated conditions respectively, Ys and Yp are the mean yield of all genotypes under stressed and fully irrigated conditions, respectively [13]. STI [14] and TOL [12] were calculated as [(Yp) × (Ys)]/ $(Yp)^2$ and Yp-Ys respectively. MP was quantified by (Yp+ Ys)/2 formula [12].

-Geometric mean productivity (GMP) and harmonic mean (HM) were calculated based on the formulas of $\sqrt{Yp \times Ys}$ and 2 (Ys) × (Yp)/ (Ys+ Yp) respectively [14].

Principal components analysis was used to classify the traits into major components [18]. Analysis of variances (ANOVA) was performed using SAS 9.2 (SAS, 2004) software and the means compared by using the least significant differences (LSD) test.

3. RESULTS AND DISCUSSION

3.1 Effect of Drought on Changes in Traits

ANOVA results showed that the effect of irrigation regimes on traits except PH was significant (Table 3). Compare to fully irrigated condition, losses in traits under drought were higher in 2010/11 than in 2011/12 indicating the role of genotype by year interactions (Fig. 1).

Fig. 1 shows that heading date was less affected by drought compare to other traits. This is because in drought stress trial, irrigation was stopped at the middle of heading stage when nearly 50% of spikes headed in each genotype. Therefore, changes in NDH are not clearly related to drought stress effects. The mean NDH in fully irrigated condition was 181.7 and 182.1 in the first and second year respectively (Suppl. Table 1).

Drought had the lowest effect on PH possibly due to the fact that the highest development in plant height forms nearly at heading and pollination stages that were coincident with the time of drought stress initiation (Fig. 1). The mean PH reduced by nearly 2 cm in drought stress condition compare to the fully irrigated trial. Landrace varieties were taller than commercial cultivars in two trials (Suppl. Table 1). The commercial cultivars of Cross-Boolani (70.6 and 57.0 cm in the first and second year respectively) and Shiraz (53.8 and 49.2 cm) were shorter than all landraces showing these cultivars has been selectively bred deliberately to conform to a particular formal and pure breed standard of traits. One of main features of landrace varieties is high plant height and their sensitivity to stalk lodging although they are less sensitive to deep sowing compare to bred varieties.

In 2010/11, the highest SPS (15.0) was found in the landrace numbers 13, 22 and 27, while the landrace numbers 10, 4 and 1 showed the lowest SPS (12.0 to 12.7). In second year, the highest (16.2 to 16.7) SPS belonged to the landrace numbers 13, 14 and 35 while the lowest (13 to 14.3) found in the landrace numbers 30, 4 and 1 (Suppl. Table 2). Mean SPS of Cross-Boolani in fully irrigated and drought conditions were 13.6 and 13.3 in 2010/11 and 14.7 and 14.3 in 2011/12 respectively. For Shiraz cultivar, SPS varied from 13 to 14 in drought and fully irrigated conditions in 2010/11 and from 14.3 to 15.6 in 2011/12 respectively.

Post-heading water deficit caused 15 and 9% reductions in GN in the first and second year respectively (Fig. 1). Similar results were obtained in Dencic et al. [19] study by evaluating wheat cultivars and landraces under low moisture regimes. Averaged over both normally irrigated and drought stress, the highest and lowest GN belonged to the landrace numbers 31 (33.8 in first and 32.0 in second year) and 4 (22.3 and 24.1 in the first and second year respectively) (Suppl. Table 2). Cross-Boolani yielded 28 and 27.6 grain per spike in fully irrigated and drought trials in 2010/11 respectively and 27.3 and 26.3 grain in 2011/12 trials. In Shiraz cultivar, GN varied from 24.3 to 31.3 in drought and fully irrigated conditions in the first year and from 27.6 to 29.3 in the second year. Generally, the highest GN in stress condition belonged to the landrace numbers 13, 31 and 35. Ashfaq et al. [20] studied the association of wheat morphological traits with GY and concluded that GY can be improved by selecting genotypes with higher SPS and GN.

Drought stress reduced biological yield by 7 and 13% in 2010/11 and 2011/12 respectively (Fig. 1). Drought stress at anthesis leads to yield loss by reductions in thousand grain weight, and if accompanied by high temperatures significantly reduces biological yield and harvest index [21]. The landrace numbers 22 (1699 g m^{-2}), 13 (1624.5 g m^{-2}), 31 (1600.5 g m^{-2}), 17 (1556.5 g m^{-2}) and 24 (1550.5 g m^{-2}) in 2010/11 and 23 (1624 g m^{-2}), 22 (1581.5 g m^{-2}), 18 (1560 g m^{-2}), 20 (1555.5 g m^{-2}), and 31 (1530 g m^{-2}) in 2011/12 had higher BY than other genotypes under both drought stress and fully irrigated conditions (Suppl. Table 3). The amounts of BY in landrace number 31 were statistically similar in both years. The highest losses in BY was observed in the landraces number 1 (18%), 26 (28%) whereas the lowest reduction recorded for landrace numbers 13 (6%) and 15 (4%) respectively.

TGW reduced by 30 and 17% under drought stress in 2010/11 and 2011/12 respectively (Fig. 1). In present study, TGW varied from 18.7 to 38.2 g in 2010/11 and from 22.3 to 36.3 g in 2011/12 (Suppl. Table 3). In both years, the highest TGW belonged to the landrace numbers 13, 16, 24, 22, 27, 31 and the cultivar Cross-Boolani. Raynolds et al. [22] reported that post-anthesis drought stress reduces grain filling rate and consequently wheat grain weight.

Post-heading drought stress reduced grain yield by 22 and 19% compare to fully irrigated conditions in the first and second year respectively (Fig. 1). Regression analysis

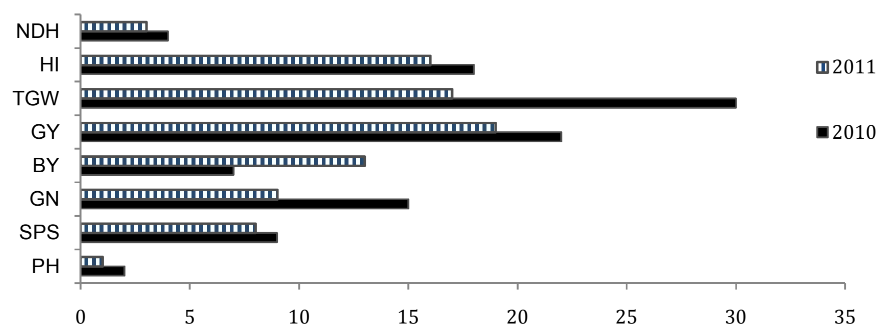

Fig. 1. Reductions (%) in agronomic traits under drought stress compare to fully irrigated conditions in 2010/11 and 2011/12. NDH: number of day to heading, PH: plant height, SPS: spikelet per spike, GN: grain number, TGW: thousand- grain weight, BY: biological yield, GY: grain yield, HI: harvest index

indicated positive relation between grain yield under fully irrigated and drought conditions in both growing seasons (Fig. 2). This shows that genotypes with higher grain yield under fully irrigated conditions had higher grain yield under drought stress and that yield potential under irrigated conditions could be an indication for better performance under water limited condition. Under drought stress, Cross-Boolani and Shiraz cultivars yielded 539 and 476 gm^{-2} in 2010/11 and 569 and 479 gm^{-2} in 2011/12 respectively (Suppl. Table 4). Combined data of two years indicated that the highest and lowest GY belonged to the landrace numbers 31 (819, 627 gm^{-2} in 2010/11 and 2011/12 respectively) and 30 (423, 273 gm^{-2} in 2010/11 and 2011/12 respectively). In 2010/11, the highest GY were 917 gm^{-2} (landrace number 27) under fully irrigated condition) and 793 gm^{-2} (landrace number 31 under drought stress). In second year, the landrace numbers 13 (723 gm^{-2}) and 30 (307 gm^{-2}) had the highest and lowest GY under drought conditions respectively. The landrace numbers 13, 14, 16, 22, 24, 31 and 35 had high GY under both drought stress and fully irrigated conditions in the first growing season. In second year, the landrace numbers 13, 31, 22, 35 and 16 had high GY under both conditions. Therefore, the landrace numbers 31, 13, 16, 22, 24 and 35 produced higher grain yield in two years under both stressed and non-stressed conditions. Due to drought stress, Cross-Boolani and Shiraz cultivars had 35 and 19% losses in 2010/11 and 20 and 10% in 2011/12 trials. Alaei et al. [23] also confirmed differences in the performance of wheat genotypes under drought and well-watered conditions.

The weight of harvested total grain as a percentage of total plant weight of the crop is an important character that can be used for selection of high yielding crops. In most cases, the improvement in harvest index has been a consequence of increased grain population density coupled with stable individual grain weight [24]. Compare to well-irrigated condition, HI reduced by 18 and 16% under drought in 2010/11 and 2011/12 respectively (Fig. 1). In the first and second year, HI averaged 48.1% and 40.9% under fully irrigated condition while under drought stress conditions it was 39.0% and 34.3%, respectively. The landrace numbers 27 (46.3%, 51.8%), 6 (47.2%, 46.7%) and 13 (49.1%, 43.4%) had highest HI (Suppl. Table 4). Having the highest HI, the landrace numbers 27, 13, 31, 16, 24 and 35 had also high grain yield in both years. HI varied for the commercial cultivars Shiraz (41.1%, and 35.0%) and Cross-Boolani (43.4%, and 45.5%) in first and second year.

3.2 Correlations of Traits

In first year, GY had significant correlations with TGW (r= 0.88**, r= 0.72** under fully irrigated and drought conditions respectively), HI (r= 0.63**, r = 0.0.71**), SPS (r= 0.67**, r = 0.59**) and GN (r= 0.59**, r = 0.36**). Grain yield was significantly correlated with the same traits in the second year (Table 4). Results of other studies indicated that positive and significant relationships exist between GY, SPS, GN and HI under drought stress [25,26].

Correlation analysis for statistical indices indicated positive and significant correlations among each of Yp and Ys with MP, GMP, HMP and STI in both years (Suppl. Table 5). SSI had negative correlations (r= -0.64 and r= -0.12 in 2010/11 and 2011/12 respectively) with Ys. MP was highly correlated with Ys (r= 0.94 and 0.93 in 2010/11 and 2011/12 respectively) and Yp (r= 0.92 and 0.96). Positive and significant correlations of STI with MP, GMP and HMP in both years show that these indices could be efficiently used for screening drought tolerant genotypes under water deficit conditions.

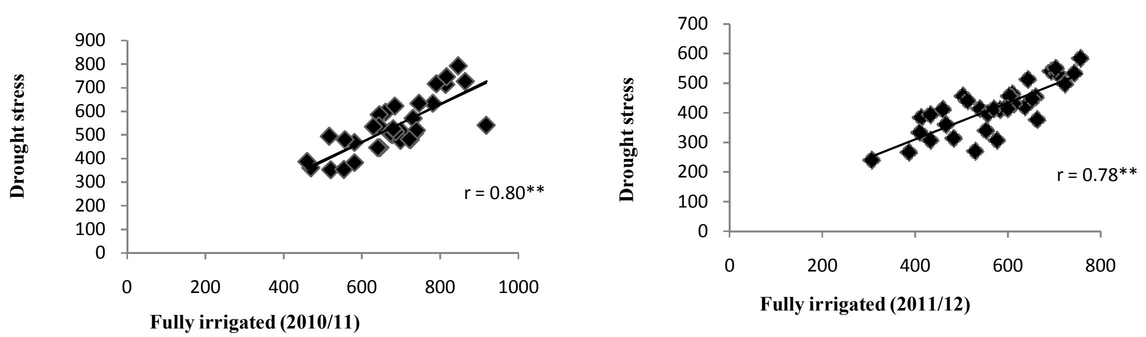

Fig. 2. Relationship of grain yield (g m^{-2}) of wheat genotypes under fully irrigated and drought stress conditions in 2010/11 and 2011/12

Table 3. Combined analysis of variances for agronomic traits in wheat landrace varieties and commercial cultivars

Sources of variation	Df	Mean square							
		NDH	PH	SPS	GN	TGW	BY	GY	HI
Year	1	44.0 ns	314.1 ns	301.2 ns	23.9 ns	2.96*	30.2 ns	140.4 *	145290.4**
Replication within year	4	129.5	305.5	18.5	61.4	102.7	238.0	24.4	649.1
Irrigation	1	33.1**	489.9 ns	170.8 *	1476.1 *	5547.9*	89.4**	234.4**	1139.9**
Irrigation* year	1	6.9 ns	4.3 ns	0.01 ns	107.6 ns	774.3*	93.7**	0.07*	1075.4**
Error	4	6.9	29.0	120.9	337.6	230.9	8.2	9.5	8.6
Genotype	34	182.2**	143.8**	6.0**	49.8**	205.1**	969.8**	9.9**	116.0**
Genotype* Irrigation	34	1.0 *	5.5 *	1.2**	8.0**	26.8**	71.7**	0.9 *	22.8**
Genotype* year	34	5.1**	67.4**	1.0**	8.0**	52.7**	246.0**	1.4**	114.2**
Irrigation* genotype* year	34	1.1ns	5.8 ns	0.6**	3.8**	13.0*	51.6**	0.5 *	22.8**
Error	272	2.0	5.4	0.5	2.0	14.0	0.5	0.6	0.8

Df: degree of freedom, NDH: day to heading, PH: plant height, SPS: spikelet per spike, GN: grain number, TGW: thousand- grain weight, BY: biological yield, GY: grain yield, HI: harvest index

Table 4. The correlation coefficients of agronomic traits under drought stress (in parenthesis) and fully irrigated conditions in 2010/11 (under diagonal) and 2011/12 (above diagonal)

Traits	GY	BY	HI	TGW	GN	SPS	PH	NDH
GY	1	0.61** (0.59**)	0.70** (0.61**)	0.95** (0.88**)	0.65** (0.60*)	0.63** (0.66**)	0.32 (0.02)	-0.13 (-0.18)
BY	0.22 (0.32)	1	-0.34 (-0.30)	-0.16 (0.15)	0.45** (0.47**)	0.31 (0.17)	0.13 (0.45*)	0.34 (0.22)
HI	0.63** (0.71**)	0.34* (-0.16)	1	0.26 (0.44**)	0.45** (0.39*)	0.34 (0.54**)	0.34 (0.09)	-0.34 (0.01)
TGW	0.88** (0.72**)	0.52* (0.42*)	0.54 (0.48*)	1	0.81** (0.63**)	0.84** (0.55**)	0.28 (0.08)	-0.03 (0.13)
GN	0.59** (0.36*)	-0.02 (0.24)	0.35 (0.23)	0.76 (0.88**)	1	0.64** (0.61**)	0.16 (0.12)	0.04 (0.01)
SPS	0.67** (0.59**)	0.67** (0.43*)	0.46 (0.34*)	0.82** (0.59*)	0.78** (0.69**)	1	0.20 (0.06)	0.01 (-0.07)
PH	0.26 (0.12)	0.11 (0.18)	0.11 (0.06)	0.19 (0.21)	0.03 (0.12)	0.10 (0.32)	1	0.13 (0.10)
NDH	-0.04 (-0.21)	-0.23 (-0.25)	-0.07 (0.04)	-0.06 (0.02)	0.01 (0.09)	0.15 (0.03)	0.21 (0.09)	1

** and **: significant at 5 and 1% probability level, GY: grain yield, BY: biological yield, HI: harvest index, TGW: thousand- grain weight, GN: grain number per spike, PH: height plant, SPS: spikelet per spike, NDH: day to heading*

3.3 Efficiency of Indices for Discriminating Drought Tolerance

The highest MP (819 and 795 g m^{-2} in 2010/11 and 2011/12 respectively) belonged to the genotype numbers 31 and 13. Mohammadi et al. [16] proposed MP as an efficient index to identify high yielding genotypes in both drought stress and non-stressed environments. The highest STI belonged to the landrace numbers 31, 13, 24, 16, 35, 26, 14 and 22 in 2010/11 and 23, 35, 31, 24, 16, 13 and 22 in 2011/12 respectively (Suppl. Table 5). Screening a large number of genotypes for drought tolerance needs a two- stage approach. In the first stage, genotypes with high values of STI should be focused and excluding sensitive genotypes with low SSI should be postponed at next stage [27]. Focusing on this approach leads to high-yielding genotypes in both stress and non-stress conditions [8]. The landrace numbers 13, 31, 24, 16, 22, 14, 35 and 23 had the highest GMP and HMP in two growing seasons. Khakwani et al [28] screened drought tolerant wheat varieties based on higher MP, GMP, STI and lower SSI under both non-stress and drought conditions. In general, based on MP, STI, HMP and GMP the landrace numbers 31, 13, 24, 16, 22, 14 and 35 can be considered as drought tolerant.

The high value of SSI is an indicative of sensitivity of a genotype to drought. SSI had negative correlations with STI, Ys and Yp. Mohammadi et al. [15] used SSI to evaluate drought tolerance in durum wheat genotypes and found year-to-year and location- to- location variations in SSI values. The highest SSI belonged to the landrace numbers 27, 29, 12, 25, 7, 11 and Shiraz cultivar in 2010/11 and 7, 14, 4, 21, 17 and Shiraz cultivar in 2011/12 (Suppl. Table 5). Therefore, SSI can be used in discriminating drought-sensitive genotypes [12].

3.4 Principle Components and Scatter Plot of Genotypes

Results of PCA showed that the highest loading coefficients belonged to STI, GMP, MP, and HMP in first PC and to TOL and SSI in second PC. The first PC explained 71.2% and 66.4% of the variation of Yp, YS, MP, HMP, GMP and STI in 2010/11 and 2011/12, respectively (Table 5). Thus, the first PC can be defined as the yield potential or drought tolerance component. The second PC explained 27.2% and 32.4% of TOL and SSI variations in 2010/11 and 2011/12, respectively that show this PC is related to drought sensitive genotypes. Thus, selection of genotypes that have high PC1 and low PC2 are suitable for both stress and non-stress conditions.

The landrace numbers 13, 2, 26, 18 and 35 in 2010/11 and 31, 24, 16, 13, 14, 35, 20 and 22 in 2011/12 had high PC1 and low PC2 (Figs. 3 and 4). The landrace numbers 23, 31, 16, 24, 22 and 15 in 2010/11 and 18 and 27 in 2011/12 with high PC1 and PC2 are suitable for non-stress conditions. The landrace numbers 30, 7, 17, 4, 11 and 32 that had low PC1 and high PC2 had also low grain yield and high sensitivity to post-heading drought stress. Similar results indicated that two PCs explained 66% and 34% of the variation of drought tolerance indices that were related to yield potential and stress tolerant of wheat substitution lines [29].

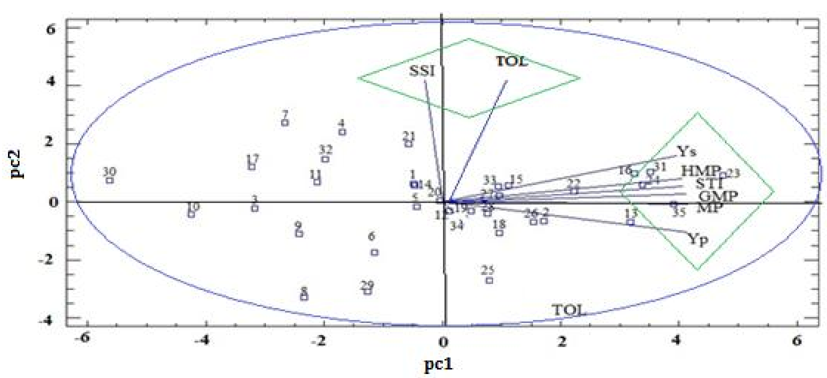

Fig. 3. Principle components (PC) plot for grain yield and statistical drought tolerance indices in 2010/11.Ys: yield under stress, Yp: yield under non-stress, STI: stress tolerance index, HM: harmonic mean, TOL: tolerance index, SSI: susceptibility stress index, MP: mean productivity, GMP: geometric mean productivity

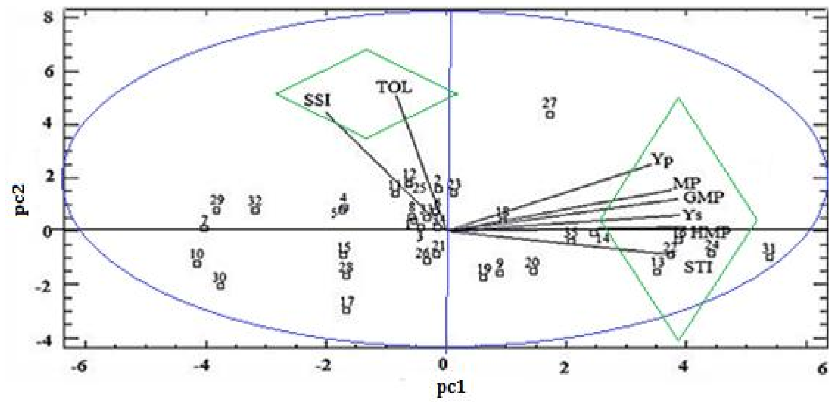

Fig. 4. Principle components (PC) plot for grain yield and statistical drought tolerance indices in 2011/12.Ys: yield under stress, Yp: yield under non-stress, STI: stress tolerance index, HM: harmonic mean, TOL: tolerance index, SSI: susceptibility stress index, MP: mean productivity, GMP: geometric mean productivity

Table 5. Principle component (PC) loadings for drought tolerance indices in wheat genotypes in 2010/11 and 2011/12 (in parenthesis) growing seasons

Components	PTV (%)	Yp	Ys	MP	TOL	GMP	SSI	STI	HMP
PC1	71.2	0.36	0.34	0.32	-0.14	0.32	-0.23	0.33	0.33
	(66.4)	(0.34)	(0.39)	(0.25)	(0.19)	(0.22)	(0.36)	(0.38)	(0.37)
PC2	27.2	0.16	0.02	0.10	0.50	0.18	-0.41	0.16	0.15
	(32.4)	(-0.14)	(0.11)	(-0.24)	(0.17)	(0.13)	(-0.18)	(0.06)	(0.11)

PTV: proportion of total variation, Yp: grain yield under fully irrigated condition, Ys: grain yield under drought stress condition, TOL: tolerance index, MP: mean productivity, SSI: stress susceptibility index, GMP: geometric mean productivity, STI: stress tolerance index, HM: harmonic mean

4. CONCLUSION

In conclusion, our results indicated that landrace varieties are useful cultigens and highly polymorphic for agronomic traits and maturity time under restricted environmental conditions. Our study showed that landrace varieties and commercial cultivars differed in plant height considerably. It shows that landrace varieties have not been selected for plant height and they may be sensitive to lodging. Grain weight and yield strongly affected by drought stress occurred after heading time while plant height and heading showed less reductions under drought conditions. Landraces had higher grain yield under drought stress compare to commercial cultivars that shows their capacity for drought tolerance. Some of landrace varieties headed earlier than commercial cultivars. This shows that landrace varieties benefit from earliness as an escape mechanism from drought at reproductive stages. Heading was not significantly correlated with grain yield. Therefore, selections for earliness does not affect grain yield in wheat landraces and vice versa. The statistical indices of HMP, MP, GMP and STI had significant and positive correlations with grain yield under fully irrigated and drought conditions. Analysis of statistical drought tolerance indices showed that selections based on HMP, MP, GMP and STI results in higher yielding genotypes under both fully irrigated and drought conditions. Principle components analysis for statistical indices and grain yield introduced two main components and these components discriminated the landrace numbers 31, 13, 16, 22, 24 and 35 as genotypes with highest grain yield in both years. Therefore, these landraces could be involved in hybridization programs of drought tolerance.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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