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Screening of Iranian safflower genotypes under water deficit and normal conditions using tolerance indices

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Abstract

Ten Iranian safflower genotypes were grown in separate experiments under well-watered irrigation and water deficit stress at flowering stage in 2009-2011 growing seasons. Different agronomical traits were measured and seven selection indices including stress susceptibility index (SSI), stress tolerance index (STI), tolerance (TOL), mean productivity (MP), geometric mean productivity (GMP), yield index (YI), yield stability index (YSI) were calculated based on grain yield. Results of combined analysis over the experiments showed significant variation (P<0.01) among the genotypes for all the studied traits and they were decreased due to water stress. Even safflower was known as tolerant crop in arid conditions but grain yield was significantly affected by drought stress in both years, which it showed the importance of irrigation at flowering stage. Drought had highly significant difference on all of the studied traits. The interaction between genotype× drought treatments was highly significant for the number of head per plant, number of grains per head. Genotype ×year interaction was significant for heads per plant, grains per head and grain yield. The results showed, MP, HM and YI were more effective in identifying high yielding genotypes in both drought-stressed and irrigated conditions because of ability of selecting high yielding genotypes in either stressed or non-stressed conditions. The results of bi-plot graphs indicated that the most desirable genotypes for stress and non-stress conditions were Esfahan 14, Esfahan-28 and Shiraz which can be promising genotypes for water limited environments. They can be utilized as donor in breeding programs for further improvement in drought tolerance of safflower genotypes.

Keywords: Drought, Field evaluation, Tolerance indices, Safflower.
Abbreviations: SSI; stress susceptibility index, STI; stress tolerance index, TOL; tolerance, GMP; geometric mean productivity, YI; yield index, YSI; yield stability index, MP; mean productivity.

Introduction

Safflower (*Carthamus tinctorious L.*) is a temperate zone plant grown in arid and semiarid regions of world (Mcpherson et al., 2004). The importance of oil crops such as safflower has increased in recent years, especially with the interest in the production of biofuels (Dordas and Sioulas, 2008). Generally safflower is produced on marginal lands that are relatively dry and relatively deprived the benefit of fertilizer inputs or irrigation. Attempts to improve seed yield and quality by developing new genotypes and agronomic practices are underway throughout the world. The fact that water stress effects on growth and yield are genotype-dependent is well known (Bannayan et al., 2008). There is limited researches around the world on safflower production under irrigated conditions that revealed it is a sensitive crop to water (Quiroga et al., 2001; Bassil and Kaffka, 2002a,b) and moderately tolerant to salinity. Some other research found safflower can be a candidate crop in dryland agroecosystems due to the potential for growth under water stress and the economic value in terms of both oil and seed (Yau, 2004; Kar et al., 2007); therefore this finding may be coming from the variability of safflower genotypes. In Iran water is a scarce resource due to the high variability of rainfall. The effects of water stress depend on the timing, duration and magnitude of the deficits (Pandey et al., 2001). Identification of the critical irrigation timing and scheduling of irrigation based on a timely and accurate basis to the crop is the key to conserving water and improving irrigation performance and sustainability of irrigated agriculture (Ngouajio et al., 2007). Some investigations are reported on the effect on water deficit on yield and its components of safflower (Marita and Muldoon, 1995; Ozturk et al. 2008). Omidi (2009) reported that the highest damage on grain yield caused in drought stress at blooming and flowering stages in safflower. Despite that, the lowest damage was observed at the stage of grain development (Omidi, 2009). Saini and Westgate (2000) pointed out that all of the reproductive sub phases of safflower are sensitive to water deficit. It reduces seed and/or flower numbers per capitulum during early reproductive growth stages. Marita and Muldoon (1995) reported that flowering phase in safflower is the most sensitive stage to drought stress. In crop production, instead of achieving maximum yield from a unit area by full irrigation, optimum irrigation number or amount of irrigation water may be limited by allowing small yield decreases from a unit area but more area is irrigated with the same amount of irrigation water and water productivity can be optimized within the concept of deficit irrigation (Fereres and Soriano, 2006). It was reported that the seed yield of safflower decreased sharply when drought stress was severe (Lovelli et al., 2007). Development of stress tolerant varieties is always a major objective of many breeding programs but success has been limited by adequate screening techniques and the lack of genotypes that show clear differences in response to various environmental stresses. To differentiate drought resistance genotypes, several selection indices have been suggested on the basis of a mathematical relationship between favorable

Table1. Mean squares for agronomic traits of 10 safflower genotypes in 2009–2011.

Source of variation	Df	HP	GH	TGW	PH	GY
Year (y)	1	19.5**	277.26**	54.45*	114.42^{ns}	12.11**
Error (a)	4	1.82	9.55	8.4	42.07	0.06
drought	1	139.93**	410.22**	566.5**	1644.88**	1.17*
Year × drought	1	1.0^{ns}	11.0^{ns}	7.3^{ns}	3.81^{ns}	0.47^{ns}
Error (b)	4	0.6	9.18	9.6	15.01	0.13
Genotype	9	60.91**	160.79**	45.4**	410.93**	0.75*
Genotype× drought	9	3.06*	14.65**	6.07^{ns}	39.18^{ns}	0.17^{ns}
Genotype× Year	9	14.44**	82.92**	11.5	92.89	1.74**
Genotype× Year ×drought	9	1.6^{ns}	7.13^{ns}	10.17^{ns}	33.15^{ns}	0.22^{ns}
Error (c)		1.8	5.7	11.26	49.37	24.44

**,* Significant at $P<0.01$ and $P<0.05$, respectively. HP: Heads per plant, GH: Grains per head, TGW: 1000-grain weight (gr), PH: Plant height (cm) GY: Grain yield.

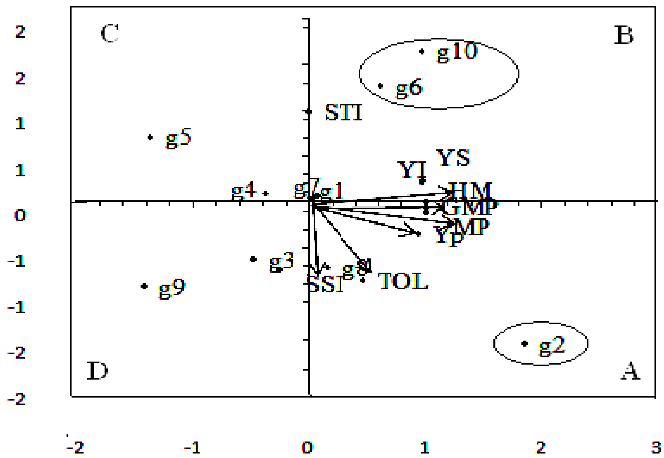

Fig1. Bi-plot based on first and second factors for 10 safflower genotypes in both years. The numbers in figure show the genotype position in bi-plot. g1: Kashan, g2: Esfahan14, g3: 7-138, g4: Esfahan, g5: Arak2811, g6: Esfahan28, g7: 22-191, g8: Golsefid, g9: IL-111, g10: Shiraz. Genotypes in oval are drought tolerant.

(non-drought stress) and drought stress conditions (Huang, 2000). Tolerance (TOL) (Clarke et al., 1992), mean productivity (MP) (Mccaig and Clarke., 1982), drought susceptibility index (SSI). geometric mean productivity (GMP) and drought tolerance index (STI) (Fernandez ,1992) have all been employed under various conditions. Since different results of drought stress may be coming from the variability in drought tolerance potential of safflower genotypes, and there is high variability potential in Iranian safflower (Amini, 2008), our purpose was assessing of Iranian safflower landraces and promising lines using multivariate statistics methods, and to detect the efficiency and profitability of different selection indices in identification of genotypes which are compatible with stressful and optimal conditions, to achieve genotypes with best drought tolerance.

Results

Combined analysis of variance

The results of analyses of variance for plant height, number of head per plant, number of grains per head, 1000- grain weight and grain yield are presented in table 1. The analysis of variance showed, the genotypes had significant differences in grain yield and other traits. The highest and lowest means of grain yield were related to Esfahan-14 (2.56 t ha^{-1}) and IL.111 (1.31 t ha^{-1}), respectively (Table 2). Drought had highly significant difference on all of the studied traits (Table 1), they were decreased in response to water deficit. The year effect was significant ($p < 0.01$) for all traits except plant height which was due to different climatic change situation in two years. The interaction between genotype× drought treatments was highly significant for the number of head per plant, number of grains per head. There was no significant difference for year × drought in all the traits that shows, even safflower was known as tolerant crop in arid conditions but grain yield was significantly affected by drought stress in both years, indicating the importance of irrigation at flowering stage. The genotype× year interaction was highly significant, indicating that genotypes performance changed from 1 year to another. Number heads per plant, grains per head, 1000-grain weight and grain yield of genotypes varied, particularly under stress conditions, with the years. This variation can be explained, in part, by the fact that traits suitable for a given environment with its own weather conditions may be unsuitable in another environment (Austin, 1987; Van Ginkel et al., 1998). The traits values for both years, their Duncan test classes are given in table 2. Data in the table show that both years' average parameters are significantly ($p < 0.01$) affected by water deficits. The highest number of grain per head (22.05) was belonging to Esfahan-14, while the lowest number of grain per head (15.44) was determined in Arak-2811 (Table 2). The highest and the lowest mean for plant height were observed in Esfahan14 (58.43) and Golsefid (37.74), respectively (Table 2). Drought stress decreased plant height via reduction in its growth rate. Drought stress could have a minor effect on plant height reduction, if it happens at later stages of safflower growing period. A significant difference was observed between control treatment and drought stress for all the traits (Table 3). The highest and lowest grain yield was belonged to control conditions and stopping the irrigation from flowering stage, respectively. It was pointed out that

Table 2. Heads per plant, Grains per head, 1000-grain weight (g), plant height, Grain yield of the genotypes (averaged over 2 years).

Genotype	HP	GH	TGW	PH	GY
Kashan	10.3^{b}	19.8^{b}	28.5^{c}	48.37^{bc}	1.82^{cd}
Esfahan14	11.67^{a}	22.05^{a}	27.6^{c}	58.43^{a}	2.56^{a}
7-138	8.78^{c}	20.1^{b}	31.4^{ab}	48.59^{b}	1.65^{bc}
Esfahan	8.03^{cde}	17.37^{c}	29.16^{bc}	52.68^{ab}	1.82^{de}
Arak2811	7.13^{f}	15.44^{d}	31.11^{ab}	44.11^{cd}	1.27^{f}
Esfahan28	$7.7d^{ef}$	17.05^{cd}	31.05^{ab}	44.85^{c}	1.97^{bc}
22-191	$7.4e^{f}$	18.8^{bc}	29.94^{abc}	44.12^{cd}	1.67^{def}
Golsefid	7.03^{f}	17.83^{c}	31.7^{a}	37.74^{d}	1.88^{def}
IL-111	8.5^{cd}	17.52^{c}	32.38^{a}	44.41^{c}	1.31^{ef}
Shiraz	9.6^{b}	17.6^{c}	31.7^{a}	47.79^{bc}	2.08^{b}

HP: Heads per plant, GH: Grains per head, TGW: 1000-grain weight (g), PH: plant height (cm) GY: Grain yield (t ha^{-1}).

Table 3. Mean comparisons of traits for treats.

Treatment	HP	GH	TGW	PH	GY
I_1	9.5^{a}	20.91^{a}	33.56^{a}	51.46^{a}	1.52^{a}
I_2	8.20^{b}	16.96^{b}	27.75^{b}	43.65^{b}	1.30^{b}

HP: Heads per plant, GH: Grains per head, TGW: 1000-grain weight (gr), PH: Plant height (cm) GY: Grain yield (t ha^{-1}).
I_1: Control conditions, I_2: Cut off the irrigation at start of flowering stage.

much larger yields of grain can be produced by irrigation conditions. The reason of reduction in grain yield under water deficit conditions could be by reason of reduction in absorption of water and nutrient and therefore it reduces photosynthesis.

Resistance indices and correlation analysis

Resistance indices were calculated on the basis of grain yield of genotypes over the years (Table 4). In this study the lowest value of SSI was observed in Shiraz, Esfahan-28, Arak2811, Esfahan and Kashan (Table 4). So these genotypes could be proposed as a tolerant genotypes to drought stress. Rosille and Hambilin (1981) reported that selection based on the tolerance index often leads to selecting cultivars which have low yields under non-stress conditions. The greater the TOL and SSI values showed more sensitivity to stress, thus a smaller value of these indices is favored. Shiraz, Esfahan-28, and Arak2811and Esfahan with a lower quantity of TOL were identified as the most tolerant genotypes, while IL-111 and Golsefid with the highest TOL value were the most sensitive genotypes. An important factor for the success of a plant breeding program in stressed environments is good performance of genotypes under severe stress conditions and maximum yield under optimum conditions. Grain yield under non stress conditions was positively correlated with stress conditions ($r= 0.819^{**}$) (Table 5). A positive correlation was observed between TOL and yield under stress (Ys) while was not correlation between TOL and irrigated yield (Yp) (Table 5). No significant correlation was found between yield under stress and non-stress with SSI (Table 5), showing that SSI will not discriminate drought sensitive genotypes under such conditions. YI, proposed by Gavuzzi et al. (1997), was significantly correlated with stress yield. This index ranks cultivars only on the basis of their yield under stress and so does not discriminate genotypes of group A. YSI, as Bouslama and Schapaugh (1984) stated, evaluates the yield under stress of a cultivar relative to its non-stress yield, and should be an indicator of drought resistant genetic materials. So the cultivars with a high YSI are expected to have high yield under both stress and non-stress conditions. In the present study, genotypes with the highest YSI exhibited the highest yield under stress conditions and non-stress conditions (Table 4). GMP, MP, HM and YI were significantly correlated with both stress and non-stress yields (Table 5). But no significant correlation was found between Yp and Ys with SSI, STI and YSI. The most value for GMP MP, HM and YI was belonged to Shiraz, Esfahan14 and Esfahan-28. GMP, MP, HM and YI were better predictors of YP and YS than other indices under both drought stressed conditions and can be introduced as the most suitable indices for identifying high yielding genotypes for both normal and stress conditions.

Factor analysis

To use all indices simultaneously FA with varimax rotation was carried out. The first two factors explained 94.14% of total variation between the data. The first factor explained 59.88 % of total variation and had a pretty high positive relationship with YS, YP, GMP, MP, HM and YI and a negative coefficient with SSI, STI and YSI (Table 6), therefore the first factor was named as the yield potential and drought tolerance. Considering the high and positive value of this FA on biplot, selected genotypes will be high yielding under stress and non-stress environments. So, the higher scores for FA1 were in accordance with the higher rank of drought tolerance, whereas low scores for FA1 showed drought-sensitive genotypes (Figure 1). The second factor (FA2) accounted for 34.5% of total variation and had high communalities with STI and YSI named as stress-tolerant dimension (Table 6). The first two factors scores are presented in table 4 for all genotypes. Genotypes with high scores of two factors have both high stress tolerance and high yield potential And selection of genotypes that have high FA1 and low FA2 are suitable for both stress and non-stress environments. Regarding the FA results for the indices and bi-plot display based on first two factors, Esfahan 14, Shiraz and Esfahan-28 identified as the most drought-tolerance genotypes (Table 4). Since FA1 showed highly significant correlation with Yp and Ys (0.93 and 0.96) respectively and also FA2 had (-0.35 and 0.22) correlation with Yp and Ys (Table 6), it is concluded that, genotype in the part A of fig1 (Esfahan14) as well as genotypes in part B of fig 1 (Esfahan-28 and Shiraz) had high tolerance and can be considered as genotype that is containing genes for stress tolerance and high production potential in drought conditions

Discussion

There is no research, and therefore no data is available on safflower production under irrigated conditions at regional

Table 4. Different stress tolerance for safflower genotypes both years.

Genotype	Yp	Ys	TOL	SSI	GMP	STI	MP	YI	YSI	FA1	FA2
Kashan	1.99	1.65	0.34	0.95	1.80	0.82	1.82	1.02	0.82	0.07	0.06
Esfahan14	3.07	2.05	1.02	1.21	2.46	0.70	2.56	1.27	0.70	1.84	-1.55
7-138	1.83	1.47	0.36	1.99	1.64	0.80	1.65	0.97	0.80	-0.48	-0.63
Esfahan	1.96	1.68	0.29	0.76	1.80	0.80	1.82	0.96	0.80	0.03	0.05
Arak2811	1.34	1.20	0.14	0.84	1.27	0.89	1.27	0.74	0.89	-1.37	0.71
Esfahan-28	2.04	1.89	0.15	0.49	1.97	0.92	1.97	1.17	0.92	0.60	1.26
22-191	1.79	1.55	0.24	1.02	1.67	0.82	1.67	0.89	0.82	-0.38	0.09
Golsefid	2.15	1.60	0.55	1.06	1.84	0.75	1.88	1.01	0.75	0.15	-0.72
IL-111	1.52	1.09	0.43	1.19	1.28	0.73	1.31	0.68	0.73	-1.43	-0.93
Shiraz	2.12	2.03	0.10	0.34	2.07	0.95	2.08	1.28	0.95	0.96	1.65

YP: the yield of lines under normal conditions, YS: the yield of lines under stress, TOL: tolerance, SSI: stress susceptibility index, GMP: geometric mean productivity, STI; stress tolerance index, MP: mean productivity, YI: yield index, YSI: yield stability index.

Table 5. Correlation coefficient between tolerance indices with grain yield in normal (Y_P) and stress condition (Y_S).

	YS	YP	TOL	SSI	GMP	STI	MP	YI	YSI
YS	1								
YP	0.819**	1							
TOL	0.744*	0.227 ns	1						
SSI	-0.009 ns	-0.399 ns	0.448 ns	1					
GMP	0.952**	0.955**	0.504 ns	-0.209ns	1				
STI	-0.349 ns	0.214 ns	-0.845**	-0.631 ns	-0.067 ns	1			
MP	0.930**	0.972**	0.447 ns	-0.239 ns	0.998**	-0.011 ns	1		
YI	0.818**	0.978**	0.249 ns	-0.313 ns	0.944**	0.218 ns	0.959**	1	
YSI	-0.349 ns	0.214 ns	-0.845**	-0.631 ns	-0.067 ns	1.000**	-0.011 ns	0.218 ns	1

*,** Significant at *P*<0.05 and *P*<0.01, respectively. YP: the yield of lines under normal conditions, YS: the yield of lines under stress, TOL: tolerance, SSI: stress susceptibility index, GMP: geometric mean productivity, STI; stress tolerance index, MP: mean productivity, YI: yield index, YSI: yield stability index.

and country level (Istanbulluoglu et al., 2009). However, FAO presents that good rainfed yields are in the range of 1.0–2.5 t ha^{-1}, under irrigation in the range of 2.0–4.0 t ha^{-1} from farmers' fields (Doorenbos and Kassam, 1979). Safflower yield data in different places under rainfed and irrigated conditions are also available for small experimental plots. For instance: the range of yield in the Sacramento Valley of California, USA (Cavero et al., 1999), in the Ariana of Tunisia (Hamrouni et al., 2001), in the Pampas region of Argentina (Quiroga et al., 2001), in the south of Italy (Lovelli et al., 2007), has reported about 1.0‑3.3 t ha^{-1}. The yield obtained in drought conditions in this research was lower (1.0- 2.05) than the above presented values. Cut off the irrigation at flowering stage is one of the most important reasons for grain yield reduction. Even safflower was known as tolerant crop in arid conditions but reduction of grain yield in both years, showed the importance of irrigation at flowering stage to reach to high grain yield. The decrease in yield and yield components in different safflower genotypes due to water deficiency has also been reported by other researchers (Kar et al., 2007; Lovelli et al., 2007).

Improvement in adaptation of safflower to water stress environments requires improved tolerance to water deficient during flowering stage. Omidi (2009) reported that the highest damage on grain yield caused in drought stress at blooming and flowering stages in safflower. MovahhedyDehnavy et al. (2009) reported that the water deficiency at the flowering stage caused higher degree of reduction of yield and dry matter production than the water deficiency before or after flowering. In the present study there was no significant difference among traits for year × drought, indicating that grain yield significantly affected by drought stress at flowering stage. In field studies grain yield of safflower was extremely sensitive to drought during the flowering stage, thus irrigation needed to be applied during the most drought-sensitive stages, ie flowering therefore good yields can be obtained with regular irrigation at the flowering growth stage. It seems that in this study, water deficit stress during flowering stage with shorting flowering period and development stage, infertile in some of flowers causes reduction of grain yield. Grain yield under non stress conditions was positively correlated with stress conditions (r= 0.819**) (Table 5) suggesting that a high potential yield under optimum conditions does necessarily result in improved yield under stress condition. Thus, indirect selection for a drought-prone environment based on the results of optimum conditions will be efficient. As MP, HM and YI were able to identify genotypes producing high yield in both conditions. Although none of the indicators could clearly identify genotypes with high yield under both stress and non-stress conditions (group A genotypes). Based on these results, MP, HM and YI favor genotypes with high yield potential and TOL and SSI Favor genotypes with low yield potential. Thus, different indices would not result in the same outcome. To employ all indices simultaneously, multivariate statistics such as FA was performed. The relationship between the genotypes and stress-tolerance indices can be plotted in the same graph (bi-plot). Considering the result of FA and bi-plot display based on first two factors, Esfahan 14, Esfahan-28 and Shiraz identified as the most drought-tolerance genotypes. MP, HM and YI were appropriate for genotypes with potential stress tolerance, thus selection based on the latter indices could be more promising than on SSI and TOL and it seems that might be better yield-based drought tolerance indices to be employed in plant breeding programs, because of ability of selecting high yielding genotypes in either stressed or non-stressed conditions. If the strategy of breeding program is to improve yield in a small stress or non-stress environment, it may be possible to explain local adaptation to increase gains from selection conducted directly in that environment (Atlin et al., 2000; Hohls, 2001). However, selection should be based on the tolerance indices calculated from the yield under

Table 6. Eigen values for factor analysis of safflower genotypes.

Indices	FA1	FA2
Yp	0.934	-0.350
Ys	0.969	0.227
TOL	0.458	-0.860
SSI	-0.267	-0.743
GMP	0.997	-0.062
STI	-0.007	0.982
MP	0.993	-0.118
YI	0.960	0.204
YIS	-0.007	0.982
Varince %	59.88	34.53
Cumulative %	59.88	94.14

both conditions, when the breeder is looking for the genotypes adapted for a wide range of environments.

Materials and methods

Plant materials and growth conditions

Ten genotypes of Iranian safflower including landraces: Kashan, Esfahan, Golsefid and Shiraz as well as promising lines: Esfahan-14, 7-138, Arak-2811, Esfahan-28, 22-191, andIL-111 were chosen for study based on their reputed differences in yield performance (Eslami et al., 2010) under well water irrigation and water deficit stress conditions. This experiment was performed as split plot experiment based on Randomized Complete Block Design in each year at research farm of Shahid Bahonar university of Kerman, Iran, (1755 m above sea level, 53° 26'E , 55° 32'N), in 2009-2011. The pH of soil experiment was 7.8 with Clay- loamy texture. Genotypes were planted as subplots within the irrigation plots in a randomized complete block design with three replications. Factor (A) was in 2 different levels of irrigation (no stress, cut-off irrigation at start of flowering stage). Irrigation to the controlled units was applied at time intervals of 8 to 10 days at all the growth stages. Plots under drought stress at flowering stage, were in accordance with normal routines however, irrigation was cut at the start of flowering stage. Sowing was done in November in both experiments and seedling density was 300 seeds m^{-2}. Plots consisted of four, 60 cm long rows spaced 10 cm apart. Fertilizer was applied before sowing (100 kg ha P_2O_5 and 25 kg ha Zn) and at stem elongation (50 kg ha N). The experimental plots were hand weeded as needed during the growing season. The measured traits were containing: plant height, number of head per plant, number of grains per head, 1000- grain weight and grain yield (ten randomly selected plants in each plot). Grain yield was determined in two row middling of plot after elimination of the marginal effects.

Statistical analysis

Combined analysis of variance for the measured traits over the experiments based on RCBD design and split plot arrangement in each year was done using SAS (SAS Institute Inc. 2004). Stress tolerance indices Stress tolerance indices were calculated with the following formula:

SSI= $\dfrac{1-Y_S\ /Y_P}{S_I}$ SI: Stress Intensity = 1- $\dfrac{\overline{Y}_S}{\overline{Y}_P}$

(Fischer and Maurer 1978)

Where Ys is the yield of lines under stress, Yp the yield of lines under normal conditions, $\overline{Y}s$ and $\overline{Y}p$ are the mean yields of all lines under stress and non -stressed conditions, respectively, and SI is the stress intensity.

TOL= Y_P- Y_S (Hossain et al., 1990).
GMP = $(Y_P \times Y_S)^{0.5}$ (Fernandez, 1992).
STI= $(Y_S+Y_P) / (\overline{Y}_P)^2$ (Fernandez, 1992).
MP = $(Y_S+Y_P) / 2$ (Hossain et al., 1990).
Yield stability index (YSI) = Ys/Yp Bouslama and Schapaugh, 1984)
Yield index (YI) = $Ys/\overline{Y}s$ (Gavuzzi et al., 1997).

Data were analyzed using SAS package (SAS Institute Inc, 2004) for the analysis of variance. Duncan's multiple range tests was employed for the mean comparisons using MSTATC software.

Correlation analysis

Evaluating correlations between stress tolerance indices and the grain yield in both environments can lead to identifying the most suitable index. To determine the most desirable drought tolerance criteria, the correlation coefficient between Y_P, Y_S and other quantitative indices of drought tolerance was performed using SPSS17.0 package which has been used.

Factor analysis

Selection based on a combination of indices may provide a more useful criterion for improving safflower drought resistance (Majidi et al., 2011).To use all stress-tolerance/sensitive indices simultaneously factor analysis (FA) with varimax rotation was performed. FA based on correlation matrix of genotypes was performed using SPSS package. Bi-plot based on two first factors showed the patterns of the genotypes in a graphical view.

Conclusion

Since there is considerable variation in Iranian safflower (Amini et al., 2008), the difference in stress tolerance observed among safflower genotypes may be coming from the variability of safflower genotypes. Under studied genotypes in this research except Esfahan-14, Esfahan-28 and Shiraz did not show tolerance to cut off irrigation at flowering stage that high drought tolerance makes these genotypes suitable sources for transferring drought tolerant genes in breeding programs for further improvement in drought tolerance of safflower genotypes. Our results clearly demonstrate that the flowering stage was sensitive to water deficit and since Esfahan-14, Esfahan-28 and Shiraz showed a better ability to recover from stress at the flowering stage, they were found suitable for stressed conditions and appeared to cope better with moisture stress during flowering stage. Golsefid and IL-111 with least tolerance than other genotypes can be used as sensitive check genotypes for drought tolerance studies in safflower breeding programs.

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