Assessment of drought tolerance in barley: integrated selection criterion and drought tolerance indices

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Abstract

Although drought stress is the most serious problem affecting barley production, progress in the development of resistant cultivars is limited due to the lack of effective selection criteria. The objectives of this study were (i) to selection drought tolerant barley lines based on agro-morphological traits and tolerance indices and (ii) to assess use-efficiency of integrated selection criterion in screening of tolerance lines across multi-environments. For these purposes, 40 doubled haploid lines along with parental genotypes were grown during two consecutive years (2013–2014) under different water regimes at the Research Station of Mahabad Payame-Noor University and Miandoab Agricultural Research Station, West Azerbaijan, Iran. According to combined analysis of variance, in both locations a large significant difference was observed among lines for most of the studied traits indicating that selection in this materials would be useful. Correlation coefficients (for two years and two locations) indicated significantly positive relation between different tolerance indices and integrated selection criterion with grain yields under non-stress and stress conditions. Multivariate analysis and three-dimensional graphs showed that integrated selection criterion index, similar to other indices, was able to distinguish the tolerant and desirable lines across multiple environments. Finally, our results indicated that doubled haploid lines numbers L3, L13, L18, L29 and L35 were desirable lines for both conditions.

Key words: barley, water deficit stress, drought tolerance indicators, integrated selection, multivariate analysis.
Abbreviations: GMP, geometric mean production; MP, mean production; PCA, principal components analysis; SI, integrated selection criterion; SSI, stress susceptibility index; STI, stress tolerance index; YSI, yield stability index.

Introduction

One of the great challenges facing economies and societies over the next decades is feeding the population, and providing water resources to produce food for a world that is experiencing a rapid population growth in a time of global climate change (Dorostkar et al. 2015). Barley (*Hordeum vulgare* L.) is a major crop ranked fourth in the worldwide production of cereals. This crop is considered as a primary staple food in the semi-arid tropics of Asia, Africa, and South America. Barley grain is usually used as food and animal fodder, and moreover as raw material for the production of beer (Pour-Aboughadareh et al. 2013). The improvement of crops requires the creation and introduction of a variant genetic resource, as well as, inbreeding coupled with evaluation of breeding materials and extensive selection in different environments to identify adapted and stable genotypes. In plant breeding programmes, the production of doubled haploid lines provides one of the easiest and fastest techniques of obtaining completely homozygous progenies from selected crosses (Choo et al. 1985).

Water deficit or drought stress is one of the most common environmental stresses that affects growth and development of plants. In other words, this stress is a permanent constraint to agricultural production in many countries, and an occasional cause of losses of agricultural production (Pour-Siahbidi et al. 2013). The success of barley breeding programs is largely due to its good capacity and stability to yield well under drought and poor management conditions where other crops would fail. Some researchers believe in selection under favorable conditions (Betran et al. 2003; Richard 1996) and some believe in selection under typical drought conditions (Ceccarelli 1987; Ceccarelli, Grando 1991). Nevertheless, there exist numerous researchers that chose the midway and believe in selection under both favorable and stressed conditions (Clark et al. 1992; Fernandez 1992). To differentiate drought tolerance genotypes, several selection indices have been used on the basis of both grain yield under normal and stressed conditions (Fischer, Maurer 1978; Lin, Binns 1988).

Indices such as stress tolerance index (STI), geometric mean productivity (GMP), and yield stability index (YSI) have been used for comparing genotypic performance across years or environments (Sio-Se Mardeh et al. 2006); however, Saba et al. (2001) recommended that STI might be better used in plant breeding programmes, because of its moderate heritability and the inherent ability of

screening high yielding genotypes in either non-stressed or stressed conditions. Recently, Hao et al. (2011) introduced a new selection criterion to assess response of genotypes to drought stress across multiple environments. They declared that this new index, integrated selection criterion (SI), provides an estimate of drought stress resistance based on grain yield and related agronomic characters, and thus it would be useful in identifying excellent drought-resistant genotypes in breeding programmes. We hypothesized that the selected lines have significant diversity in terms of agro-morphological traits. However, to provide more knowledge for selecting of lines as well as determining contribution of each trait to drought tolerance, we aimed to assess the effects of drought stress on agro-morphological traits in 40 doubled haploid lines and also to evaluate use-efficiency of integrated selection criterion in screening of tolerance lines across different environments.

Materials and methods

Plant material, design and experimental sites
The plant material used in this work consisted of 40 doubled haploid lines along with parental genotypes. These materials were evaluated during two consecutive cropping seasons at two locations and under two different water regimes. These doubled haploids derived from a cross between cv. 'Morex' (resistance to drought stress) and cv. 'Steptoe' (susceptible to drought stress) genotypes. The cross was carried out in a barley breeding programme at Oregon University (North American Barley Genome Mapping Project).

Field experiments were conducted at two research stations, Miandoab Agricultural Research Station and Research Station of Mahabad Payame-Noor University, in West Azerbaijan Province (northwest of Iran) during 2012–2013 and 2013–2014 cropping seasons. Based on De-Martonne classification, these experiment sites are located in semi-arid regions of Iran. The first station (1371 m above sea level, 46°09'N, and 36°58'E) had 289 mm annual rainfall on a long-term average. In both experiment sites the soil texture was silt-clay-loam (30% clay, 52% silt and 18% sand) with pH of 8.05. Available P and K were 6.69 and 314 ppm, respectively. The second station, (1371 m above sea level, 45°43'N, 36°1'E) had 326 mm annual rainfall on a long-term average. The soil texture was silt-clay-loam (30% clay, 54% silt and 16% sand) with pH of 8.09. Available P and K were 14.62 and 444 ppm, respectively.

In each of the areas, 40 lines along with three checks and parental genotypes were planted in a randomized complete block design with two replications and grown under two water regimes. Sowing was done by hand in November in all experiments. Plots consisted of four, 2.5-m-long rows spaced 25 cm apart. Fertilizer was applied before sowing (80 kg ha^{-1} P$_2$O$_5$ and 50 kg ha^{-1} KNO$_3$) and at stem elongation (100 kg ha^{-1} CH$_4$N$_2$O).

The plants were grown under two moisture regimes

of irrigation after 90 mm and 190 mm evaporation from a class-A pan for normal and drought-stress conditions, respectively. The drought-stress treatments were applied from the booting stage till physiological maturity. Crop management practices such as pest and weed control and plant nutrition were practiced as needed during the growing season.

The following agro-morphological characteristics were recorded: plant height (cm), peduncle length (cm), number of spikes (per 1 m^2), spike length (cm), number of grains per spike, 1000-grains weight (g), hectoliter grain weight (kg), grain yield (kg ha^{-1}), biological yield (kg ha^{-1}) and harvest index. Ten randomly chosen plants from each plot were used for recording data on agro-morphological characters.

Data analysis
Combined analysis of variance (ANOVA) was performed using SAS software (SAS, 1987). Five drought resistance indices including stress tolerance index (STI), mean production (MP), geometric mean production (GMP), stress susceptibility (SSI), and yield stability index (YSI), were calculated using the following relationships (Fischer, Maurer 1978; Rosielle, Hamblin 1981; Fernandez 1992; Gavuzzi et al. 1997):

$$STI = \frac{Y_p + Y_s}{\overline{Y}_p^2} ,$$

$$MP = \frac{Y_p + Y_s}{2} ,$$

$$GMP = \sqrt{(Y_p \times Y_s)} ,$$

$$SSI = \frac{1 - (Y_s / Y_p)}{1 - (\overline{Y}_s / \overline{Y}_p)} ,$$

$$YSI = \frac{Y_s}{Y_p} ,$$

where Y_p is particular yield in non-stress conditions, Y_s is particular yield in stress conditions, $\overline{Y}_p$ is mean yield in non-stress conditions, $\overline{Y}_s$ is mean yield in stress conditions.

The integrated selection index (SI) was calculated according to Hao et al. (2011) on the basis of the obtained results from factor analysis for agro-morphological traits under non-stress and water deficit stress conditions using the following steps:

$$S_{ij} = (X_{ij} - \mu_j) / \sigma_j ,$$

$$MP_{ij} = (S_{ijd} + S_{ijw}) / 2 ,$$

$$SI = b_1 MP_{i1} + b_2 MPi2 + ... + b_j MP_{ij} ,$$

where S_{ij} is the standardized agronomic value of the trait j^{th} ($j = 1$ to 10) in line i^{th} under non-stress and drought-stress conditions, X_{ij} is agro-morphological value of line i^{th} on trait j^{th}, μ_j is mean value of trait j^{th} in all of the lines, σ_j is the standard deviation of the trait j^{th}, MP_{ij} is the mean productivity of the trait j^{th} on line i^{th}, b_j is the weight value of the trait j^{th}; b_j was calculated from the average contribution to factor 1. The contributions of each trait on factor 1 are

Table 1. Contribution of factor 1 of agro-morphological traits related to drought resistance at eight environments in the factor analysis. L_1 and Y_1, first location and year; L_2 and Y_2, second location and year; N and S, non-stress and stress conditions

Trait	L_1Y_1N	L_1Y_1S	L_2Y_1N	L_2Y_1S	L_1Y_2N	L_1Y_2S	L_2Y_2N	L_2Y_2S	Average
Plant height	−0.04	−0.62	0.04	−0.44	0.04	0.08	0.06	0.16	−0.09
Peduncle length	0.68	0.63	0.44	0.64	0.71	0.73	0.74	0.73	0.66
Spike length	0.50	0.12	0.71	−0.01	0.56	0.51	0.57	0.57	0.44
Number of grains per spike	0.63	0.32	0.82	0.23	0.26	0.41	0.29	0.39	0.41
Number of spike	−0.12	−0.29	0.18	−0.52	0.02	−0.16	0.02	−0.14	−0.12
1000-grains weight	0.87	0.90	0.07	0.74	0.91	0.93	0.93	0.92	0.78
Hectoliter grain weight	0.72	0.65	0.03	0.75	0.76	0.79	0.78	0.77	0.65
Grain yield	0.38	0.27	0.93	0.89	0.56	0.66	0.57	0.63	0.61
Biological yield	0.08	0.03	0.92	0.77	0.10	0.22	0.13	0.21	0.31
Harvest index	0.82	0.84	0.02	0.76	0.87	0.92	0.87	0.89	0.75

shown in Table 1. Multivariate analyses were also used for distinguishing drought tolerance lines and getting better understanding of relationships among grain yields and the drought tolerance indices. Principal components analysis (PCA) and biplot diagrams were used to identify tolerant and susceptible lines by Minitab software (Minitab 2004). For recognizing drought-tolerant and high-yielding lines in both conditions, three-dimensional graphs based on the best drought tolerance indices and grain yields were drawn using Statistica software (Statistica 2007).

Results

The results of multi-environment trials analysis for grain yield and agro-morphological traits in Miandoab and Mahabad stations are shown in Table 2. At both locations, there was a significant difference in the performance of lines for all evaluated traits. Also, there was a significant difference between years and water regime conditions for grain yield and other traits. At Miandoab station, the year × line interaction differed significantly for all of the traits

except for grain yield and biological yield, whereas the line × water regime conditions had significant effect on all traits except 1000-grains weight and harvest index. On the other hand, at the Mahabad station, the results of analysis of variance were different in that the interaction between lines × year was highly significant for all of the traits studied. Additionally, the interaction between lines and water regime conditions was significant for plant height, grain yield and biological yield. Grain yield under non-stress condition was significantly correlated with grain yield under drought stress condition (Fig. 1). Yield performance of lines in non-stress condition ranged from 4256 to 7049 kg ha^{-1}, while under drought stress condition it varied from 3276 to 5144 kg ha^{-1}. Line L35 followed by L3 and L30 had the highest grain yield under both conditions. Lines L28 and L34 had poor performance under non-stress and stress conditions, while line L32 was highly adapted to the non-stressed conditions. Lines L6, L16 and L18 had a similar response to drought-stress conditions, however their response to non-stressed conditions differed and varied from 5475 to 6156 kg ha^{-1} (Fig. 1). The biggest difference in yield performance
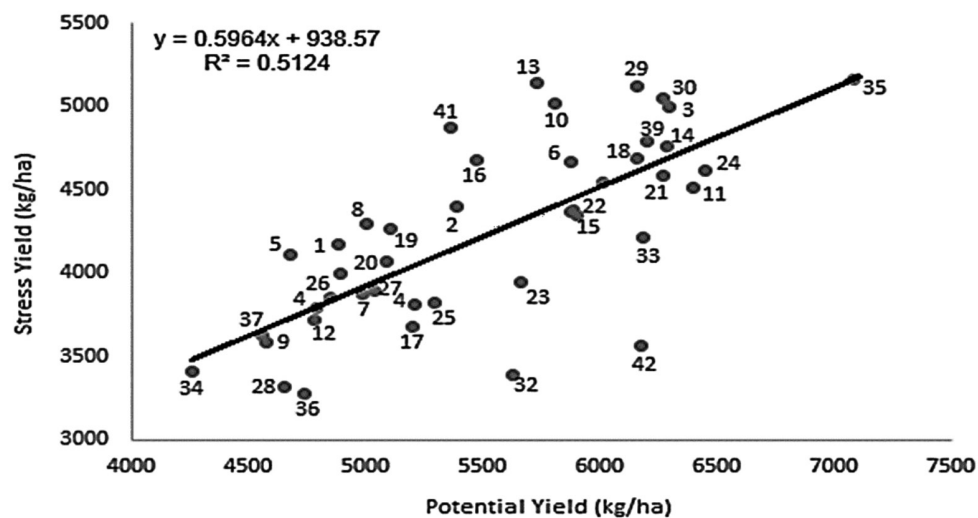

Fig. 1. Association between grain yield under non-stress and stress conditions in barley doubled haploid lines. Each point is the mean yield over the years and locations.

Table 2. Mean squares for agro-morphological traits of barley doubled haploid lines in different environments. ns, * and **, non-significant and significant at 0.05 and 0.01 probability levels, respectively

S.O.V	df	Plant height	Peduncle length	Spike length	Number of spike	Grains per spike	1000-grain weight	Hectoliter weight	Grain yield	Biological yield	Harvest index
Mahabad station											
Year	1	4167.72**	202.71**	77.65**	15880.22**	674.58**	111.62**	90.75**	102849.70**	842735.10**	769.83**
R (Year)	2	271.95	7.98	7.22	0.26	74.14	116.89	17.46	88137.29	106652.6	173.89
Stress	1	10076.39**	236.35**	1.57ns	207.02**	215.6**	723.86**	98.4**	1549203**	2926756**	815.16**
Year × Stress	1	6412.71**	1.19ns	1.09ns	204**	191.55**	68.88**	2.93ns	676.36ns	1412.29ns	0.05ns
Line	41	212.79**	60.89**	1.68**	25.59**	133.85**	40.66**	8.83**	28297.59**	46177.63**	67.24**
Line × Year	41	106.84**	29.26**	0.31ns	2.62**	35.85**	19.52**	1.07ns	2799.83ns	8285.91ns	29.89**
Line × Stress	41	73.16**	11.3*	1.15**	4.82**	25.5*	3.44ns	4.12*	5658.19*	15694.76**	5.78ns
Line × Stress × Year	41	54.28*	9.35ns	0.39ns	2.47**	24.72*	2.24ns	1.22ns	596.81ns	1955.33ns	3.47ns
Error	82	47.48	7.35	0.42	1.19	15.57	4.15	4.76	3757.49	6935.4	5.58
Miandoab station											
Year	1	509.82**	65.28**	95.01**	21871.21**	2046.90**	167.88**	64.94**	303595.20**	690234.70**	43.91**
R (Year)	2	500.52	22.29	4.13**	0.87	105.7	130.49	91.29**	93781.31	121195.2	141.757
Stress	1	3388.11**	966.45**	2.04*	64.17**	173.63**	732.22**	256.88**	1425567**	2675312**	718.03**
Year × Stress	1	13982.48	153.12**	1.78*	108.9**	7.51ns	0.12ns	1.72ns	1204.47ns	117.72ns	1.73ns
Line	41	131.17**	43.85**	1.69**	21.83**	108.22**	35.61**	32.99**	22110.50*	35220.50**	58.73**
Line × Year	41	72.91**	21.03**	0.52ns	3.53**	55.08**	24.07**	3.12ns	4779.20*	9864.22**	28.25**
Line × Stress	41	68.09*	9.48ns	1.04**	6.40*	38.16ns	10.24ns	10.54**	3385.47*	8810.11**	3.57ns
Line × Stress × Year	41	45.22ns	7.13ns	0.53ns	3.55**	16.31ns	4.08ns	3.09ns	485.25ns	1747.25ns	3.77ns
Error	82	44.14	5.99	0.41	1.16	14.26	4.124	3.51	2360	4269.75	4.47

Table 3. Drought tolerance indices for barley doubled haploid lines (averaged over two years and two locations. Yp, grain yield under non-stressed conditions (g m^{-2}); Ys, grain yield under stress conditions; SSI, stress susceptibility index; STI, stress tolerance index; MP, mean productivity; GMP, geometric mean productivity; YSI, yield stability index; SI, integrated selection index. LSD, least significant difference at 0.05 probability level

Line	Yp	Ys	SSI	STI	MP	GMP	YSI	SI
L1	488.77	417.18	0.63	0.67	452.98	451.56	0.85	−1.47
L2	538.67	439.75	0.79	0.78	489.21	486.70	0.82	0.92
L3	630.04	499.72	0.89	1.04	564.88	561.11	0.79	1.60
L4	479.26	379.21	0.89	0.60	429.24	426.31	0.79	−4.06
L5	468.05	411.32	0.52	0.63	439.68	438.77	0.88	−2.70
L6	587.33	466.63	0.88	0.90	526.98	523.51	0.79	2.32
L7	498.43	387.15	0.96	0.64	442.79	439.28	0.78	−2.41
L8	500.70	429.18	0.61	0.71	464.94	463.56	0.86	−0.51
L9	457.35	358.65	0.93	0.54	408.00	405.00	0.78	−2.70
L10	581.26	501.88	0.59	0.96	541.57	540.12	0.86	2.06
L11	639.83	451.63	1.26	0.95	545.73	537.55	0.71	−0.72
L12	478.45	372.23	0.95	0.59	425.34	422.01	0.78	−2.70
L13	573.38	514.44	0.44	0.97	543.91	543.11	0.90	1.22
L14	628.97	476.00	1.04	0.99	552.49	547.17	0.76	2.04
L15	589.88	434.46	1.13	0.84	512.17	506.24	0.74	−0.06
L16	547.57	467.19	0.63	0.84	507.38	505.79	0.85	−1.44
L17	520.16	367.77	1.26	0.63	443.97	437.38	0.71	−2.97
L18	615.61	469.05	1.02	0.95	542.33	537.35	0.76	0.91
L19	510.60	426.33	0.71	0.72	468.47	466.57	0.83	−1.36
L20	509.36	407.04	0.86	0.68	458.20	455.33	0.80	−1.94
L21	627.17	458.01	1.16	0.95	542.59	535.96	0.73	1.12
L22	588.26	437.91	1.10	0.85	513.08	507.55	0.74	0.92
L23	566.65	394.43	1.30	0.74	480.54	472.76	0.70	−3.24
L24	645.01	461.82	1.22	0.98	553.41	545.78	0.72	1.04
L25	529.23	381.82	1.19	0.67	455.53	449.53	0.72	−2.63
L26	484.83	385.45	0.88	0.62	435.14	432.29	0.80	−3.05
L27	503.73	389.28	0.97	0.65	446.50	442.82	0.77	−2.94
L28	465.75	331.07	1.24	0.51	398.41	392.67	0.71	−2.99
L29	616.10	512.03	0.72	1.04	564.06	561.66	0.83	2.55
L30	627.44	504.39	0.84	1.04	565.92	562.56	0.80	2.81
L31	601.81	454.02	1.05	0.90	527.91	522.72	0.75	1.55
L32	563.26	338.49	1.71	0.63	450.88	436.65	0.60	−2.62
L33	618.13	420.97	1.37	0.86	519.55	510.11	0.68	1.23
L34	425.65	340.88	0.85	0.48	383.26	380.91	0.80	−4.09
L35	704.97	504.94	1.22	1.17	604.95	596.63	0.72	4.14
L36	473.89	327.63	1.32	0.51	400.76	394.03	0.69	−4.79
L37	456.26	362.22	0.88	0.54	409.24	406.53	0.79	−3.52
L38	489.00	400.07	0.78	0.64	444.53	442.30	0.82	−1.57
L39	620.20	479.12	0.98	0.98	549.66	545.11	0.77	1.45
L40	521.23	380.60	1.16	0.65	450.91	445.40	0.73	−2.83
41 ('Morex')	536.10	486.92	0.39	0.86	511.51	510.92	0.91	3.09
42 ('Steptoe')	617.68	356.55	1.81	0.73	487.11	469.29	0.58	−3.55
LSD (0.05)	131.76	109.78	0.61	0.35	111.94	111.55	0.142	4.74

under non-stress condition was showed between L35, L34 and L37.

Of the 45 cultivated lines used in this study, L5, L7, L8, L10 and L13 had the lowest values of SSI as well as the highest values of YSI and were suggested as the most drought-tolerant lines under drought-stress. These lines showed highest and lowest performance under stress and under non-stress conditions, respectively. YSI evaluates the performance under stress condition of a genotype relative to its non-stress performance, hence the lines with a high

Table 4. Simple correlation coefficients of stress indices with grain yield of barley doubled haploid lines at Mahabad and Miandoab stations in two consecutive years (2013–2014). Yp, grain yield under non-stress conditions (g m^{-2}); Ys, grain yield under stress conditions (gr m^{-2}); SSI, stress susceptibility index; MP, mean productivity; GMP, geometric mean productivity; STI, stress tolerance index; YSI, yield stability index; SI, integrated selection index. * and **, significant at 0.05 and 0.01 probability levels, respectively

Indices	Averaged over years and locations		Miandoab 2013		Mahabad 2013		Miandoab 2014		Mahabad 2014	
	Yp	Ys	Yp	Ys	Yp	Ys	Yp	Ys	Yp	Ys
SSI	0.27	−0.47**	0.32*	−0.50**	0.41**	−0.54**	0.12	−0.46**	0.19	−0.39**
STI	0.92**	0.93**	0.91**	0.89**	0.91**	0.84**	0.96**	0.94**	0.96**	0.95**
MP	0.94**	0.91**	0.93**	0.89**	0.90**	0.85**	0.96**	0.95**	0.96**	0.94**
GMP	0.91**	0.93**	0.90**	0.91**	0.86**	0.89**	0.94**	0.96**	0.95**	0.96**
YSI	−0.27	0.47**	−0.29	0.48**	−0.40**	0.52**	−0.19	0.42**	−0.16	0.37*
SI	0.76**	0.89**	–	–	–	–	–	–	–	–

YSI are expected to have high yield under both stress and non-stress conditions. In our study, lines with the highest YSI exhibited the lowest and highest performance under non-stress conditions and stress conditions, respectively (for example L10 and L13). The highest values of STI, GMP, and MP were observed for L3, L14, L29, L30 and L35. Thus, they were identified as the most stable and productive lines among the cultivated lines under both environmental conditions. Based on SI index, the highest value belonged to L35, L30, L29, L10 lines and 'Morex' (parental genotype); thus they were recognized as drought tolerant lines (Table 3). Correlation coefficients (for two years and two locations) indicated significantly positive correlation between STI, MP and GMP with each other and with both grain yields under non-stress and stress conditions. Also, a highly positive significant correlation was observed between SI with both yields under non-stress and stress conditions. On the other hand, SSI negatively correlated with both grain yields. YSI index had negative and positive correlations with grain yield under non-stress and stress conditions, respectively (Table 4).

In order to identify tolerant lines, three-dimensional graphs were drawn based on Yp, Ys, STI and SI indices (Fig. 2). These graphs separated the lines into four groups: lines with high yields under both non-stress and stress environments (A group), high yield in a non-stress environment (B group), high yield in a stress environment (C group), and low yield under both non-stress and stress environments (D group). Evaluation of three-dimensional graphs revealed that according to both STI and SI indices lines L3, L6, L10, L11, L14, L18, L21, L24, L29, L30 and L35 were placed in A group. These lines are firstly preferable in yield in non-stress and stress conditions, and are secondly superior for quantitative tolerance indices than others; thus they are recommended as candidate lines for tolerance to drought. However, line numbers L2, L8, L13, L16, L19, L41 and L45 had a high yield in stress condition, but under non-stress condition had a low performance; thus they were placed in C group. L15, L22, L23, L33, L42 and L44 had the highest and lowest yield under non-stress and stress conditions, respectively, thus these lines were identified as drought susceptible lines and were recommended only for favorable environments or regions with adequate water. Consequently, the remaining lines were placed in D group,
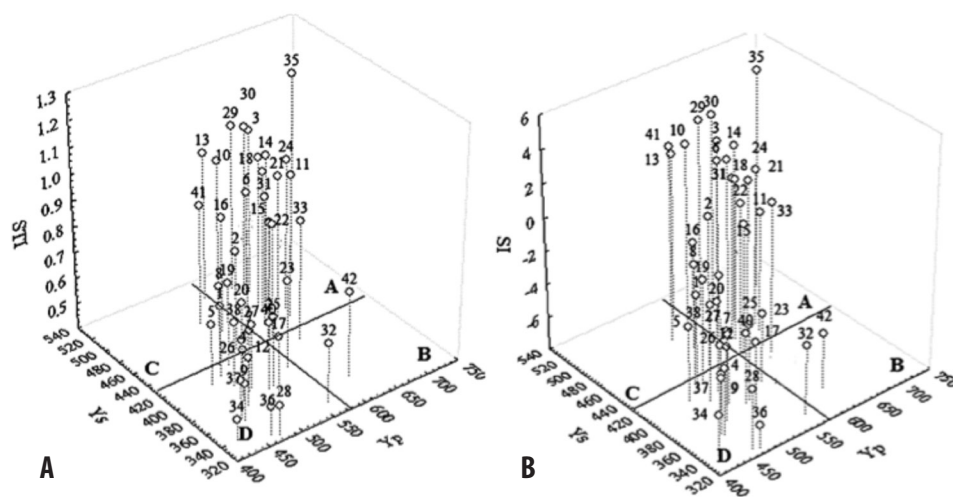

Fig. 2. Three-dimensional diagram for identifying drought-tolerant lines based on grain yield (g m^{-2}) under non-stress (Yp) and stress (Ys) conditions as well as the stress tolerance index (STI; A) and integrated selection index (SI; B).
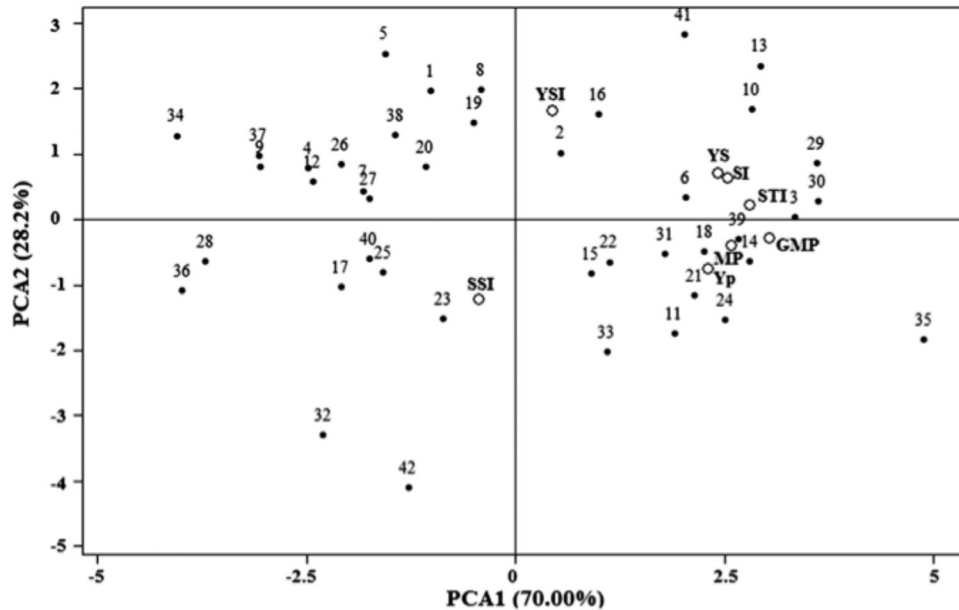
Fig. 3. Biplot drawn based on the first two components obtained from PCA using the stress susceptibility index (SSI), mean productivity (MP), geometric mean productivity (GMP), stress tolerance index (STI), yield stability index (YSI), integrated selection index (SI) and grain yield under non-stress (Yp) and stress (Ys) conditions in barley doubled haploid lines.

as they had low yield under both non-stress and stress conditions. Principal components analysis (PCA) was conducted using the grain yields and drought tolerance indices, and the lines were then subjected to biplot analysis to determine relationships among the indices (Fig. 3). The first component (PCA1) explained 70% of the total yield variation and showed a positive correlation with both grain yield under non-stress and stress conditions, STI, MP, GMP, YSI, and SI indices. The second component (PCA2) explained 28.2% of the total yield variation and had a high positive correlation with SSI. A biplot of PCA1 and PCA2 for 40 cultivated lines revealed that 10 lines (L3, L6, L14, L18, L21, L24, L29, L30, L35 and L39) were located near to the best drought tolerance indices (STI, MP, GMP, IS) with high PCA1 but low PCA2 values. On the other hand, the majority of lines with low PCA1 and high PCA2 values were distinguished as susceptible lines. In general, the results of the biplot and three-dimensional graphs demonstrated that lines such as L2, L8, L13, L16, L19, L41 and L45 had the best performance in stressful environments (C group) and lower sensitivity among lines (Fig. 2 and 3).

Discussion

Grain yield and its related traits are complex quantitative characters controlled by multiple genes and are highly influenced by environmental conditions (Shi et al. 2009). A highly significant difference was found among the lines for grain yield and agro-morphological traits studied in different environments (combination of year, location and water regime conditions), suggesting that traits which are suitable for an environment may be unsuitable in another

environment (Mohammadi et al. 2011). Also, the lines × year interaction was highly significant for grain yield and other traits, indicating that line performance changed from either one year to another or non-stress to stress conditions. The significant correlation between grain yield under non-stress and stress environments (Fig. 1) suggested that a high potential yield under optimum conditions does not necessarily result in enhanced yield under a stress conditions. Therefore, indirect selection for a drought-prone environment based on the results of optimum condition will be efficient (Mohammadi et al. 2011).

Our finding showed selection of superior lines on the basis of each indicator differedr. Khalili et al. (2012) found that, although selection based on a combination of indices may provide a more useful criterion for improving drought tolerance, correlation analysis between both grain yields (under non-stress and stress conditions) and tolerance indices can be a good criterion for screening the best genotypes and indices. STI, MP and GMP indices positively significantly correlated with grain yield under both conditions. Negative relation between SSI and grain yield under both conditions indicated that selection on the basis of this index decreases grain yield under favorable conditions but increases it under drought-stress conditions. As a remarkable result in the present study, a highly positive significant correlation was shown between SI and grain yield under both non-stress and stress conditions (Table 4), indicating capability of this indicator to discriminate A group lines under stress conditions across different environments. According to three-dimensional graphs, STI and SI show similar results: in both graphs L3, L6, L10, L11, L14, L18, L21, L24, L29, L30 and L35 were placed in A group

(Fig. 2). Thus, based on SI, it seems that plant breeders can select lines with high yield and suitable agronomic traits for drought-prone condition. The ability of the STI, MP and GMP indices to identify genotypes suitably under both conditions observed in this study is consistent with the results reported by Nouri et al. (2011) with durum wheat, Farshadfar et al. (2012) with bread wheat, Naghavi et al. (2013) with maize, Khalili et al. (2014) with safflower, and Poursiahbidi and Pour-Aboughadareh (2013) with chick pea.

While MP, GMP and STI indices were highly correlated with both yields under non-stress and stress conditions (across the different environments), and among them STI index has been usually accepted for assessing of drought-resistant lines, however these indices ignore other agro-morphological traits related to performance of excellent lines under drought stress. Hence the new selection criterion (SI) considers both yields under non-stress and stress conditions as well as agro-morphological traits; thus it can be more suitable to select lines for unpredicted drought stress. Additionally, the selection of agro-morphological traits as important factors related to grain yield and their weight values to drought tolerance were acquired from the statistical results across multiple environments. Furthermore, as an integrated selection index, the agro-morphological traits related to grain yield were selected as the most important traits that contributed to drought tolerance across eight environments, thus these traits were integrated to derive the final selection criterion. For example, based on this index, when the weight of each trait was defined (Table 1), the number of spikes and plant height indicated negative contributions to the final result, while the 1000-grain weight and peduncle length showed a high positive contribution to the final result, which were consistent with predictions. These agronomic traits are simple criteria for drought tolerance, and using these traits in integrated selection criterion (SI) decreases the risk of selection of tolerant lines. Likewise, Hao et al. (2011) and Khalili et al. (2013) used the integrated selection index (SI) to screen tolerance genotypes of corn and barley under normal and stress conditions, respectively. Principal components analysis showed that PCA1 and PCA2 explained 98.2% of the total yield variation, hence the first and second component were named as yield potential and stress susceptibility, respectively. Accordingly, biplot graph (Fig. 3) demonstrated ten lines L3, L6, L14, L18, L21, L24, L29, L30, L35 and L39 nearly located to the best drought tolerance indices (STI, MP, GMP, SI) with high PCA1 and low PCA2 scores.

Drought tolerance is not often discussed as an independent character by plant breeders because tolerance mechanisms can be fairly general and polygenic in nature. Therefore, the demand to screen for tolerance has encouraged plant breeders to look for a reliable index. Based on grain yield, yield components and drought tolerance

indices doubled haploid lines numbers L3, L18, L29 and L35 were superior to others, thus they can be recommended as candidate lines for improvement of drought tolerance in other genotypes.

Moreover, similar to STI, MP and GMP, there was positive and high significant correlations between SI and grain yield under both conditions. Consequently, according to our findings, SI index, similar to MP, GMP and STI indicators, can be efficiently used to screen drought-tolerant lines and also to detect superior lines for both non-stress and stress field conditions across multiple environments.

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