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RESEARCH PAPER

Evaluation of faba bean genotypes in normal and drought stress conditions by tolerance and susceptibility indices

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Highlights

- The production of faba bean usually reduces by abiotic stresses.
- Identification of drought tolerant genotypes is very effective in increasing faba bean production.
- Genotypes G7 (autochthonous Landraces from Lorestan, Khorramabad), G8 and G2 (autochthonous Landraces from Lorestan, Borujerd) from were as the drought tolerance and superior genotypes based on many of indices.
- We also proposed the use of standardized (based on standard deviation) and normalized (based on range) yield in potential and stress conditions for valuation tolerance and susceptibility of genotypes.

Graphical Abstract

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Abstract

In the 2017-2018 growing season, two separate experiments were conducted in Iran in a randomized block experiment with three replicates and under two irrigation conditions. Genotypes G2, G8, G5 and G7 with the highest seed yield under both conditions were classified in group A. Genotypes G7, G8 and G2 were the drought tolerant and superior genotypes based on the indices MP, GM, STI, YI, YSI, HM, RDI, DI, SNPI, MRP, REI, MSTIK1 and MSTIK2. Genotypes G2, G8, and G7 with the lowest average sum of ranks (ASR) were tolerant genotypes. Yp had a positive significant correlation with TOL, MP, GMP, STI, HM, ATI, SSPI, MRP, REI, MSTIK1, MSTIK2, Ynorm, and Z. Cluster analysis also identified genotypes G2, G8, G5, and G7 with the highest tolerance to drought stress. The stress tolerance index (STI), modified stress tolerance index K1 (MSTIK1), and average sum of ranks (ASR) were more useful to select favorable field bean genotypes under dryland and irrigated conditions. Using these three indices, genotype G7 was found to be the most tolerant genotype to drought stress. Moreover, this study proposed a new idea for evaluating the stress tolerance and susceptibility of genotypes by using standardized and normalized yield data under stress and normal conditions based on the range of variation and standard deviation, and verified these values in current data and other data of 18 rice genotypes. Moreover, the present study recommended the application of this idea to other data sets and verified its advantages.

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1. Introduction

Faba bean (*Vicia faba* L.) is an important source of protein for humans. Water deficit is one of the most limiting factors in production of crops in agricultural systems (Mollasadeghi et al., 2011). The production of faba bean usually reduces by a-biotic stresses such as drought or winter hardiness (Link et al., 2010). therefore, a better understanding of response of this crop to drought stress is necessary to perform sustainable yield in water-limited environments (Khan et al., 2010).

Screening of tolerant genotypes to drought stress performed by several indices, which assess the response of genotypes to stress based on the loss of yield under stress condition (Mitra, 2001). Drought resistance index (DI) (Akcura, 2011), mean productivity (MP) and stress tolerance (TOL)(Rosielle and Hamblin, 1981), stress tolerance index (STI) and geometric mean productivity (GMP) (Nouri et al., 2011), stress susceptibility index (SSI) (Fischer and Maurer, 1978) are the more comprehensive indices for evaluation the crop tolerance and susceptibility. The other indices for evaluation of tolerance and susceptibility to stresses are yield index (YI) (Gavuzzi et al., 1997); relative drought index (RDI) (Fischer and Wood, 1979); yield stability index (YSI) (Bouslama and Schapaugh, 1984) and yield reduction (YR) (Fageria, 1985). Stress susceptibility percentage index (SSPI), abiotic tolerance index (ATI) and stress non-stress production index (SNPI) are the other tolerance indices (Mousavi et al., 2008). The other indices for estimation potential of crops to stress are relative efficiency index (REI), mean relative performance (MRP) (Hossain et al., 1990); modified stress tolerance index K1 (MSTIK1) and modified stress tolerance index K2 (MSTIK2) (Toorchi et al., 2012); and golden mean (GM) (Moradi et al., 2012).

Some of researchers studied drought indices in legumes. Link et al., (1999), evaluated some of faba bean genotypes and indicated highly significant variances between genotypes (Link et al., 1999). Sepahvand et al., (2021) evaluated (*Celtis caucasica L.*) genotypes under drought stress and recognized the tolerant and sensitive genotypes (Sepahvand et al., 2021). Sarker et al., (2020) studied 25 chickpea genotypes under water stress condition and indicated GMP, MP, and STI as the most suitable indices for determination of drought tolerant genotypes (Sarker et al., 2020). Ouji et al., (2017) evaluated four Tunisian faba bean genotypes and identified relatively drought tolerant genotype by drought susceptibility index (DSI) (Ouji et al., 2017). Sánchez-Reinoso et al., (2020), assessed the effect of drought in vegetative and reproductive stages on grain yield of common bean by tolerance indices and indicated SSI is as the best drought tolerance index (Sánchez-Reinoso et al., 2020). Siddiqui et al., (2015), evaluated 10 faba bean genotypes under drought stress condition and found genotypes "C5" and "Zafar 1" ares relatively tolerant genotypes to drought stress (Siddiqui et al., 2015). Desoky et al., (2020), indicated that 'Nubaria-2', 'Giza-843', and 'Sakha-3' were the more tolerant to drought stress than 'Giza-716' and 'Sakha-4'(Desoky et al., 2020). The objectives of present study are evaluation of response of faba bean genotypes to drought stress and determine the best indices to identify drought tolerant genotypes in faba bean using multivariate analysis.

2. Materials and Methods

2.1. Experimental field area

This study was carried out during 2017-18 growing season, in agriculture and natural resources station in Broujerd, Iran (Latitude, 35°55′N; longitude, 48°45′E; Altitude, 1629 m). Two separate experiments were performed in randomized complete block design with three replications, under supplemental irrigation and dryland conditions. The distance between two separate experiments was 50 m in length. The seeds of eight faba bean genotypes (Table 1) sown on 8 March 2017. Each plot consisted of four rows with a length of six m and a row spacing of 50 cm, so that the plant density was 15 plants per m2. Fifteen kilogram per hectare of nitrogen, phosphorus and potassium fertilizers added to the soil, before planting. Irrigation performed twice in the supplementary irrigation experiment at stem elongation and seed filling period stages (Khan et al., 2010). Weeds controlled by hand hoeing during crop growth and development. Other recommended agronomic such as fertilization and pest control followed raising good crop.

Table 1. Description Of studied genotype**.**

Genotype code	Origin	Breeding status	Seed structure
G1	Iran/Guilan	Autochthonous Landrace	Large
G2	Iran/Lorestan (Borujerd1)	autochthonous Landrace	Small
G3	France	improved breeding cultivars	Intermediate
G4	Iran/Gurgan	improved breeding cultivars	Large
G5	Iran/Lorestan (Borujerd2)	autochthonous Landrace	Small
G6	Iran/Mazandaran	autochthonous Landrace	Large
G7	Iran/Lorestan (Khorramabad)	autochthonous Landrace	Small
G8	Iran/Lorestan (Borujerd3)	autochthonous Landrace	Small

2.2. Estimated characters and drought indices

Seed yield measured per m^2 and reported to kilogram per hectare. Tolerance of faba genotypes to drought stress evaluated by 19 indices (Table 2). Where, Yp and Ys indicates yields of a given genotype under favorable or potential environment (supplemental irrigation) and unfavorable or stress (dryland) conditions, and $\overline{Yp}$ and $\overline{Ys}$ indicates the mean yield in favorable and unfavorable conditions, respectively.

All of the statistical procedures including analysis of variance, calculation of susceptibility and tolerance indices, Pearson correlation coefficient, principal component and cluster analyses were carried out by R software codes named as TSIfPS (Tolerance and Susceptibility Indices for Plant Stress) (Sharifi et al., 2017). For correlation analysis, was used tolerance and susceptibility Indices themselves, not their ranks. Therefore, Pearson correlation was used to evaluate the relationships between the indices.

Tolerance and susceptibility can be measured in different genotypes using the indices in Table 2. The average of genotypes in both normal and stress conditions was used to calculate all the above indices. In addition to these indices, it seems that standardized and normalized performance under stress and normal conditions can also be used as another index to assess the tolerance and susceptibility of genotypes to stress. Standardization or Z-score conversion for a data set is to obtain values that have a mean of zero and a standard variance or deviation of one. Another method of scaling is to use the Min-Max normalization method. Thus, in addition to unifying the scale of the data, the edges of their change are also will be in the range (0,1). Therefore, we used the standardized and normalized yield in potential and stress condition (Saffariha et al., 2021).

In the normalization method based on the range, the value of yield under potential and stress conditions are between zero and one, so the total value of the Ynorm varies from zero to two. A genotype in which both the SYnorm and PYnorm indices are one or close to it, and the sum of the two indices is two or close to it, will be more tolerant to stress. The more balanced PYnorm and SYnorm in the genotype are close to one, the superior the genotype will be, in other words, it will have a high yield under both stress and normal conditions. The advantage of this index is that the maximum and minimum values of yield of genotypes are used to denote its fraction, and therefore it is a relative index that is used to evaluate tolerance and susceptibility to stress. The formula for calculating this index is as follows:

$$Y_{norm} = PY_{norm} + SY_{norm} = \left(\frac{Y_{pi} - Y_{p\,\min}}{Y_{p\,\max} - Y_{p\,\min}}\right) + \left(\frac{Y_{si} - Y_{s\,\min}}{Y_{s\,\max} - Y_{s\,\min}}\right) \quad (1)$$

Where, Y_{pi}, Y_{pmin} and Y_{pmax} are the mean yield of i^{th} genotype and the least and most yield of genotypes under potential condition, respectively. Y_{si}, Y_{smin} and Y_{smax} are also the performance of i^{th} genotype and the performance of the genotypes with the lowest and highest values under stress conditions.

In the standardization method based on the mean and standard deviation, also, the genotype with the highest positive value of the index is the most tolerant and the genotype with the highest negative value are the most susceptible genotype.

Table 2. Formula for calculating stress indices.

No.	Index	Desirable genotypes	Equation	References
1	Tolerance Index (TOL)	Low value of this index	$TOL = Yp - Ys$	Rosielle and Hamblin, 1981
2	Stress Susceptibility Index (SSI) Stress Index (SI)	Low value of this index	$SSI = \frac{1-(Ys/Yp)}{SI}$ $SI = 1 - \frac{\bar{Y}s}{\bar{Y}p} = \frac{(\bar{Y}p - \bar{Y}s)}{\bar{Y}p}$	Fischer, Maurer, 1978
3	Mean Productivity (MP)	High value of this index	$MP = \frac{Yp + Ys}{2}$	Rosielle and Hambline, 1981
4	Geometric Mean Productivity (GMP)	High value of this index	$GMP = \sqrt{YpYs}$	Nouri et al., 2011
5	Stress Tolerance Index (STI)	High STI values will be tolerant to stress	$STI = \frac{YpYs}{(\bar{Y}p)^2}$	Nouri et al., 2011
6	Yield Index (YI)	High value of this index	$YI = \frac{Y_S}{\bar{Y}_S}$	Gavuzzi et al., 1997
7	Yield Stability Index (YSI)	High value of this index	$YSI = \frac{Y_S}{Y_P}$	Bouslama and Schapaugh, 1984
8	Harmonic Mean (HM)	High value of this index	$HM = \frac{2(Y_P \times Y_S)}{Y_P + Y_S}$	Nouri et al., 2011
9	Relative drought index (RDI)	High value of this index	$RDI = \frac{(\frac{Y_s}{Y_p})}{(\frac{\bar{Y}_s}{\bar{Y}_p})}$	Fischer and Wood, 1979
10	Drought Index (DI)	High value of this index	$DI = \frac{\frac{(Y_s)^2}{Y_p}}{\bar{Y}_s}$	Akcura, 2011
11	Yield Reduction (YR)	Low value of this index	$YR = 1 - \frac{Y_s}{Y_p}$	Fageria, 1985
12	Abiotic Tolerance Index (ATI)	Low value of this index	$ATI = [\frac{(Y_p - Y_s)}{(\bar{Y}_p / \bar{Y}_s)}] * [\sqrt{Y_p * \dots}$	Mousavi et al., 2008
13	Stress Susceptibility Percentage Index (SSPI)	Low value of this index	$SSPI = [\frac{(Y_p - Y_s)}{2(\bar{Y}_p)}] * 100$	Mousavi et al., 2008
14	Stress Non-Stress Production Index (SNPI)	High value of this index will be suitable for dryland condition	$SNPI = [\sqrt[3]{\frac{Y_p + Y_s}{Y_p - Y_s}}] * [\sqrt[3]{Y_p * Y_s * Y \dots}$	Mousavi et al., 2008
15	Mean Relative Performance (MRP)	High value of this index	$MRP = (\frac{Y_s}{\bar{Y}_s}) + (\frac{Y_p}{\bar{Y}_p})$	Hossain et al., 1990
16	Relative Efficiency Index (REI)	High value of this index	$REI = (\frac{Y_s}{\bar{Y}_s}) * (\frac{Y_p}{\bar{Y}_p})$	Hossain et al., 1990
17	Modified Stress Tolerance Index K1 (MSTIk1)	High value of this index	$MSTIK1 = (\frac{Y_p^2}{\bar{Y}_p^2}) * STI$	Toorchi et al., 2012
18	Modified Stress Tolerance Index K2 (MSTIk2)	High value of this index	$MSTIK2 = (\frac{Y_s^2}{\bar{Y}_s^2}) * STI$	Toorchi et al., 2012
19	Golden Mean (GM)	High value of this index	$GM = \frac{Y_P + Y_S}{Y_P - Y_S}$	Moradi et al., 2012

$$Z = Z_{PY} + Z_{SY} = \left(\frac{Y_{pi} - Y_p}{SY_p}\right) + \left(\frac{Y_{si} - Y_s}{SY_s}\right) \quad (2)$$

Where, Z_{PY} and Z_{SY} are the standard deviation of genotypes under potential and stress conditions, respectively. In addition to the current research data, drought stress data in 18 rice genotypes were also used to verify the accuracy of Ynorm and Z scores of grain yield. This dataset was for I and obtained from a field trial which conducted at Iranian Rice Research Centers in North of Iran, Rasht (latitude 37°28', longitude 49°28'E and altitude 7m below the sea level), during the 2014-2015 growing season. The seeds were sown in a nursery on the 10 May and 25 day old seedlings were transplanted to the field. Two separately experiment was carried out under reproductive stage drought stress and controlled conditions based on randomized complete block design with three replications. The results of stress tolerance assessment of this rice dataset were previously reported (Aminpanah et al., 2018; Asadi and Jalilian, 2021; Sharifi et al., 2017). Therefore, these two indices and their components were estimated for this dataset.

3. Results and Discussion

3.1. Estimation of susceptibility and tolerance indices

In dryland condition, the lowest value of seed yield (473.3 kg/ha) was obtained in genotype G6, which decreased by 74.4% compared to supplemental irrigation (Table 3). In this experiment, genotypes G2 and G8 had the highest seed yield and their yield reduction were 43.7 and 46.1% than supplementary irrigation, respectively. According to classification of genotypes based on Nouri et al., (2011) four genotypes G2, G8, G5, and G7 with the high yields under both conditions were located into group A. Genotype G6 with the highest yield under non-stress condition is into group B; and the genotypes G1, G3, and G4 with poor performance under both conditions are into group D (Fig. 1). The seed yield in the two conditions also used to calculate the susceptibility and tolerance indices (Table 3). Two-dimensional plot indicated the genotypes G2, G5, G7 and G8 located in group A, and had stable seed yield in two conditions (Nouri et al., 2011).

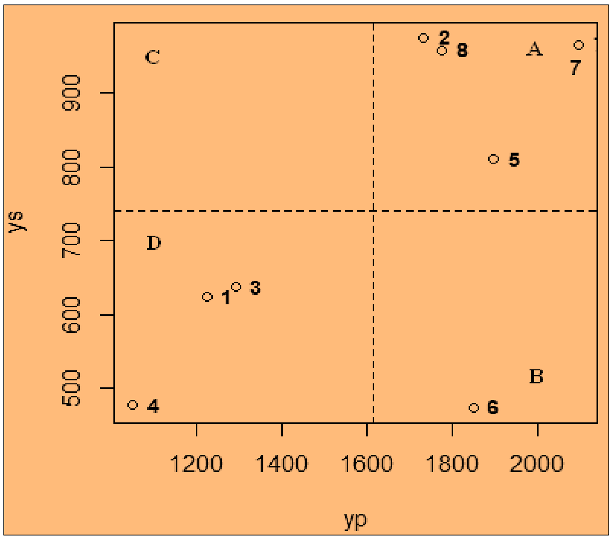


Figure 1. Tow dimensional graphs based on Nouri et al., (2011) classification. Note: Genotypes: 1) Landrace from Guilan; 2) Landrace from Borujerd; 3) France, 4) Barrakat; 5) Landrace from Borujerd; 6) Landrace from Mazandaran; 7) Landrace from Khorramabad; 8) Landrace from Borujerd.
Yp: Seed yield in non-stress condition; Ys: Seed yield in stress condition.

Normalized potential and stress yield based on range (Ynorm) indicated that genotypes G7, G8, and G2 were the most tolerant genotypes to drought stress, while genotype G4 was the most sensitive genotype (Table 3). This result was also seen using MP, GM, STI, YI, YSI, HM, RDI, DI, SNPI, MRP, REI, MSTIK1, and MSTIK2 indices. According to these indices, genotype G7 with the highest standards of yield in both conditions (PYnorm and SYnorm) was superior to the other two genotypes (G2 and G8). The Z score of potential and stress yield also show that the genotypes G7, G8, and G2 were superior to the others and have more tolerance to drought, but given that genotype G7 had higher performance in both conditions compared to the other two genotypes, it has more superiority. Ranking of genotypes based on seed yield in both conditions, as well as susceptibility and tolerance indices indicated in Table 4. The tolerant genotypes had the lowest values of TOL, SSI, YR, ATI, and SSPI, and highest values of YS, YP, HM, MP, YSI, GMP, STI, YI, RDI, DI, SNPI, MRP, REI, MSTIK1, and MSTIK2. The highest value of seed yield in drought stress condition (Ys) was recorded for G2 (975 kg/ha), which indicated significant preference compared to the other genotypes. In supplemental irrigation condition, the genotype G7 (2098 kg/ha) had significant preference to other genotypes, followed by the genotypes G5, G6, and G2. According to the ranking on MP, GM, STI, YI, YSI, HM, RDI, DI, SNPI, MRP, REI, MSTIK1, and MSTIK2, the best performances of seed yield observed by the genotypes G7, G8, and G2. Thus, these genotypes found drought tolerance. In the other hand, the two genotypes G1 and G4 indicated the lowest value of these indices and were as sensitive genotypes to water deficit (Awan et al., 2021). While, the genotype G6 with the highest values of TOL, SSI, YR, ATI, and SSPI were recorded the susceptible genotypes to drought stress. Based on the results of these indices, two genotypes G2 and G8 were as the tolerant genotypes to drought stress (Table 4). The latest columns in Table 4 indicate sum ranks (SR), average sum of ranks (ASR) and standard deviation (Std) for genotypes. Average sum of ranks for all indices could be used to select superior genotypes. The genotypes with the lowest ASR including G2 (ASR = 2.39; Std = 1.31), G8 (ASR = 2.70; Std = 1.06) and G7 (ASR = 2.96; Std = 2.36), were as tolerant genotypes; while G4 had the highest value of ASR (6.52; Std = 2.33) and were as susceptible genotype to drought stress.

3.2. Correlation coefficient analysis

Seed yield under supplementary irrigation (Yp) showed positive correlation with TOL, MP, GMP, STI, HM, ATI, SSPI, MRP, REI, MSTIK1, MSTIK2, Ynorm, and Z. Seed yield under dryland condition (Ys) had positively correlated with GMP, MP, HM, STI, YI, YSI, RDI, DI, SNPI, MRP, REI, MSTIK1, MSTIK2, GM, Ynorm, and Z. On the other hand, there were not significant correlation between Ys and TOL and SSPI. The correlation between yield under drought condition (Ys) was negative with SSI and YR indices (Fig. 2). Seed yield in both environments were positively correlated with MP, GMP, STI, HM, MRP, REI, MSTIK1, MSTIK2, Ynorm, and Z. Correlation analysis between tolerance and susceptibility indices and seed yield in stress and non-stress conditions is a good criterion to determine the suitable index for distinguishing the superior genotypes under drought stress (Farshadfar et al., 2013). Since the appropriate index had positive correlation with seed yield under two environments, so MP, GMP, STI, HM, MRP, REI, MSTIK1, MSTIK2, Ynorm, and Z can be effective in identifying high yielding and drought-tolerant genotypes (e.g. G7, G5, G8, and G2) under different water conditions (Mitra, 2001). Sánchez-Reinoso et al., (2020) indicated MP had significant correlation with yield of common bean in stress and non-stress conditions (Sánchez-Reinoso et al., 2020). Based on the other study, not significant correlation between potential yield (Yp) and SSI is agreement (Ehdaie and Shakiba, 1996). In the other researches, the positive and significant correlation between Ys and GMP, MP, and STI reported (Toorchi et al., 2012; Naghavi et al., 2013; Farshadfar et al., 2012). Farshadfar et al., (2012), stated the suitable indices for selection of drought tolerant genotypes have relatively high correlation with seed yield in both conditions (Farshadfar et al., 2012). The other researchers also reported MP, GMP and STI as suitable indices for distinguishing tolerant genotypes (Mohammadi et al., 2010; Nouri et al., 2011; Karimizadeh and Mohammadi, 2011; Mohammadi et al., 2011). Ouji et al., (2017), used drought susceptibility index (DSI) and found Chahbi cultivar as high yielding and drought tolerant (Ouji et al., 2017).

Table 3. Drought tolerance indices of eight faba bean genotypes.

Gen	1	2	3	4	5	6	7	8
Yp (kg/ha)	1223	1732	1291	1049	1897	1849	2098	1775
Ys (kg/ha)	623	975	636	476	810	473	965	957
TOL	600.1	757.4	654.3	572.8	1087.3	1376.0	1132.5	818.3
SSI	0.91	0.91	0.94	1.01	1.06	1.37	1.00	0.85
MP	923	1353	963	763	1353	1161	1531	1366
GMP	873.3	1299.7	9.6.6	707.3	1239.7	935.6	1423.2	1304.0
STI	0.29	0.65	0.32	0.19	0.59	0.34	0.78	0.65
YI	0.84	1.32	0.86	0.64	1.09	0.64	1.31	1.29
YSI	0.51	0.56	0.49	0.45	0.43	0.26	0.46	0.54
HM	825	1247	852	655	1135	753	1322	1244
RDI	1.11	1.23	1.08	0.99	0.93	0.56	1.00	1.18
DI	0.43	0.74	0.42	0.29	0.47	0.16	0.60	0.70
YR	0.49	0.44	0.51	0.55	0.57	0.74	0.54	0.46
ATI	240095	451010	271792	185608	617584	589832	738478	488899
SSPI	18.6	23.5	20.3	17.7	33.7	42.6	35.1	25.3
SNPI	1058.1	1675.2	1076.6	803.5	1355.6	829.4	1617.2	1631.9
MRP	1.60	2.39	1.66	1.29	2.27	1.79	2.60	2.39
REI	0.64	1.41	0.69	0.42	1.29	0.73	1.70	1.42
MSTIK1	0.17	0.75	0.20	0.08	0.81	0.44	1.31	0.79
MSTIK2	0.21	1.13	0.23	0.08	0.71	0.14	1.32	1.09
GM	3.08	3.57	2.95	2.66	2.49	1.69	2.71	3.34
PYnorm	0.17	0.65	0.23	0.00	0.81	0.76	1.00	0.69
SYnorm	0.30	1.00	0.33	0.01	0.67	0.00	0.98	0.97
Ynorm	0.46	1.65	0.56	0.01	1.48	0.76	1.98	1.66
Z_{PY}	-1.04	0.31	-0.86	-1.51	0.75	0.63	1.29	0.43
Z_{SY}	-0.54	1.10	-0.48	-1.22	0.33	-1.24	1.05	1.01
Z	-1.58	1.41	-1.34	-2.73	1.08	-0.61	2.34	1.44

Note: Gen: Genotype; Yp: Seed yield in non-stress condition; Ys: Seed yield in stress condition; TOL: Tolerance Index; SSI: Stress Susceptibility Index; MP: Mean Productivity; GMP: Geometric Mean Productivity; STI: Stress Tolerance Index; YI: Yield Index; YSI: Yield Stability Index; HM: Harmonic Mean; RDI: Relative drought index; DI: Drought Index; YR: Yield Reduction; ATI: Abiotic Tolerance Index; SSPI: Stress Susceptibility Percentage Index; SNPI: Stress Non-Stress Production Index; MRP: Mean Relative Performance; REI: Relative Efficiency Index; MSTIk1: Modified Stress Tolerance Index K1; MSTIk2: Modified Stress Tolerance Index K2; GM: Golden Mean; SI: Stress Index; Ynorm: Normalized Potential and Stress Yield; PYnorm: Normalized Potential Yield; SYnorm: Normalized Stress Yield; Z: Standardized Potential and Stress Yield; Z_{PY}: Standardized Potential Yield; Z_{SY}: Standardized Stress Yield. Genotypes: 1) Landrace from Guilan; 2) Landrace from Borujerd; 3) France, 4) Barrakat; 5) Landrace from Borujerd; 6) Landrace from Mazandaran; 7) Landrace from Khorramabad; 8) Landrace from Borujerd.

Table 4. Ranking of eight faba bean genotypes based on drought tolerance and susceptibility indices.

Gen	1	2	3	4	5	6	7	8
Yp (kg/ha)	7	5	6	8	2	3	1	4
Ys (kg/ha)	6	1	5	7	4	8	2	3
TOL	2	4	3	1	6	8	7	5
SSI	3	1	4	6	7	8	5	2
MP	7	3	6	8	4	5	1	2
GMP	7	3	6	8	4	5	1	2
STI	7	3	6	8	4	5	1	2
YI	6	1	5	7	4	8	2	3
YSI	3	1	4	6	7	8	5	2
HM	6	2	5	8	4	7	1	3
RDI	3	1	4	6	7	8	5	2
DI	5	1	6	7	4	8	3	2
YR	3	1	4	6	7	8	5	2
ATI	2	4	3	1	7	6	8	5
SSPI	2	4	3	1	6	8	7	5
SNPI	6	1	5	8	4	7	3	2
MRP	7	3	6	8	4	5	1	2
REI	7	3	6	8	4	5	1	2
MSTIK1	7	4	6	8	2	5	1	3
MSTIK2	6	2	5	8	4	7	1	3
GM	3	1	4	6	7	8	5	2
Ynorm	7	3	6	8	4	5	1	2
Z	7	3	6	8	4	5	1	2
SR	119	55	114	150	110	150	68	62
AR	5.17	2.39	4.96	6.52	4.78	6.52	2.96	2.70
Std.	1.99	1.31	1.11	2.33	1.59	1.56	2.36	1.06

Note: Gen: Genotype; Yp: Seed yield in non-stress condition; Ys: Seed yield in stress condition; TOL: Tolerance Index; SSI: Stress Susceptibility Index; MP: Mean Productivity; GMP: Geometric Mean Productivity; STI: Stress Tolerance Index; YI: Yield Index; YSI: Yield Stability Index; HM: Harmonic Mean; RDI: Relative drought index; DI: Drought Index; YR: Yield Reduction; ATI: Abiotic Tolerance Index; SSPI: Stress Susceptibility Percentage Index; SNPI: Stress Non-Stress Production Index; MRP: Mean Relative Performance; REI: Relative Efficiency Index; MSTIk1: Modified Stress Tolerance Index K1; MSTIk2: Modified Stress Tolerance Index K2; GM: Golden Mean; SI: Stress Index; Ynorm: Normalized Potential and Stress Yield; PYnorm: Normalized Potential Yield; SYnorm: Normalized Stress Yield; Z: Standardized Potential and Stress Yield; Z_{PY}: Standardized Potential Yield; Z_{SY}: Standardized Stress Yield; ASR: average sum of ranks; SR: Sum ranks; Std: Standard deviation. Genotypes: 1) Landrace from Guilan; 2) Landrace from Borujerd; 3) France, 4) Barrakat; 5) Landrace from Borujerd; 6) Landrace from Mazandaran; 7) Landrace from Khorramabad; 8) Landrace from Borujerd.

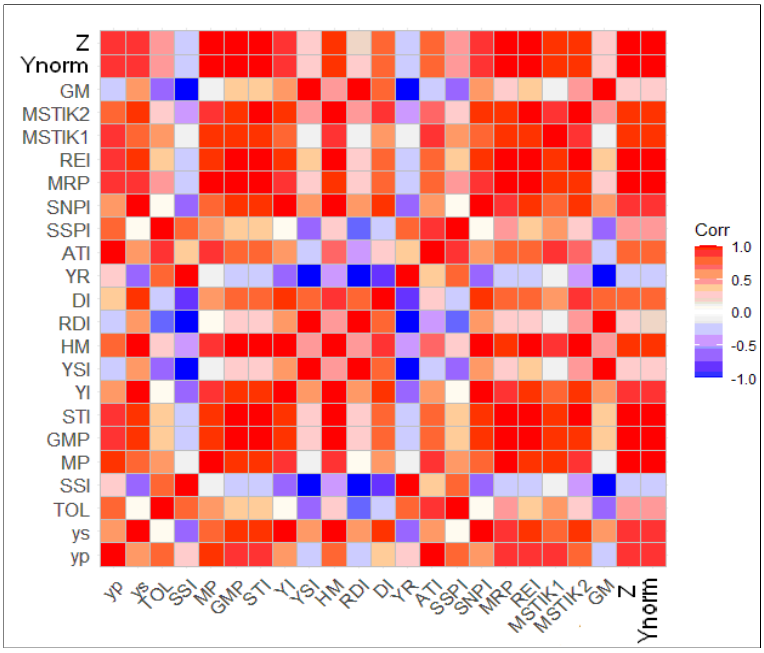


Figure 2. Heat map graph for correlation analysis between YP, YS and tolerance indices.
Note: Gen: Genotype; Yp: Seed yield in non-stress condition; Ys: Seed yield in stress condition; TOL: Tolerance Index; SSI: Stress Susceptibility Index; MP: Mean Productivity; GMP: Geometric Mean Productivity; STI: Stress Tolerance Index; YI: Yield Index; YSI: Yield Stability Index; HM: Harmonic Mean; RDI: Relative drought index; DI: Drought Index; YR: Yield Reduction; ATI: Abiotic Tolerance Index; SSPI: Stress Susceptibility Percentage Index; SNPI: Stress Non-Stress Production Index; MRP: Mean Relative Performance; REI: Relative Efficiency Index; MSTIk1: Modified Stress Tolerance Index K1; MSTIk2: Modified Stress Tolerance Index K2; GM: Golden Mean; Ynorm: Normalized Potential and Stress Yield; Z: Standardized Potential and Stress Yield.

3.3. Cluster analysis

Cluster analysis allows grouping of the genotypes based on the indices. For cluster analysis, we used Ward linkage and squared Euclidean distance. Genotype grouping by cluster analysis (Ward method) using all of the susceptibility and tolerance indices and yield in stress (Ys) and irrigation (Yp) conditions grouped the genotypes in three clusters with three, one and four genotypes, respectively (Fig. 3). In this dendrogram, genotypes G2, G8, G5, and G7 were located in the same group, which was previously grouped in two-dimensional plot (tolerant group). The genotypes in this group had the highest values of MP, GM, STI, YI, YSI, HM, RDI, DI, SNPI, MRP, REI, MSTIK1, and MSTIK2. These genotypes, with relation to seed yield in supplemental irrigation (Ys) and dryland (Yp) and highest values of tolerance indices were superior in comparison to the others. Genotype G6 laid in a separate group in the non-stress susceptible region. Genotypes G1, G3, and G4 in the other group (Fig. 3), had low value of Yp and Ys and tolerance indices and considered as a group with poor performance in both conditions. The differences between second (G6) and third (G1, G3, and G4) groups is according to low yielding in third group in non-stress condition. Therefore, it is possible to use the genotypes lay in the separate groups for genetic analysis (Mursalova et al., 2015). These results are consistent with the finding of other research (Golabadi et al., 2006; Mohammadi et al., 2011). Also divided faba bean genotypes into three groups by cluster analysis.

3.4. Principal component and biplot analyses

A principal component analysis (PCA) carried out to describe and gain better understanding sources of variance among faba bean genotypes. Principal component analysis (PCA) indicated the first two components explained 66 and 33% of the total variation, respectively (Table 5). Thus, biplot was drawn based on the first two components and indicated the PC1 showed highly coordination and loading values with Ys, Yp, STI, GMP,

MP, YSI, YI, HM, ATI, DI, MRP, SNPI, REI, MSTIK1, MSTIK2, Ynorm, and Z. The second PCA had high positive coordination with YSI, RDI, DI, and GM. Biplot analysis is a useful approach to identify the superior genotypes in stress and non-stress conditions. Principal component analysis, which determines the number of components, is accounted the total variation in yield and tolerance indices, used to draw two-dimensional diagram in a PCA-based biplot (Lever et al., 2017). Since the first two PCs accounted for 99% (63 and 33%) of total variation, the biplot could best show the relationships between the indices as well as their extent in each of the genotypes. The first principal component separates the stress-tolerant genotypes with high yield from the other genotypes. Regarding the biplot, genotypes G5 and G7, were drought tolerance and high yielding. Genotypes G1, G3, and G4 were in low yield and sensitive region and identified as drought sensitive genotypes. Large obtuse angles between Ys and SSI indicated a strong negative association. The acute angles between Yp and Ys with GMP, MP, STI, Ynorm, and Z indicated a positive correlation between these indices and yield in stress and non-stress environments (Yan and Rajcan, 2002) (Fig. 4).

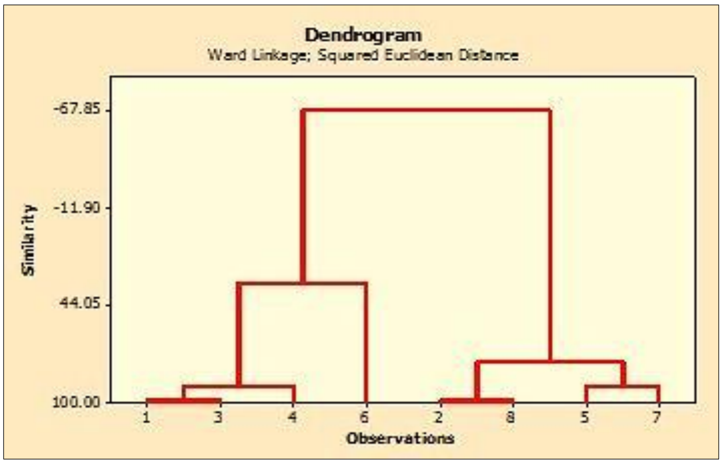


Figure 3. Dendrogram of indices for 8 faba bean genotypes by Ward method

Note: Genotypes: 1) Landrace from Guilan; 2) Landrace from Borujerd; 3) France, 4) Barrakat; 5) Landrace from Borujerd; 6) Landrace from Mazandaran; 7) Landrace from Khorramabad; 8) Landrace from Borujerd.

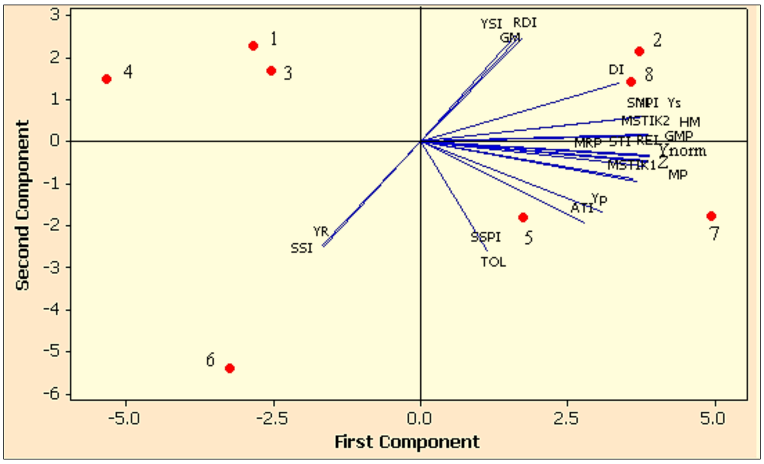


Figure 4. Biplot of drought tolerance indices.

Note: Gen: Genotype; Yp: Seed yield in non-stress condition; Ys: Seed yield in stress condition; TOL: Tolerance Index; SSI: Stress Susceptibility Index; MP: Mean Productivity; GMP: Geometric Mean Productivity; STI: Stress Tolerance Index; YI: Yield Index; YSI: Yield Stability Index; HM: Harmonic Mean; RDI: Relative drought index; DI: Drought Index; YR: Yield Reduction; ATI: Abiotic Tolerance Index; SSPI: Stress Susceptibility Percentage Index; SNPI: Stress Non-Stress Production Index; MRP: Mean Relative Performance; REI: Relative Efficiency Index; MSTIk1: Modified Stress Tolerance Index K1; MSTIk2: Modified Stress Tolerance Index K2; GM: Golden Mean, Ynorm: Normalized Potential and Stress Yield; Z: Standardized Potential and Stress Yield.

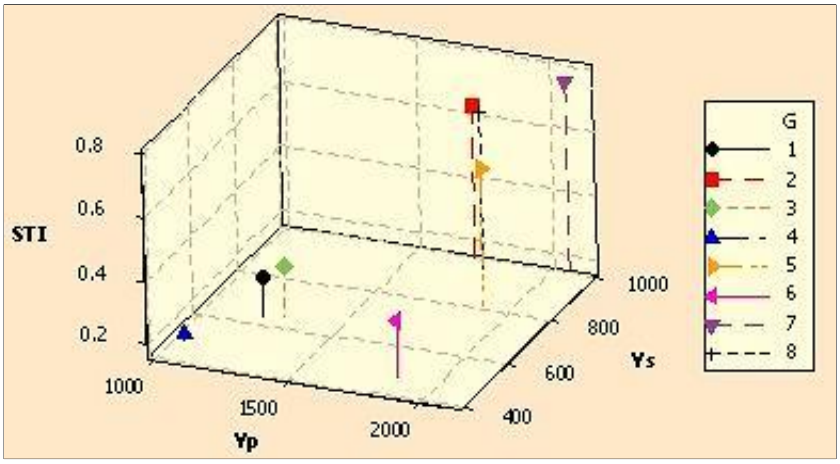
Table 5. Principle component analysis of faba bean genotypes.

Indices	PC1	PC2
Yp	0.20	-0.22
Ys	0.25	0.08
TOL	0.07	-0.34
SSI	-0.11	-0.33
MP	0.24	-0.13
GMP	0.25	-0.05
STI	0.25	-0.04
YI	0.24	0.08
YSI	0.11	0.33
HM	0.26	0.02
RDI	0.11	0.33
DI	0.22	0.18
YR	-0.11	-0.32
ATI	0.18	-0.26
SSPI	0.08	-0.34
SNPI	0.25	0.08
MRP	0.25	-0.06
REI	0.25	-0.04
MSTIK1	0.24	-0.12
MSTIK2	0.25	0.02
GM	0.11	0.32
Ynorm	0.25	-0.07
Z	0.25	-0.08
Standard deviation	3.6591	2.7311
Proportion of Variance	0.66	0.33
Cumulative Proportion	0.6376	0.9928

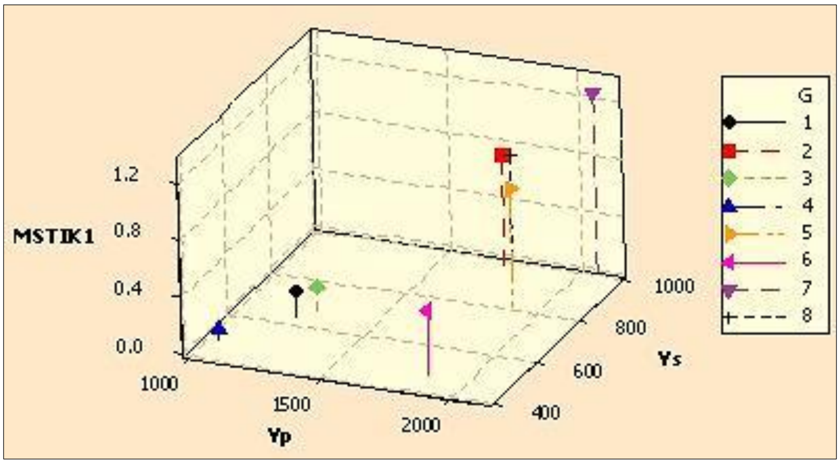
Yp: Seed yield in non-stress condition; Ys: Seed yield in stress condition; TOL: Tolerance Index; SSI: Stress Susceptibility Index; MP: Mean Productivity; GMP: Geometric Mean Productivity; STI: Stress Tolerance Index; YI: Yield Index; YSI: Yield Stability Index; HM: Harmonic Mean; RDI: Relative drought index; DI: Drought Index; YR: Yield Reduction; ATI: Abiotic Tolerance Index; SSPI: Stress Susceptibility Percentage Index; SNPI: Stress Non-Stress Production Index; MRP: Mean Relative Performance; REI: Relative Efficiency Index; MSTIk1: Modified Stress Tolerance Index K1; MSTIk2: Modified Stress Tolerance Index K2; GM: Golden Mean; Ynorm: Normalized Potential and Stress Yield; Z: Standardized Potential and Stress Yield.

3.5. Three dimensional plots

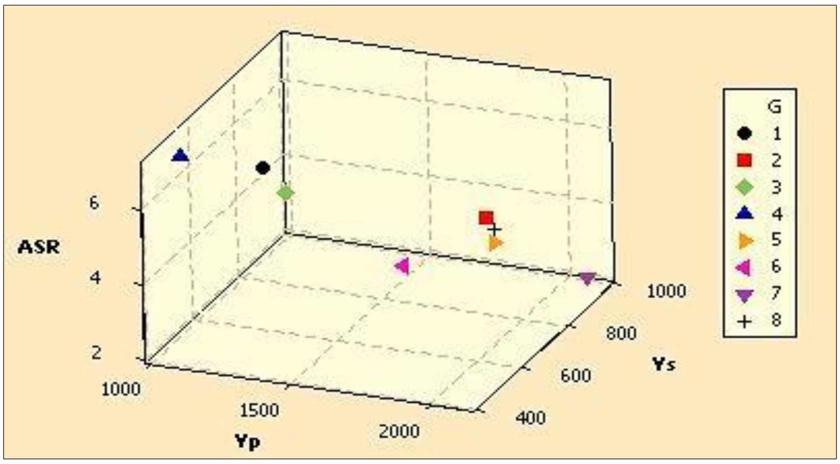
Three-dimensional plots draw to identify drought tolerant genotypes based on STI, MSTIK1 and average sum of ranks (ASR) (Figs. 5A-C). The selection of the first two indices was based on their high correlation with potential and stress yield, and the third index showed the average rank of all the indices. Three-dimensional plot based on STI separated the high-yielding genotypes of group A in both conditions, from the other three groups (B, C and D). In these three dimensional plots, three small seed landrace from Borujerd (G2, G5, and G7) and Khorramabad small seed landrace (G8) were included into group A. The genotypes G1 (large seed landrace from Guilan), G3 (France) and G4 (Barrakat) were located into group D. G6 was located into group B. The highest value of STI observed in genotypes G2, G7, and G8 (Fig. 5). The results of three dimensional plot based on MSTIK1 was similar to each one from STI (Dixit, 2020).



A



B



C

Figure 5. Three-dimensional plots between Yp, Ys and STI (A), MSTIK1 (B), and ASR (C).
Note: Genotypes: 1) Landrace from Guilan; 2) Landrace from Borujerd; 3) France, 4) Barrakat; 5)Landrace from Borujerd; 6)Landrace from Mazandaran; 7) Landrace from Khorramabad; 8) Landrace from Borujerd.
Yp: Seed yield in non-stress condition; Ys: Seed yield in stress condition; ASR: average sum of ranks; MSTIk2: Modified Stress Tolerance Index K2; Red: Reduction; GM: Golden Mean; TYI: Total Yield Index; SI: Stress Index.

3.5. Verification of standardized and normalized potential and stress yield in rice genotypes under drought stress and potential conditions

The using of standardized (based on standard deviation) and normalized (based on range) Was proposed yield under potential and stress conditions. To verification of this proposed methodology, a dataset of rice genotypes under drought stress and normal irrigation condition was also used for evaluation the tolerance and susceptibility of genotypes with this formula. This dataset is for me .The Ynorm score is the sum of PYnorm and SYnorm scores, which vary from zero to two, and the higher the value of this score in the genotype, the higher the yield potential of that genotype under stress and normal conditions. The genotype with the highest PYnorm and SYnorm is the best genotype. In the absence of such a genotype, the genotype with the highest Ynorm could be considered as a preferred genotype. Because in calculating of this score, the range of yield of genotypes taken into account and normalized data used, it could be considering as a good indicator for evaluating the superior genotypes. According to normalized potential and stress yield based on range of variation (Ynorm), genotypes G1, G2, G3, G4, G5, and G7 were the most tolerant genotypes to drought stress, while genotype G11, G16, G14, G17, and G15 were the most susceptible genotypes (Table 6). The other standardized potential and stress yield (Z score) based on standard deviation of yield performance in both of condition was also confirmed the above results. In the other study, similar results of Ynorm and Z score, was analyzed this dataset by drought stress indices (YI, HM, GMP, YSI, STI, TOL, SSI and MP) and indicated genotypes G1, G2, G3, G4, G5, and G7 were as drought tolerant and G14, G15, G16, and G17 were as susceptible to drought stress (Aminpanah et al., 2018). In the other research, were also analyzed this dataset by some of multivariate methods (cluster, discriminate, principal component and factor analyses) and identified genotypes G1, G3, G4, and G7 as superior genotypes with higher grain yield and the other desirable traits including high grain fertility and low length of panicle from pod under drought stress condition (Sharifi et al., 2017).

Table 6. Yield in potential and stress condition and standardized potential and stress yield in rice dataset.

Gen	Yp	Ys	PYnorm	SYnorm	Ynorm	Z_{PY}	Z_{SY}	Z
1	4915	2788	0.97	1.00	1.97	1.24	1.89	3.13
2	4587	2163	0.73	0.71	1.44	0.30	0.67	0.98
3	4784	2178	0.87	0.72	1.59	0.86	0.70	1.57
4	4956	2194	1.00	0.72	1.72	1.35	0.73	2.09
5	4761	1966	0.86	0.62	1.47	0.80	0.29	1.09
6	4248	1971	0.48	0.62	1.10	-0.66	0.30	-0.36
7	4633	2375	0.76	0.81	1.57	0.43	1.09	1.52
8	4428	1697	0.61	0.49	1.10	-0.15	-0.23	-0.38
9	4638	1684	0.77	0.49	1.26	0.47	-0.26	0.21
10	4645	1638	0.77	0.46	1.24	0.47	-0.35	0.12
11	4078	1878	0.35	0.58	0.93	-1.15	0.12	-1.03
12	4572	1723	0.72	0.50	1.22	0.26	-0.18	0.08
13	4473	2024	0.65	0.64	1.29	-0.02	0.40	0.38
14	4378	726	0.56	0.04	0.61	-0.29	-2.13	-2.42
15	4022	643	0.31	0.00	0.31	-1.31	-2.29	-3.59
16	4157	1621	0.41	0.46	0.87	-0.92	-0.38	-1.30
17	3597	1859	0.00	0.57	0.57	-2.52	0.08	-2.44
18	4779	1576	0.87	0.44	1.30	0.85	-0.47	0.38

Yp: Seed yield in non-stress condition; Ys: Seed yield in stress condition; Ynorm: Normalized Potential and Stress Yield; PYnorm: Normalized Potential Yield; SYnorm: Normalized Stress Yield; Z: Standardized Potential and Stress Yield; Z_{PY}: Standardized Potential Yield; Z_{SY}: Standardized Stress Yield.

4. Conclusions

High correlation between Ys, Yp, MP, GMP, STI, HM, MRP, REI, MSTIK1, MSTIK2, Ynorm, and Z indicated these indices are suitable for screening drought tolerant genotypes. Screening drought tolerant cultivars using three dimensional plots, biplot analysis and cluster analysis discriminated genotypes G2, G5, G7 and G8 as the most drought tolerant genotypes. Consequently, stress tolerant index (STI), modified stress tolerance index K1 (MSTIK1) and average sum of ranks (ASR) were more appropriate for selecting the favorable faba bean genotypes. Using these three indices, genotype G7 recognized as most drought-tolerant genotype. We also proposed using of standardized (based on standard deviation) and normalized (based on range) yield in potential and stress conditions. According to these scores, genotype G7 was the best genotype in both drought stress and normal irrigation conditions. It is suggested that use of this methodology in other datasets and, if appropriate, the use of standardized data should be considered as a new idea in the assessment of stress tolerance and susceptibility in genotypes.

References

Akcura, M., Ceri, S., 2011. Evaluation of drought tolerance indices for selection of Turkish oat (*Avena sativa* L.) landraces under various environmental conditions. *Zemdirbyste Agric.*, **98**(2), 157-166.

Aminpanah, H., Sharifi, P., Ebadi A.A., 2018. Evaluation of drought response in some rice mutant lines using stress tolerance indices. *Iranian J. Field Crop. Res.*, **16**(1), 191-202. [In Persian] https://doi.org/10.22067/gsc.v16i1.61793

Asadi, N., Jalilian, S., 2021. The effect of methyl jasmonate on the germination of lemon seeds under the influence of salinity stress. *Cent. Asian J. Environ. Sci. Technol. Innov.*, **2**(3), 119-128. https://doi.org/10.22034/CAJESTI.2021.03.03

Awan, B., Sabeen, M., Shaheen, S., Mahmood, Q., Ebadi, A., Toughani, M., 2020. Phytoremediation of zinc contaminated water by marigold (*Tagetes Minuta* L). *Cent. Asian J. Environ. Sci. Technol. Innov.*, **1**(3), 150-158. https://doi.org/10.22034/CAJESTI.2020.03.04

Bouslama, M., Schapaugh, W.T., 1984. Stress tolerance in soybean. 1- Evaluation of three screening techniques for heat and drought tolerance. *Crop Sci.*, **24**(5), 933-937. https://doi.org/10.2135/cropsci1984.0011183X002400050026x

Desoky E.M., Mansour E., Yasin M.A.T., El-Sobky E.E.A., Rady M.M., 2020. Improvement of drought tolerance in five different cultivars of Vicia faba with foliar application of ascorbic acid or silicon. *Spanish J. Agric. Res.*, 18(2), 1-20. https://doi.org/10.5424/sjar/2020182-16122

Dixit, G., 2020. Assessment of biological parameters in tomato cultivars irrigated with fertilizer factory wastes. *Cent. Asian J. Environ. Sci. Technol. Innov.*, **1**(4), 219-225. https://doi.org/10.22034/CAJESTI.2020.04.04

Ehdaie B., Shakiba M.R., 1996. Relationship of inter node specific weight and water-soluble carbohydrates in wheat. *Cer. Res. Commun.*, **24**, 61-67.

Fageria, N.K., 1985. Influence of aluminum in nutrient solutions on chemical composition in two rice cultivars at different growth stages. *Plant Soil*, **85**(1), 423-429. https://doi.org/10.1007/BF02220197

Farshadfar, E., Mohammadi, R., Farshadfar, M., Dabiri, S., 2013. Relationships and repeatability of drought tolerance indices in wheat-rye disomic addition lines. *Aust. J. Crop Sci.*, **7**(1), 130–198.

Farshadfar, E., Poursiahbidi, M.M., Abooghadareh, A.P., 2012. Repeatability of drought tolerance indices in bread wheat genotypes. *Int. J. Agric. Crop Sci.*, **4**(13), 891-903.

Fischer, R.A., Maurer, R., 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. *Aust. J. Agric. Res.*, **29**(5), 897-912. https://doi.org/10.1071/AR9780897

Fischer, R.A., Wood, J.T., 1979. Drought resistance in spring wheat cultivars. III.* Yield associations with morpho-physiological traits. *Aust. J. Agric. Res.*, **30**(6), 1001-1020. https://doi.org/10.1071/AR9791001

Gavuzzi, P., Rizza, F., Palumbo, M., Campanile, R.G., Ricciardi, G.L., Borghi, B., 1997. Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. *Can. J. Plant Sci.*, **77**(4), 523-531. https://doi.org/10.4141/P96-130

Golabadi, M., Arzani, A.S.A.M., Maibody, S.M., 2006. Assessment of drought tolerance in segregating populations in durum wheat. *Afr. J. Agric. Res.*, **1**(5), 162-171. https://doi.org/10.5897/AJAR.9000070

Hossain, A.B.S., Sears, R.G., Cox, T.S., Paulsen, G.M., 1990. Desiccation tolerance and its relationship to assimilate partitioning in winter wheat. *Crop Sci.*, **30**(3), 622-627. https://doi.org/10.2135/cropsci1990.0011183X003000030030x

Karimizadeh, R., Mohammadi, M., 2011. Association of canopy temperature depression with yield of durum wheat genotypes under supplementary irrigated and rainfed conditions. *Aust. J. Crop Sci.*, **5**(2), 138-146.

Khan, H.R., Paull, J.G., Siddique, K.H.M., Stoddard, F.L., 2010. Faba bean breeding for drought-affected environments: A physiological and agronomic perspective. *Field Crops Res.*, **115**(3), 279-286. https://doi.org/10.1016/j.fcr.2009.09.003

Lever, J., Krzywinski, M., Altman, N., 2017. Points of significance: Principal component analysis. *Nat. Method.*, **14**(7), 641-643. https://doi.org/10.1038/nmeth.4346

Link, W., Abdelmula, A.A., Kittlitz, E.V., Bruns, S., Riemer, H., Stelling, D., 1999. Genotypic variation for drought tolerance in Vicia faba. *Plant Breed.*, **118**(6), 477-484. https://doi.org/10.1046/j.1439-0523.1999.00412.x

Link, W., Balko, C., Stoddard, F.L., 2010. Winter hardiness in faba bean: physiology and breeding. *Field Crops Res.*, **115**(3), 287-296. https://doi.org/10.1016/j.fcr.2008.08.004

Mitra, J., 2001. Genetics and genetic improvement of drought resistance in crop plants. *Curr. Sci.*, 758-763.

Mohammadi, M., Karimizadeh, R., Abdipour, M., 2011. Evaluation of drought tolerance in bread wheat genotypes under dryland and supplemental irrigation conditions. *Aust. J. Crop Sci.*, **5**(4), 487-493.

Mohammadi, R., Armion, M., Kahrizi, D., Amri, A., 2010. Efficiency of screening techniques for evaluating durum wheat genotypes under mild drought conditions. *Int. J. Plant Prod.*, **4**(1), 11-23. https://doi.org/10.22069/ijpp.2012.677

Mollasadeghi, V., Valizadeh, M., Shahryari, R., Imani, A.A., 2011. Evaluation of end drought tolerance of 12 wheat genotypes by stress indices. *World Appl. Sci. J.*, **13**(3), 545-551.

Mousavi, S.S., YAZDI, S.B., Naghavi, M.R., Zali, A.A., Dashti, H., Pourshahbazi, A., 2008. Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. *Desert*, **12**, 165-178.

Moradi, H., Akbari, G.A., Khorasani, S.K., Ramshini, H.A., 2012. Evaluation of drought tolerance in corn (Zea mays L.) new hybrids with using stress tolerance indices. *Eur. J. Sustain. Dev.*, **1**(3), 543-543. https://doi.org/10.14207/ejsd.2012.v1n3p543

Mursalova, J., Akparov, Z., Ojaghi, J., Eldarov, M., Belen, S., Gummadov, N., Morgounov, A., 2015. Evaluation of drought tolerance of winter bread wheat genotypes underdrip irrigation and rain-fed conditions. *Turk. J. Agric. For.*, **39**(5), 817-824. https://doi.org/10.3906/tar-1407-152

Naghavi, M.R., Aboughadareh, A.P., Khalili, M., 2013. Evaluation of drought tolerance indices for screening some of corn (*Zea mays* L.) cultivars under environmental conditions. Notulae Scientia Biologicae, **5**(3), 388-393. https://doi.org/10.15835/nsb539049

Nouri, A., Etminan, A., Jaime, A., Teixeira, S., Mohammadi, R., 2011. Assessment of yield, yield-related traits and drought tolerance of durum wheat genotypes (*Triticum turjidum* var. *durum* Desf.). *Austr. J. Crop Sci.*, **5**(1), 8-16.

Ouji, A., Naouari, M., Mouelhi, M., Ben Younes, M., 2017. Yield and yield components of faba bean (*Vicia faba* L.) as influenced by irrigation under semi-arid region of Tunisia. *World J. Agric. Res.*, 5(1), 52-57. https://doi.org/10.12691/wjar-5-1-7

Rosielle, A.A., Hamblin, J., 1981. Theoretical aspects of selection for yield in stress and non-stress environment 1. *Crop Sci.*, **21**(6), 943-946. https://doi.org/10.2135/cropsci1981.0011183X002100060033x

Saffariha, M., Azarnivand, H., Zare Chahouki, M.A., Tavili, A., Nejad Ebrahimi, S., Potter, D., 2021. Phenological effects on forage quality of Salvia limbata in natural rangelands. *Cent. Asian J. Environ. Sci. Technol. Innov.*, **2**(1), 36-44. https://doi.org/10.22034/CAJESTI.2021.01.04

Sánchez-Reinoso, A.D., Ligarreto-Moreno, G.A., Restrepo-Díaz, H., 2020. Evaluation of drought indices to identify tolerant genotypes in common bean bush (*Phaseolus vulgaris* L.). *J. Integr. Agric.*, **19**(1), 99-107. https://doi.org/10.1016/S2095-3119(19)62620-1

Sarker, M., Choudhury, S., Islam, N., Zeb, T., Zeb, B., Mahmood, Q., 2020. The effects of climatic change mediated water stress on growth and yield of tomato. *Cent. Asian J. Environ. Sci. Technol. Innov.*, **1**(2), 85-92. https://doi.org/10.22034/CAJESTI.2020.02.03

Sepahvand, D., Matinizadeh, M., Etemad, V., Shirvany, A., 2021. Changes in morphological and biochemical properties of *Celtis caucasica* L. mycorrhizal fungi-inoculated under drought stress condition. *Cent. Asian J. Environ. Sci. Technol. Innov.*, **2**(4), 142-155. https://doi.org/10.22034/CAJESTI.2021.04.01

Sharifi, P., Aminpanah, H., Ebadi, A.A., 2017. Classification of mutant rice (*Oryza sativa* L.) genotypes under drought stress conditions. *Iranian J. Crop Sci.*, **19**(2), 148-164. [In Persian] 20.1001.1.15625540.1396.19.2.5.3

Siddiqui, M.H., Al-Khaishany, M.Y., Al-Qutami, M.A., Al-Whaibi, M.H., Grover, A., Ali, H.M., Al-Wahibi, M.S., Bukhari, N.A., 2015. Response of different genotypes of faba bean plant to drought stress. *Int. J. Mol. Sci.*, **16**(5), 10214-10227. https://doi.org/10.3390/ijms160510214

Toorchi, M., Naderi, R., Kanbar, A., Shakiba, M.R., 2012. Response of spring canola cultivars to sodium chloride stress. *Ann. Biol. Res.*, **2**(5), 312-322.

Yan, W., Rajcan, I., 2002. Biplot analysis of test sites and trait relations of soybean in Ontario. *Crop Sci.*, **42**(1), 11-20. https://doi.org/10.2135/cropsci2002.1100

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