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Evaluating drought tolerance of castor ecotypes in the center of Iran

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Abstract

In order to study the reaction of six castor ecotypes to drought stress, a split plot experiment was carried out in randomized complete blocks. Eight indices including stress sensitivity index (SSI), tolerance index (TOL), mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HARM), stress tolerance index (STI), sensitivity drought index (SDI) index and yield index (YI) were calculated for ecotypes by using seed yield in normal condition and under stress. After that, correlations between indices were calculated and dendrogram and biplot results were drawn. Normal yield and stress yield had positive significant correlations with MP, GMP, STI, and HARM indices in mild, moderate and severe stresses. Biplot analysis showed that Isfahan and Naein ecotypes had desirable yield under mild and average stress and Naein had desirable yield under severe stress and also normal condition.

Keywords: Agriculture

1. Introduction

Seed yield is an important complicated trait which is affected by interaction of many traits including genotype (Evans, 1993). Existence of genetic diversity for

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agronomical traits, quality and quantity shows that selecting desirable varieties from native varieties is possible and can lead to produce breeder varieties. Discovery of new genes and gene combinations is crucial for newer requirements to challenge climate change effects (Anjani, 2012). Drought is one of the most important abiotic factors limiting global production. Exposure to long term drought conditions inhibits growth and lead to yield losses (Zhang et al., 2018). Drought is the most important physical stress of terrestrial ecosystems and limits vegetation growth, increases wildfires, and induces tree mortality (He et al., 2014). Even drought can impact on macro and micro nutrients in castor (Tadayyon et al., 2018). Yield gap exists between the germ-plasm yield potential and average yield. A common practice in developing countries is improving germ-plasm and reducing yield gap (George, 2014).

Drought stress indices are measured based on yield reduction under drought stress in proportion to normal condition and are used for screening drought resistance genotypes (Mitra, 2001). Main goal of yield test is selecting genotypes which can adapt to both stress and normal conditions because plants grow in desirable conditions and biotic and abiotic stresses occur periodically (Fernandez, 1993). Varieties which produce high yields in normal condition may show low yields under stress. Therefore, a stress tolerating variety should be evaluated under stress and then the most resistance one be selected (Hurd, 1976).

Drought tolerance is the ability of a genotype to produce more yield than other genotypes in similar to moisture condition (Quisenberry, 1982). Drought tolerance is important trait related to yield. To improve this trait, breeding requires fundamental changes in the set of relevant attributes (Fathi and Barari Tari, 2016). Introducing varieties which tolerate stress better than other genotypes and have less yield reduction is the aim of preparing drought varieties (Srivastava et al., 1987).

Fernandez (1993) divided genotypes into four groups according to their reaction to stress or non-stress conditions: Group A: genotypes which produce desirable yield in both environments; Group B: genotypes which produce good yield only in non-stress environments. Group C: genotypes which produce good yield in stress environments. Group D: genotypes which produce low yield in both environments.

Various indices have been introduced to evaluate genotypes reaction in various environmental conditions and determine tolerance or sensitivity of them. The best criteria for selecting genotypes under stress is one which is able to distinguish group A (Fernandez, 1993). One of indices is stress sensitivity index (SSI) which was proposed by (Fischer and Maurer, 1978). Lower SSI amount shows lower changes of a genotypes yield under stress and therefore more stability of it. Rosielle and Hamblin (1981) introduced tolerance index (TOL) and mean performance (MP) indices. High TOL amount shows sensitivity of genotype to stress and genotypes with less TOL

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must be selected. Selecting based on MP increases average yield in both normal and stress conditions.

Fernandez (1993) proposed stress tolerance index (STI). High amounts of STI show more drought tolerance and potential yield, He introduced also geometric mean productivity (GMP). This index has more power to distinguish group A in proportion to MP index. Indices which have high correlation with seed yield in both normal and stress conditions are better indices (Fernandez, 1993). Schneider et al. (1997) recommended genotype selection genotypes based on GMP as a breeding strategy.

Castor (*Ricinus communis* L.) from Euphorbiaceae grows in warm climates and is originated from West Africa (Anjani, 2012). Castor seeds contain 46 to 55% oil by weight. Although castor oil is inedible, it is extensively used for more than 700 industrial chemical products (Ogunniyi, 2006, Anjani, 2012). Castor oil contains 90% of ricinoleic acid which has many industrial medicinal profits including environment friendly industrial lubricants, insulation liquids for electrical uses such as converters, and additive for asphalt and biodiesel (Ogunniyi, 2006, Metzger and Bornscheuer, 2006). Indeed, 1.5 million hectares of world lands are under cultivation of castor which produces about 1.8 million tons of seed. Average seed yield of this plant is 1235 kg/ha and the highest production amounts are belonging to India, China, and Brazil (Kiran and Prasad, 2017). Castor production is in primary stages and cannot meet industry needs. However, it is expanding to arid and semiarid regions too and it is cultivated in marginal lands (Pinheiro et al., 2008, Li et al., 2010). The ability of castor to grow under unfavorable growing conditions such as drought stress makes it a potentially appropriate plant for these regions (Weiss, 2000). Current study was carried out to estimate the extant diversity in yield and reaction of castor ecotypes to mild, average and severe drought stress in the center of Iran based on sensitivity and resistance indices. Our findings can help farmers to use more tolerant castor ecotypes in marginal lands where drought stress occurs regularly or accidentally.

2. Materials and methods

The study was carried out in Fozveh Agricultural Research center in 2013 located in west Isfahan (51°26’E, 32°36’N, 1612 m) with mean annual precipitation of 125 mm. According to Emberger climate classification, the region has cold, dry climate and based on De martin method the climate is dry. Meteorological information and results of soil analysis are presented in Table 1.

The study was done as split plot experiment in randomized complete blocks design with three replications. Treatment were four moisture levels (no stress equal to 30% moisture depletion, mild water deficit 45%, medium water deficit is 60% and severe water deficit is 75% moisture depletion of available soil moisture) as main plots and

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Table 1. Meteorological information and results of soil analysis.

	June	July	August	September	October	November	
Precipitation (mm)	0	0	0	0	0.1	36	
Average temperature (°C)	29.6	33.2	30.5	26.8	19.2	11.7	

Soil depth (cm)	Soil texture	EC (dS/m)	pH	Total nitrogen%	Organic carbon%	P (mg/kg)	K (mg/kg)
30	Sandy clay loam	3.2	7.6	0.47	0.05	29.7	300

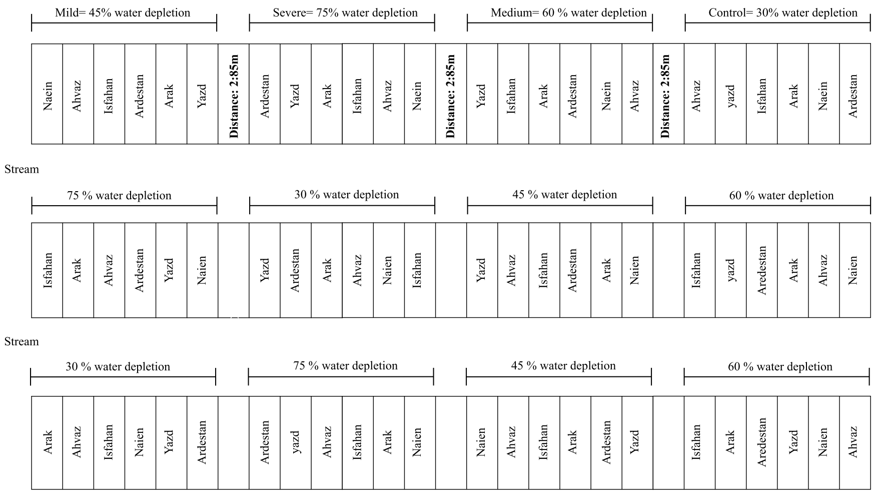

Figure 1. Diagram for split plot design.

six castor ecotypes (Isfahan, Ardestan, Arak, Naein, Yazd and Ahvaz) as subplots. We refer to Figure 1 for the diagram for the split plot design. The ecotypes are named according to the locations they were collected from and they were all cultured in a field located in Isfahan city. The spatial distributions of these ecotypes (locations where the ecotypes were collected from) are as follows: Yazd is located 270 km (170 mi) southeast of Isfahan. Arak is the capital of Markazi Province and is located 280 km (175 mi) southwest of Isfahan. Naein and Ardestan are both located in Isfahan Province. Naein lies 170 km north of Yazd and 140 km east of Isfahan, and Ardestan is located at the southern foothills of the Karkas mountain chain and is 110 km northeast of Isfahan. Finally, Ahvaz is a city in the southwest of Iran and the capital of Khuzestan province. Ahvaz is located 320 km (200 mi) southwest of Isfahan.

To enforce the water stress, soil moisture's curve was identified in area, moisture was measured regularly using soil moisture meter GMK-S77 in root zone and irrigation was done at definite times. Drought stress was enforced 50 days after sowing before stem elongation. Moisture curve of Isfahan soils is presented in Figure 2.

Soil was prepared using plough, disc and leveler. Then rows with 65 cm inter row space were prepared and five seeds of various ecotypes were sown in 3–4 cm depth. The distance between plants on rows was 50 cm. Plots had about 2.85 m distance.

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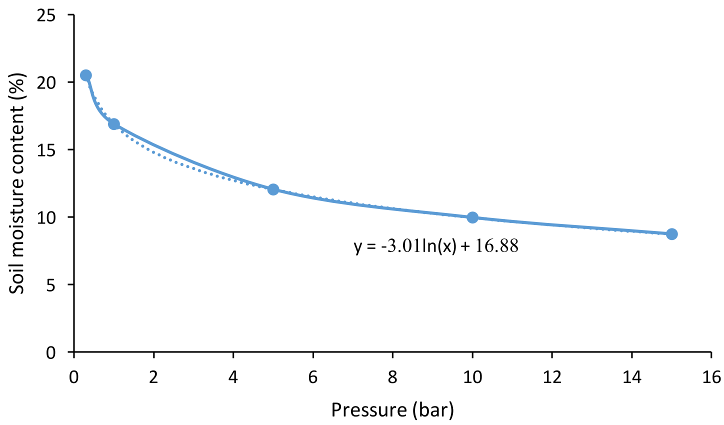

Figure 2. Moisture curve of soil (r^2 = 0.95).

Cultivation was done at June 21st and thinning was done at two-four leaves stage. Weeding was done two times at four leaves stage and before stem elongation to control weeds. Harvesting was carried out at November 6th and 7th. Sampling for yield calculation was done from one square meter. Seeds had 15% moisture in this stage.

To evaluate drought tolerance, various indices of resistance and sensitivity were calculated using yield and following equations:

$$\mathrm{GMP} = \sqrt{Y_p \times Y_s}\,. \tag{1}$$

(Fernandez, 1993)

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

(Rosielle and Hamblin, 1981)

$$\mathrm{Tol} = Y_p - Y_s\,. \tag{3}$$

(Rosielle and Hamblin, 1981)

$$\mathrm{SDI} = \frac{Y_p - Y_s}{Y_p}, \quad \mathrm{STI} = \frac{Y_p \times Y_s}{(\bar{Y}_p)^2}\,. \tag{4}$$

(Fernandez, 1993)

$$\mathrm{SSI} = \frac{1 - (Y_s | Y_p)}{1 - (\bar{Y}_s | \bar{Y}_p)}\,. \tag{5}$$

(Fischer and Maurer, 1978)

$$\mathrm{Harm} = \frac{2 \times Y_s \times Y_p}{(Y_p + Y_s)}\,. \tag{6}$$

(Fernandez, 1993)

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$$YI = \frac{Y_s}{\bar{Y}_s}. \tag{7}$$

(Gavuzzi et al., 1997)

In these equations, Y_s and Y_p are yields under stress and in normal condition respectively, and $\bar{Y}_s$ and $\bar{Y}_p$ are average yield of all ecotypes under stress and in normal condition. Correlations were calculated using Minitab 14 program. Biplot analysis was done using SAS 9.0 and dendrogram was drawn using Statistica 8.

3. Results and discussion

In this experiment, 30%, 45%, 60% and 75% moisture depletion were considered as normal, mild, average and severe stress. After that, indices were calculated using yield (kg/ha) under normal and stress conditions (Table 2).

Under normal, mild and severe stresses, Isfahan ecotype had the highest yield, while the lowest yield was belonging to Arak ecotype. The rest of ecotypes were placed in a statistical group (Table 2). The lowest yield amount in normal condition was belonging to Arak and Ahvaz ecotypes and for mild stress Ahvaz and Ardestan had the lowest yield (Table 2). Among indices, only SDI in average stress could not show difference and other indices had statistical differences. (Severino and Auld, 2013) reported that irrigation increased seed yield in the cultivars that were tested and BRS Nordestina cultivar showed the biggest increase from 232 kg/ha to 2785 kg/ha because of water amounts. Most of the differences in the oil yield was described by the number of racemes, the number of seeds per raceme and then by the seed weight. Another research studied the response of 45 castor genotypes to drought stress in the laboratory experiment and observed the highest tolerance for germination by RG2474. This genotype showed high shoot and root length (Radhamani et al., 2012).

MP, GMP, STI, and HARM indices had significant correlations with yield ($P < 0.01$) in normal condition and under mild and severe stresses (Table 3). These four indices had also high correlations under average stress ($P < 0.01$) and only STI-normal yield correlation was significant at 5% probability level. GMP had very significant correlations with MP, STI, HARM and YI indices under all stresses (Table 3).

Results of factor analysis are presented considering that two first components which was greater than one were chosen (Table 4). First component explained 63%, 67% and 69% for mild, average and severe stresses and second one explained 36%, 32% and 30% (Table 4).

Biplot analysis results were divided into four parts of A, B, C and D and indices which were between yields of normal condition and under stress were introduced as

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Table 2. Selection indices in six ecotypes under mild stress.

Ecotype	Y_p (Kg/ha)	Y_s (Kg/ha)	GMP	MP	TOL	SDI	STI	SSI	HARM	YI
45% soil moisture depletion										
Isfahan	1388.03	1369.23	1375.49	1378.63	18.80	0.0016	1.9908	−3.45	1372.36	1.5106
Ardestan	1004.27	699.14	836.38	851.70	305.12	0.2940	0.7350	11.32	821.41	0.7706
Arak	601.70	1072.64	802.86	837.17	−470.94	0.7825	0.6870	−48.46	770.20	1.1831
Naein	1085.47	962.39	1021.77	1023.93	123.10	0.1131	1.0975	4.96	1019.61	1.0607
Yazd	1019.65	776.92	886.86	898.29	242.73	0.2388	0.8259	17.71	875.68	0.8605
Ahvaz	764.95	555.55	651.00	660.25	209.40	0.2692	0.4488	10.97	641.91	0.6141
LSD	197.34	183.39	139.89	142.18	253.54	0.2283	0.2441	56.05	139.20	0.1861
60% soil moisture depletion										
Isfahan	1388.03	647.90	933.55	1017.94	740.17	0.5242	0.9725	1.5056	859.08	1.0251
Ardestan	1004.27	751.30	846.86	877.77	252.99	0.2342	0.7892	0.5375	852.21	1.2362
Arak	601.70	476.10	533.57	538.88	125.64	0.2108	0.3119	0.5065	528.23	0.7699
Naein	1085.47	524.80	750.53	805.12	560.68	0.5100	0.6049	1.5919	700.50	0.8504
Yazd	1019.65	776.92	887.14	898.29	242.73	0.2299	0.8368	0.5666	876.19	1.2716
Ahvaz	764.95	524.64	624.93	645.29	239.31	0.3001	0.4254	0.7910	606.40	0.8468
LSD	197.34	261.51	161.29	128.3	385.76	0.3393	0.4193	0.6420	198.29	0.2927
75% soil moisture depletion										
Isfahan	1388.03	942.48	1135.46	1160.25	455.55	0.3239	1.3483	0.7797	1111.34	1.6432
Ardestan	1004.27	531.62	726.82	767.94	472.64	0.4600	0.5528	1.089	688.71	0.9365
Arak	601.70	482.05	536.16	541.88	119.65	0.1965	0.3005	0.4616	530.61	0.8440
Naein	1085.47	524.78	753.34	805.12	560.68	0.5173	0.5927	1.2283	705.19	0.9202
Yazd	1019.65	489.74	706.48	754.70	529.91	0.5190	0.5234	1.2404	661.39	0.8672
Ahvaz	764.95	441.88	578.46	603.41	323.07	0.4152	0.3580	0.9879	554.98	0.7889
LSD	197.34	161.71	132.54	132.41	245.06	0.2109	0.1209	0.484	139.72	0.2270

the best indices. Ecotypes of A and D zones were identified and the most tolerant and sensitive ecotypes were determined considering the indices.

Isfahan and Naein were located in group A under mild and average stresses which means those have desirable yield in both stress and normal conditions (Figure 3(a) and 3(b)). However, under severe stress, only Naein ecotype had acceptable yield (Figure 3(c)). The only ecotype which did not have good yield and was located in part D was Ahvaz ecotypes (Figure 3).

MP, GMP, STI and HARM indices were more appropriate indices under three stress levels and were placed in the angle between normal and stress yield (Figure 3).

In Canola, also high positive correlations were observed between GMP, STI, and MP indices and yield under normal and stress condition which makes them the best indices for introducing tolerant varieties (Shiranirad and Abbasian, 2011). Also, (Mollasadeghi et al., 2011) selected MP, GMP and STI as the best indices in normal and drought condition in wheat.

Cluster analysis was carried out by using ward method to classify various ecotypes in three stress levels. In mild stress, Isfahan ecotype was different from other ecotypes

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Table 3. Correlation analysis between selection indices and seed yield.

	Y_p	$Y_s(45)$	GMP	MP	TOL	SDI	STI	SSI	HARM	YI
Under mild stress (45% soil moisture depletion)										
Y_p	1									
$Y_s(45)$	0.456^{ns}	1								
GMP	0.856**	0.849**	1							
MP	0.844**	0.863**	0.999**	1						
TOL	0.480*	−0.562*	-0.041^{ns}	−0.066^{ns}	1					
SDI	0.483*	−0.536*	−0.016^{ns}	−0.048^{ns}	0.977**	1				
STI	0.798**	0.832**	0.960**	0.956**	−0.079^{ns}	−0.029^{ns}	1			
SSI	0.236^{ns}	−0.377^{ns}	−0.065^{ns}	−0.093^{ns}	0.591**	0.630*	−0.076^{ns}	1		
HARM	0.865**	0.835**	0.999**	0.995**	−0.019^{ns}	0.013^{ns}	0.963**	−0.038^{ns}	1	
YI	0.452^{ns}	0.994**	0.845**	0.867**	−0.560*	−0.533*	0.844**	−0.388^{ns}	0.832**	1
Under medium stress (60% soil moisture depletion)										
	Y_p	$Y_s(45)$	GMP	MP	TOL	SDI	STI	SSI	HARM	YI
Y_p	1									
$Y_s(45)$	0.224^{ns}	1								
GMP	0.775**	0.805**	1							
MP	0.880**	0.660**	0.975**	1						
TOL	0.812**	−0.387**	0.232^{ns}	0.437^{ns}	1					
SDI	0.612**	−0.598**	−0.020^{ns}	0.179^{ns}	0.937**	1				
STI	0.586*	0.870**	0.937**	0.876**	0.033^{ns}	−0.204^{ns}	1			
SSI	0.568*	−0.214^{ns}	0.221^{ns}	0.334^{ns}	0.666**	0.685**	0.218^{ns}	1		
HARM	0.607**	0.903**	0.979**	0.908**	0.033^{ns}	−0.205^{ns}	0.952**	0.104^{ns}	1	
YI	0.400^{ns}	0.818**	0.806**	0.708**	−0.112^{ns}	−0.279^{ns}	0.668**	−0.228^{ns}	0.860**	1
Under severe stress (75% soil moisture depletion)										
	Y_p	$Y_s(45)$	GMP	MP	TOL	SDI	STI	SSI	HARM	YI
Y_p	1									
$Y_s(45)$	0.704**	1								
GMP	0.912**	0.933**	1							
MP	0.950**	0.891**	0.994**	1						
TOL	0.725**	0.022^{ns}	0.379^{ns}	0.473*	1					
SDI	0.355^{ns}	0.389^{ns}	−0.043^{ns}	0.056^{ns}	0.878**	1				
STI	0.859**	0.924**	0.970**	0.956**	0.313^{ns}	−0.082^{ns}	1			
SSI	0.373^{ns}	−0.365^{ns}	−0.018^{ns}	0.078^{ns}	0.880**	0.992**	−0.063^{ns}	1		
HARM	0.867**	0.963**	0.995**	0.979**	0.286^{ns}	−0.134^{ns}	0.973**	−0.108^{ns}	1	
YI	0.672**	0.970**	0.901**	0.857**	0.005^{ns}	−0.374^{ns}	0.938**	−0.366^{ns}	0.932**	1

*: Significant at the 0.05% level.

**: Significant at the 0.01% level.

ns: Non-significant.

Since correlation matrix is symmetric, only the lower triangle part is given.

obviously (Figure 4(a)). Under average stress, ecotypes were placed in three groups: 1) Isfahan and Naein, 2) Ardestan and Yazd, and 3) Arak and Ahvaz (Figure 4(b)). Under severe stress also ecotypes were placed in three groups: 1) Isfahan, 2) Ardestan, Naein and Yazd, 3) Arak and Ahvaz in third group (Figure 4(c)). Cluster analysis in spring Canola also divided cultivars into three groups of tolerant, sensitive and resistant to drought stress (Khalili et al., 2012). In fact, 99% of total changes are explained by yield as the first component and tolerance indices as the second component in wheat. Cluster analysis helps these researchers to choose the

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Table 4. Eigenvalues and eigenvectors of the first and second components for tolerance and sensitivity indices.

	Eigenvalue	Cumulative	Y_p	$Y_s(45)$	GMP	MP	TOL	SDI	STI	SSI	HARM	YI
Under mild drought stress												
1	6.32	0.632	0.301	0.374	0.389	0.392	-0.096	-0.079	0.388	-0.074	0.387	0.374
2	3.64	0.996	0.339	-0.176	0.102	0.083	0.506	0.512	0.098	0.511	0.119	-0.175
Under medium drought stress												
	Eigenvalue	Cumulative	Y_p	$Y_s(45)$	GMP	MP	TOL	SDI	STI	SSI	HARM	YI
1	6.72	0.672	0.367	0.281	0.380	0.385	0.270	0.193	0.380	0.177	0.364	0.269
2	3.22	0.994	0.164	-0.379	-0.094	-0.009	0.393	0.480	-0.072	0.489	-0.181	-0.396
Under severe drought stress												
	Eigenvalue	Cumulative	Y_p	$Y_s(45)$	GMP	MP	TOL	SDI	STI	SSI	HARM	YI
1	6.96	0.696	0.363	0.356	0.378	0.378	0.206	0.034	0.374	0.039	0.376	0.356
2	3.01	0.998	0.159	-0.195	-0.027	0.018	0.479	0.573	-0.084	0.572	-0.069	-0.192

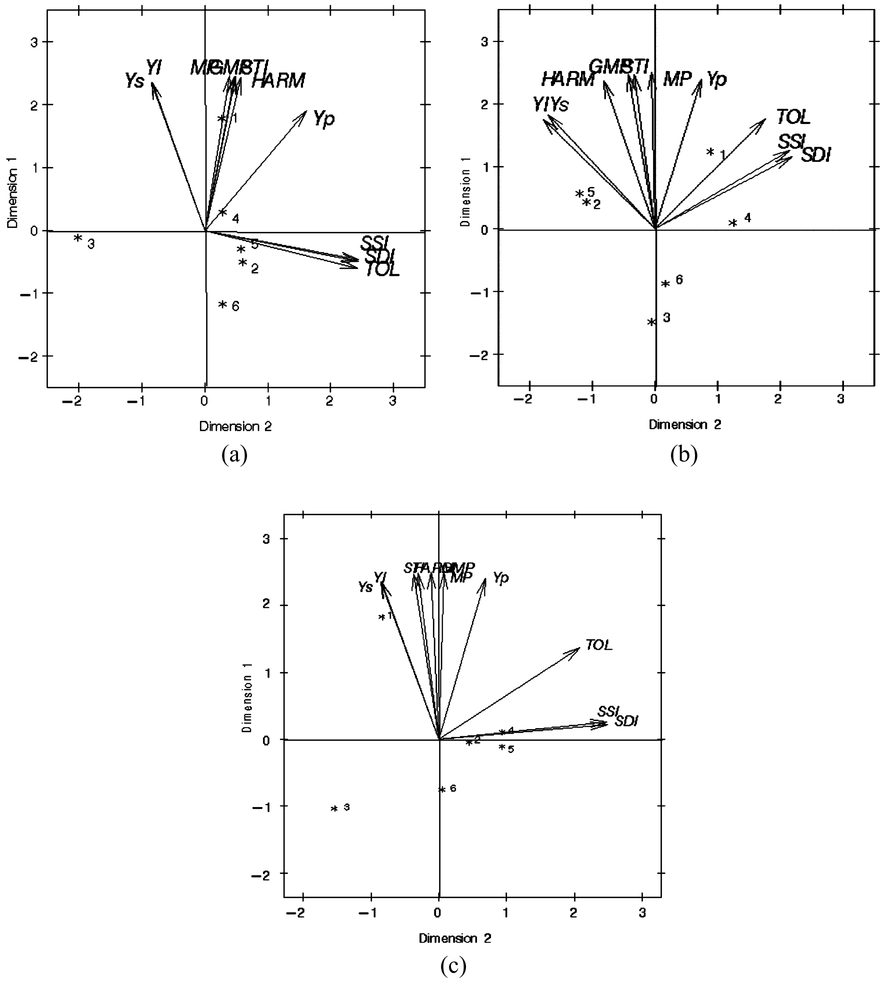

Figure 3. Biplot analysis for identifying the best ecotypes and selection indices under mild (a), medium (b) and severe drought stress (c) (Ecotypes 1, 2, 3, 4, 5, and 6 are Isfahan, Ardestan, Arak, Naein, Yazd and Ahvaz, respectively).

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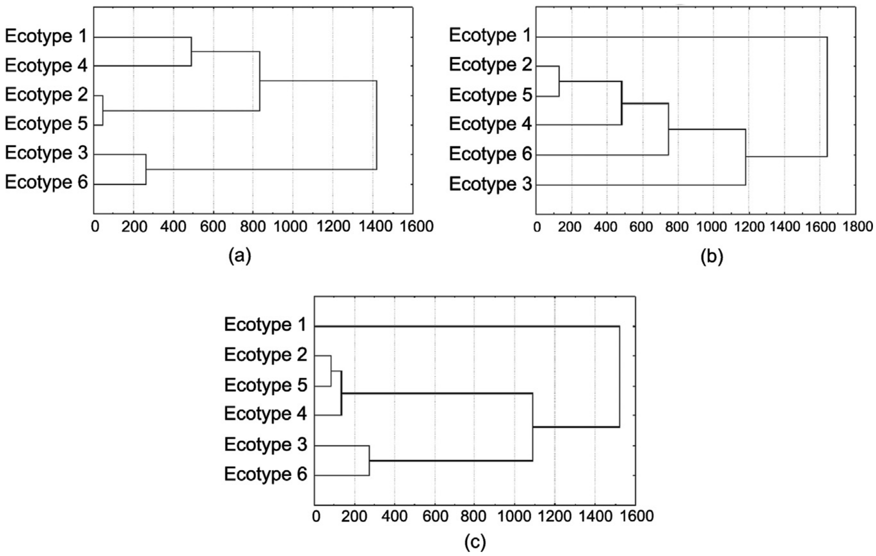

Figure 4. Cluster analysis under mild (a), medium (b) and severe (c) drought stress (Ecotypes 1, 2, 3, 4, 5, and 6 are Isfahan, Ardestan, Arak, Naein, Yazd and Ahvaz, respectively).

best wheat genotypes which have higher yield in both stressed and non-stressed conditions (Mollasadeghi et al., 2011).

4. Conclusion

Correlation and biplot analysis showed that MP, GMP, STI and HARM indices were the best indices to identify castor tolerant ecotypes. Isfahan and Naein were in group A under mild and average stresses. They have suitable yield in both stress and normal conditions. Only Naein ecotype produced good yield under severe stress. Ahvaz did not have acceptable yield and was located in part D. This information can help us to use drought stress indices to identify best genotypes in non-stressed and stressed locations.

Declarations

Author contribution statement

Pejman Nikneshan, Ali Tadayyon, Milad Javanmard: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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