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Evaluation of rapeseed (*Brassica napus* L.) cultivars performance under drought stress

Ruhollah Naderi[1*] and Yahya Emam[2]

[1]Department of Agroecology, Darab Agricultural College and Natural Resources, Shiraz University, Iran
[2]Department of Crop Production and Plant Breeding, College of Agriculture, Shiraz University, Iran

***Corresponding author: rnaderi@shirazu.ac.ir**

Abstract

To evaluate the drought tolerance of four rapeseed cultivars using drought indices, a greenhouse experiment was conducted. Treatments consisted of four rapeseed cultivars (Hayola 401, Hayola 308, RGS and Option) and two water regimes: stress (50 % field capacity (FC)) and non-stress (well watered). Seven drought indices including stress susceptibility index (SSI), stress tolerance index (STI), tolerance (TOL), mean productivity (MP), harmonic mean (HARM), geometric mean productivity (GMP), and yield loss ratio (S) were calculated based on rapeseed yield under drought-stress and non-stress conditions. Significant positive correlations were found among rapeseed yield and several drought indices such as STI ‹GMP ‹MP and HARM under both stress and non-stress conditions, revealing these indices were fit to identify the drought tolerance of rapeseed cultivars. Biplot graph and correlation of the above indices also showed that Hayola 408 and Hayola 308 were superior to other cultivars and might be used as promising cultivars for drought conditions, and these two elite cultivars could be considered as candidates for further field evaluations under both stress and non-stress conditions.

Keywords: Stress conditions, Oilseed, Yield.
Abbreviation: FC_field capacity; SSI_stress susceptibility index; STI_stress tolerance index; TOL_tolerance; MP_mean productivity; HARM_harmonic mean; GMP_geometric mean productivity; S_yield loss ratio; PC_principal components.

Introduction

Rapeseed (*Brassica napus* L.), of the family *Brassicaceae*, is one of the most important oilseed crops in Iran, including Fars Province (Naderi and Ghadiri, 2011). It can be also grown as an alternative crop for cereal-based cropping systems (as a broad leaf dicot plant) and thus can be used as a break crop for a continuous wheat cropping systems (Khachatourians et al., 2004). Drought is one of the most important abiotic constraints which can cause major crop yield losses (Khan et al., 2007; Ricciardi et al., 1997; Nezami et al., 2008; Moradi et al., 2008). In southern areas of Iran with an arid climate, rapeseed is more often planted in late autumn and harvested in early summer. Accordingly, this stress is also considered as an essential limiting factor for rapeseed growth and production due to poorly distributed rainfalls over the crop growing season and lack of rainfall before plant growth completion. Therefore, rapeseed plants are exposed to terminal drought stresses, in reproductive growth phases. Since the portion of fresh water currently available for agriculture is decreasing, an efficiently improved water use system in agriculture is necessary (Abbasi and Sepaskhah, 2011; Bijanzadeh and Emam, 2010). One of the strategies for increasing the crop production in limited water resources conditions is genetic improvement, i.e., drought resistance cultivars (Nemoto et al., 1998). However, there is a lack of required information to adopt new rapeseed cultivars with high yield potential under water limited conditions. Several researchers suggested that screening should be performed under favorable conditions (Rajaram and Van Ginkle, 2001; Betran et al., 2003). However, selection in the stressed conditions has been emphasized as well (Ceccarelli and Grando, 1991; Rathjen, 1994). Interestingly, many researchers have recommended that screening of drought resistance cultivars must be carried out based on high performance in both stress and non-stress conditions so that high yield genotypes in both stress and non-stress conditions would be considered as drought resistant (Blum, 1988; Fischer and Maurer, 1978; Clarke et al. 1992; Nasir Ud-Din et al. 1992; Fernandez, 1992; Byrne et al. 1995; Rajaram and Van Ginkle, 2001). Some screening indices for evaluating drought resistance genotypes have been stressed based on a mathematical relationship between non-stress and stress conditions (Clarke et al. 1984; Huang, 2000). Most of these drought indices such as tolerance (TOL) (McCaig and Clarke 1982; Clarke et al. 1992), mean productivity (MP) (McCaig and Clarke, 1982), stress susceptibility index (SSI) (Fischer and Maurer, 1978), geometric mean productivity (GMP) and stress tolerance index (STI) (Fernandez, 1992) have been used in various crops. Fernandez (1992) suggested that STI is the best criteria for screening drought resistance in bean (*Phaseolus vulgaris*). However, Yadav and Bhatnagar (2001) reported that GM is the most useful criteria to select drought tolerant cultivars of pearl millet (*Pennisetum glaucum*). Harmonic mean (HARM), MP, GMP and STI have been all considered as the most suitable indices for screening drought resistance of various crop cultivars such as chickpea (*Cicer arietinum*) (Ganjeali et al., 2005; Ganjeali et al., 2011), wheat (*Triticum aestivum*) (Sio-Se Mardeh et al. 2006), durum wheat (*Triticum durum*) (Golabadi et al., 2006), Rice (*Oryza sativa*) (Abbasi and Sepaskhah, 2011). Although there are many

Table 1. Drought tolerance indices in different rapeseed cultivars.

	Indices								
Cultivars	TOL	MP	GMP	SSI	HARM	STI	S	Yp	Ys
Hayola408	2.03a[†]	1.43a	1.00a	2.36b	0.702a	0.359a	0.01c	2.44a	0.41a
Hayola308	1.60b	1.20b	0.89b	2.27c	0.665b	0.286b	0.11b	2.00b	0.39a
Option	1.18c	0.74c	0.45c	2.52a	0.270d	0.072c	0.55a	1.33c	0.15c
RGS	0.72d	0.55d	0.42c	2.25c	0.314c	0.062c	0.58a	0.91d	0.19b

STI= stress tolerance index, TOL= stress tolerance, SSI= stress susceptibility index, MP= mean productivity, GMP= geometric mean productivity, S=yield loss ratio, Ys= grain yield under drought conditions and Yp= grain yield under normal conditions. Means with the same letter are not significantly different (Duncan 0.05).

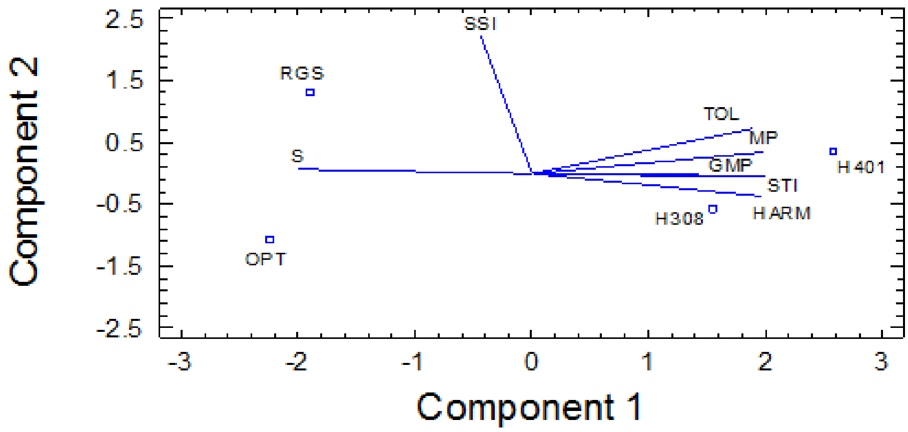

Fig 1. Biplot based on eight drought indices of rapeseed cultivars (RGS, Option, Hayola408, Hayola308). STI= stress tolerance index, TOL= stress tolerance, SSI= stress susceptibility index, MP= mean productivity, GMP= geometric mean productivity, S=yield loss ratio, Ys= grain yield under drought conditions and Yp= grain yield under normal conditions.

reports dealing with the employing of the drought resistance indices in cultivated crops, only a few are available on rapeseed. The authors could not find any research report on drought tolerant rapeseed cultivars in Iran. The objective of the present study was to evaluate the relevance of various drought indices in rapeseed and to select high-yielding cultivars under drought and non-stress conditions for further field studies.

Results

Drought tolerance Indices

Drought tolerance indices of the rapeseed cultivars are given in Table 1. Highest values of the indices obtained for Hayola 408 and Hayola 308. There were positive and highly significant correlations (Table 2) among drought tolerance indices including STI, HM, MP and GMP and yield in stress and non-stress conditions. TOL had only significant correlation with yield in non-stress conditions. A positive correlation between TOL and non-stress yield ($r= 0.94$, $p<0.01$) and a negative correlation between TOL and stress yield ($r=-0.45$, $p<0.01$). There were no significant correlation between yield under stress and non-stress conditions, and SSI and S (Table 2). The correlation coefficients among the drought indices are given in Table 4.

Principal components analysis

Based on principal components analysis, the first two components retained as they explained 99.919 % of the total variation and the other components which had negligible values of the total variation (<0.1 %) or no significant effect omitted (Table 3). Principal components analysis showed that the first component only explained 84.157 % of the total variation. The second component also explained 15.762 % of the total variation. The first component had positive and highly significant correlations with rapeseed yield in stress conditions and tolerant indices including HARM, STI, GMP and MP. Component 1 called drought tolerant component so that the higher value of this component is the more appropriate. Therefore, drought tolerant and susceptible cultivars were classified by higher and lower values of this component, respectively. The second component had positive and significant correlation with yield potential, TOL and SSI. Component 2 called drought susceptibility component so that the lower value of this component is the more appropriate. This component could classify cultivars which are well adapted to availability of water or humid environments. There were positive and highly significant correlation between the first component, stress yield and drought tolerance indices as well as positive and highly significant correlation between the second component and yield potential. Therefore, rapeseed cultivars placed on upper space of these components were identified as highly yielding and tolerant cultivars (Figure1).

Discussion

Drought tolerance Indices

Drought tolerance indices showed that Hayola 408 at first place and Hayola 308 cultivars at second place might be considered as drought tolerant cultivars which can be used in further field surveys under either fully irrigated or deficit irrigated conditions in Fars province. Correlation analysis

Table 2. Correlation coefficients between Yp, Ys and drought tolerance indices.

Indices Yield	S	GMP	HARM	STI	MP	TOL	SSI
Yp	-0.01 ns†	0.96**	0.92**	0.96**	0.97**	0.94**	-0.002 ns
Ys	-0.001 ns	0.98**	0.90**	0.90**	0.93**	-0.45 ns	-0.42 ns

STI= stress tolerance index, TOL= stress tolerance, SSI= stress susceptibility index, MP= mean productivity, GMP= geometric mean productivity, S=yield loss ratio, Ys= grain yield under drought, conditions and Yp= grain yield under normal conditions. †: ns: not significant, * $P < 0.05$, **$P < 0.01$, *** $P < 0.001$.

Table 3. Principal component analysis of 7 drought tolerance indices.

Component	Eigenvalue	Percent of variation	Cumulative percentage
1	5.89	84.157	84.157
2	1.103	15.762	99.919
3	0.005	0.081	100.000

Table 4. Correlation coefficients among drought tolerance indices.

	TOL	MP	GMP	SSI	HARM	STI	S
TOL	1						
MP	0.98**†	1					
GMP	0.94**	0.98**	1				
SSI	0.12ns	-0.05 ns	-0.22*	1			
HARM	0.88**	0.95**	0.99**	-0.36*	1		
STI	0.94**	0.99**	0.99**	-0.22*	0.99**	1	
S	0.12 ns	-0.05 ns	-0.22*	-0.22*	-0.36**	-0.22*	1

STI= stress tolerance index, TOL= stress tolerance, SSI= stress susceptibility index, MP= mean productivity, GMP= geometric mean productivity, S=yield loss ratio, Ys= grain yield under drought conditions and Yp= grain yield under normal conditions. †: ns: not significant, * $P < 0.05$, **$P < 0.01$, *** $P < 0.001$.

among drought tolerance indices indicated that STI, HM, MP and GMP are appropriate criteria to identify drought tolerant cultivars. Our results are consistent with the findings of Ganjeali et al. (2011), who reported that MP, GMP, STI and HARM are useful criteria for identifying drought tolerant genotypes of Iranian chickpea. Results of other studies also documented that the aforementioned indices are superior in some crops such as wheat (Sio-Se Mardeh et al. 2006), rice (Abbasi and Sepaskhah, 2011) and sugar beet (*Beta vulgaris*) (Bazrafshan et al. 2008). Correlation analysis between TOL, non stress and stress yield showed that screening based on TOL will lead to reduced yield under well-watered conditions. These results are in accordance with those of Bazrafshan et al. (2008), Ramirez-Vallejo and Kelly (1998), Clarke et al. (1992) and Rosielle and Hamblin (1981). Similarly, Rizza et al. (2004) showed that a selection based on TOL failed to identify the best genotypes. Correlation analysis among SSI, S, non-stress and stress yield showed that SSI and S cannot discriminate drought sensitive cultivars under such conditions. This is in contrast to the results obtained by Bansal and Sinah (1991), who examined the drought resistance in 20 accessions of *T. aestivum* and related species. They used SSI and grain yield as stability parameters and identified resistant genotypes. However, this is consistent with the results of a number of studies that have found that these indices are not very suitable for identifying drought tolerant genotypes (Schneider et al., 1997; Clarke et al., 1992; Sio-Se Mardeh et al., 2006; Bazrafshan et al., 2008).

Principal components analysis

Since Option cultivar was placed on lower space of the components as well as near to the S, the cultivar considered as the most susceptible to water shortage. Similarly, Golabadi et al. (2006) also found that some families of durum wheat collected from different parts of Iran could be distinguished based on biplot display. Cultivar selection by using the combination of indices might provide the more useful criterion to improve drought resistance of crops, and thus employing both biplot and correlation coefficient together is a better approach for identifying the superior genotypes for both stress and non-stress conditions (Yan and Rajcan, 2002; Golabadi et al., 2006). Accordingly, in the biplot, a vector is drawn from the biplot origin to indices' sign for facilitating visualization of the relationships between and among the indices. Given that the biplot describes an adequate amount of the total variation, the correlation coefficient between the indices is approximated by the cosine of the angle between their vectors so that r=cos180= -1, cos0=1, and cos90=0 (Yan and Rajcan 2002). The most important relationships indicated by the biplot are (i) a highly negative correlation between S and STI, and between S and GMP showing by the large obtuse angles between their vectors. (ii) a near zero association between SSI and MP and between SSI and GMP, showing by the near perpendicular vectors. (iii) a positive correlation among GMP, STI, MP and HARM, showing by the acute angles. Results of correlation coefficient among drought indices also showed that biplot correctly displays relationships among the drought indices which had proportionately large loadings on either the first principal component or the second.

Materials and Methods

Plant material

Four rapeseed cultivars (Hayola 401, Hayola 308, RGS and Option) were compared under different moisture regimes (field capacity (FC) and 50% FC on pot weight basis) in a greenhouse experiment at the College of Agricultue, Shiraz University, Iran during 2006. Six uniform seeds were sown in pots containing 5 kg soil and thinned to three uniform plants at 3 leaf stage. The soil type was Daneshkadeh soil series (Fine mixed, Mesic Calcixerpets, Xerochrepts) which was collected from the top 20 cm layer. The soil was air-dried and sieved at 2 mm. The greenhouse conditions were maintained at 24°C /16°C day/night, controlled light 16H/8H (day/night). Plants were irrigated up to FC for three weeks after sowing, and then were subjected to two water regimes. The experimental design was randomized complete block with four replications. All pots kept free from diseases during the experimental period. A pesticide, metasistox, was applied on every other week basis to control aphids.

Measurements

Plants from each pot were sampled at maturity to determine rapeseed aboveground dry matter, oven-dried at 75 °C for 72 h, and weighed. Drought tolerance indices were calculated using the following relationships:

(1) SSI=[1-(Ys/Yp)]/SI (Fischer and Maurer, 1978)
(2) SI=1-($\overline{Y_S} / \overline{Y_P}$) (Sio-Se Mardeh et al., 2006; Ganeali et al., 2011)
(3) HARM= 2(Yp.Ys)/(Yp + Ys) (Ganeali et al., 2011)
(4) MP=(Yp+Ys)/2 (McCaig and Clarke, 1982)
(5) TOL=Yp-Ys (McCaig and Clarke 1982; Clarke et al. 1992)
(6) STI=(Yp.Ys)/($\overline{Y_P}$)^2 (Fernandez, 1992)
(7) S=1-(Ys/Yp) (Sio-Se Mardeh et al., 2006; Ganeali et al., 2011)
(8) GMP= (Yp.Ys)$^{1/2}$ (Fernandez, 1992)

Where, Ys is the stress yield for each cultivar, Yp is the non-stress yield for each cultivar, $\overline{Y_S}$ and $\overline{Y_P}$ are the mean yields of all cultivars under stress and non-stress conditions, respectively.

Statistical analysis

All statistical analyses performed using SAS software (2000). Principal Components Analysis (PCA) based on the covariance matrix to construct a biplot of genotypes (PC scores) and drought tolerance indices including SSI, SI, TOL, MP, HARM, STI and yield in stress and non-stress conditions (PC factor loading) was also performed by using STATGRAPHIC Plus (version 5.1, 2001).

Conclusion

Biplot graph and correlation analysis of the drought indices showed that Hayola 408 and Hayola 308 were superior to other cultivars and could be considered as promising cultivars for drought tolerance. Therefore, these two elite cultivars might be used as candidates for further field studies under both stress and non-stress conditions in Fars province. Furthermore, STI, HM, MP and GMP were found as suitable indices for selection of drought tolerant cultivars of rapeseed.

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