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Evaluation of drought tolerance in winter rapeseed cultivars based on tolerance and sensitivity indices

Amir Hossein SHIRANI RAD[1], Abouzar ABBASIAN[2]

[1]Seed and Plant Improvement Institute
Karaj, Iran

[2]Young Researchers Club of Shahr-e-Qods Branch
E-mail: abouzar.abbasian@gmail.com

Abstract

Drought is a wide-spread problem seriously influencing rapeseed (*Brassica napus* L.) production and quality, but development of resistant cultivars is hampered by the lack of effective selection criteria. The objective of this study was to evaluate the ability of several selection indices to identify drought resistant cultivars under a variety of environmental conditions. In order to evaluate winter rapeseed cultivars based on sensitivity and tolerance indices, an experiment was conducted as split plot with three replications at Seed and Plant Improvement Institute of Karaj, Iran during 2007–2009. Four irrigation levels consisting of irrigation after 80 mm evaporation from class "A" pan as control, no irrigation from stem elongation stage, flowering stage and podding stage were applied in main plots and subplots which consisted of split application of cultivars at six levels ('Licord', SLMO64, 'Okapi', 'Orient', 'Zarfam' and 'Opera'). The results showed the highest mean productivity (MP) index, geometric mean productivity (GMP) and stress tolerance index (STI) indices for 'Okapi' cultivar and least stress susceptibility index (SSI) and tolerance (TOL) for 'Opera' cultivar in all stress levels. High and positive correlation between geometric mean productivity (GMP), stress tolerance index (STI) and mean productivity (MP) index with yield in optimum and drought conditions indicated them as the best indices for introducing drought tolerant cultivars. The assessment of different water stress indices (SSI, TOL, MP, GMP and STI) revealed that GMP, STI and MP seem to be most suitable recognizing the more tolerant genotypes to drought conditions and based on these indices, 'Okapi' and 'Opera' cultivars were the most tolerant genotypes. These indices can be used as the best indices for rapeseed breeding programs to introduce drought tolerant cultivars.

Keywords: rapeseed, water stress, irrigation, sensitivity and tolerance index.

Introduction

Drought stress significantly limits plant growth and crop productivity. However, in certain tolerant-adaptable crop plants such as rapeseed, morphological and metabolic changes occur in response to drought, which contribute towards adaptation to such unavoidable environmental constraints (Sinha, 1982; Blum, 1996; Tohidi-Moghadam et al., 2009). In Iran, water is a scarce resource, due to the high variability of rainfall. The effects of water stress depend on timing, duration, and magnitude of water deficiency (Pandey et al., 2001).

Breeding for drought resistance is complicated by the lack of fast, reproducible screening techniques and the inability to routinely create defined and repeatable water stress conditions when a large amount of genotypes can be evaluated efficiently (Ramirez, Kelly, 1998). Achieving a genetic increase in yield under these environments has been recognized to be a difficult challenge for plant breeders while progress in grain yield has been much higher in favourable environments (Richards et al., 2002). Thus, drought indices which provide a measure of drought based on yield loss under drought conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes (Mitra, 2001).

Fernandez (1992) classified plants according to their performance in stressful and stress free environments to four groups: genotypes with similar good performance in both environments (group A), genotypes with good performance only in non-stress environments (group B) or stressful environments (group C), and genotypes with weak performance in both environments (group D).

To evaluate response of plant genotypes to drought stress, some selection indices based on a mathematical relation between stress and optimum conditions have been proposed (Rosielle, Hamblin, 1981; Clarke et al., 1992; Fernandez, 1992; Sio-Se Mardeh et al., 2006). Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between the stress (Ys) and non-stress (Yp) environments and mean productivity (MP) as the average yield of Ys and Yp. Fischer and Maurer (1978) proposed a stress susceptibility index (SSI) of the cultivar. Fernandez (1992) defined a new advanced index (STI = stress tolerance index), which can be used to identify genotypes that produce high yield under both stress and non-stress conditions. Geometric mean productivity (GMP) and stress tolerance index (STI) (Fernandez, 1992) have been employed under various conditions. Fischer and Maurer (1978) explained that genotypes with an SSI of less than a unit are drought resistant, since their yield reduction in drought conditions is smaller than the mean yield reduction of all genotypes (Bruckner, Frohberg, 1987). Other yield based estimates of drought resistance are harmonic mean (HM) (Dehdari, 2003; Yousefi, 2004), yield index (YI) (Gavuzzi et al., 1997), yield stability index (YSI) (Bouslama, Schapaugh, 1984) and % reduction (Choukan et al., 2006).

Sio-Se Mardeh et al. (2006) reported that under moderate stress, MP, GMP and STI were more effective in identifying high yielding cultivars in both drought-stressed and irrigated conditions (group A cultivars). Under severe stress, none of the indices used were able to identify group A cultivars, although regression coefficient (b) and SSI were found to be more useful in discriminating resistant cultivars. So, the effectiveness of selection indices in differentiating resistant cultivars varies with the stress severity.

The suitability of indicators seems to depend on the timing and severity of stress in drought-prone environments. The objective of this study was to test this hypothesis in order to identify the most suitable indices/cultivars for each environment.

Materials and methods

This study was carried out at the experimental farm of Seed and Plant Improvement Institute, Karaj, Iran (latitude 35°55′ N, longitude 50°54′ E, elevation 1313 m above mean sea level) during 2007–2009. This region has a semi-arid climate (354 mm annual rainfall). The soil of the experimental site is a clay loam, with montmorillionite clay mineral, low in nitrogen (0.06–0.07%), low in organic matter (0.56–0.60%), and alkaline in reaction, with a pH of 7.9 and Ec = 0.66 dS m^{-1}. The soil texture is sandy loam, with 10% of neutralizing substances. The experimental design was split plot based on randomized complete block design (RCBD) with three replications. Four irrigation levels consisting of irrigation after 80 mm evaporation from class "A" pan as control (irrigation during full season), no irrigation from stem elongation stage, flowering stage, podding stage until end of the growth stage were applied in main plots and subplots which consisted of split application of winter rapeseed cultivars at six levels ('Licord', SLMO46, 'Okapi', 'Orient', 'Zarfam' and 'Opera') based on their reputed differences in yield performance under irrigated and non-irrigated conditions and main cultivars of Karaj region.

Individual plot consisted of 6 rows, 6 m long and spaced 30 cm apart using a seeding rate of 7 kg ha^{-1}. The experimental fields were mould-board ploughed and seedbed preparation consisted of two passes with a tandem disk. Seeds were planted 1 to 1.5 cm deep at a rate of 100 seeds m^{-2} on 10 October 2007 and 2008. For all treatments, N:P:K fertilizers were applied at rates of 150:60:50 kg, respectively. All of P, K fertilizer and one-third of N fertilizer were incorporated and added to soil pre-sowing. Other two-third of N fertilizer was split equally at the beginning of stem elongation and flowering stages. Weeds were controlled by application of haloxyfop-R-methyl ester (Gallant Super, 10% EC) at 0.6 L ha^{-1}. Broadleaf weeds were also hand weeded during the season. Final harvests were carried out on 16 June 2008 and 28 June 2009.

The seed yield was measured by harvesting 4.8 m^2 of the central part of each plot at crop maturity. Oil content was determined by the nuclear magnetic resonance (NMR). Oil yield was obtained multiplying seed yield by oil content. Drought resistance indices were calculated using the following relationships:

$$(1)\quad Stress\ susceptibility\ index\ (SSI) = \frac{1-(Ys/Yp)}{1-(\overline{Ys}/\overline{Yp})}$$

(Fischer, Maurer, 1978),

where Ys is the yield of cultivar under stress, Yp the yield of cultivar under irrigated condition, $\overline{Ys}$ and $\overline{Yp}$ are the mean yields of all cultivars under stress and non-stress conditions, respectively, and $1-(\bar{Y}s/\bar{Y}p)$ is the stress intensity. The irrigated experiment was considered to be non-stress conditions in order to have a better estimation of optimum environment.

(2) $Mean\ productivity\ (MP)\ index = \frac{Yp+Ys}{2}$ (Hossain et al., 1990).

(3) $Tolerance\ (TOL) = Yp - Ys$ (Hossain et al., 1990).

(4) $Stress\ tolerance\ index\ (STI) = \frac{Yp \times Ys}{(\bar{Y}p)^2}$ (Fernandez, 1992).

(5) $Geometric\ mean\ productivity\ (GMP) = \sqrt{Yp \times Ys}$ (Fernandez, 1992).

(6) $Yield\ index\ (YI) = \frac{Ys}{\bar{Y}s}$ (Gavuzzi et al., 1997).

(7) $Yield\ stability\ index\ (YSI) = \frac{Ys}{Yp}$ (Bouslama, Schapaugh, 1984).

(8) $\%\ Reduction = \frac{Yp-Ys}{Yp} \times 100$ (Choukan et al., 2006).

The data were analyzed using *SAS* software (SAS System, 1996) for analysis of variance, and Duncan's multiple range test (at the 0.05 probability level) was employed for the mean comparisons.

Results and discussion

Because of bad climate conditions in the second year as well as great difference between the amount of seed yield and oil yield in these two years, we have measured these data separately. Also, in the second year, we had higher reduction in percentage yield compared with the first year. Resistance indices were calculated on the basis of seed and oil yield of cultivars (Tables 1, 2, 3 and 4). Selection based on a combination of indices may provide a more useful criterion for improving drought resistance of rapeseed but study of correlation coefficients is useful in finding the degree of overall linear association between any two attributes. As shown in Tables 1, 2, 3 and 4, the greater value TOL has, the larger yield reduction under stress and the higher drought sensitivity are. A positive correlation between TOL and irrigated yield (Yp) and a negative correlation between TOL and yield under stress (Ys) (Table 5) suggest that selection based on TOL will result in reduced yield under well-watered conditions. Similar results were reported by Clarke et al. (1992) and Sio-Se Mardeh et al. (2006). Rizza et al. (2004), however, showed that a selection based on minimum yield decrease under stress with respect to favourable conditions (TOL) failed to identify the best genotypes. 'Licord', SLMO46, 'Okapi' and 'Orient', for example, with relatively low yields under stress conditions, exhibited high MP values (Tables 1 and 2). The MP can be related to yield under stress only when stress is not too severe and the difference between yield under stress and non-stress conditions is not too big (Sio-Se Mardeh et al., 2006). Hossain et al. (1990) used MP as a resistance criterion for wheat cultivars in moderate stress conditions. Ahmad Zadeh (1997) introduced MP as appropriate criterion for selection of high yield and drought tolerance in corn. The SLMO46 and 'Opera' with high yield under stress produced a lower yield under non-stress conditions and showed the lowest SSI (Tables 1 and 2). SSI showed a negative correlation with yield under stress (Table 5).

No significant correlation was found between yield under stress and SSI in various stress stages (Table 5), showing that SSI will not discriminate drought sensitive cultivars under such conditions. SSI has been widely used by researchers to identify sensitive and resistant genotypes (Clarke et al., 1984, Sio-Se Mardeh et al., 2006; Golabadi et al., 2006). In the present study, the mean SSI appeared to be a suitable selection index to distinguish resistant cultivars. In the second year, SLMO46 and 'Opera' with a lower SSI were identified as resistant cultivars, whereas 'Licord' and 'Zarfam', with the highest SSI were sensitive (Table 2) but in the first year, 'Orient' and 'Zarfam' cultivars also had lower SSI (Table 1). The difference between the highest and lowest yielding cultivars was about 946.4 and 527 kg ha^{-1} in 2007–2008 and 618.1 and 585.5 kg ha^{-1} in 2008–2009 in non-stress and stress conditions, respectively (Tables 1 and 2).

YI, proposed by Gavuzzi et al. (1997), was significantly correlated with stress yield. This index ranks cultivars only on the basis of their yield under stress (Table 5) and so does not discriminate genotypes of group A. YSI, as Bouslama and Schapaugh (1984) stated, evaluates the yield under stress of a cultivar relative to its non-stress yield, and should be an indicator of drought resistant genetic material. As a result, the cultivars with a high YSI are expected to have high yield under both stress and non-stress conditions. In the present study, however, cultivars with the highest YSI exhibited the least yield under non-stress conditions and the highest yield under stress conditions (Tables 1 and 2).

Table 1. Resistance indices of 6 rapeseed genotypes under stress and non-stress environments for seed yield in 2007–2008

Cultivar	Yp kg ha^{-1}	Ys kg ha^{-1}	SSI	TOL	MP	GMP	STI	YI	YSI	Reduction %
No irrigation from stem elongation stage										
‘Licord’	4841.6 a	3379 c	1.64	1462.6	4110.3	4044.7	0.79	0.91	0.69	30.2
SLMO46	4625 ab	3906 a	0.84	719	4265.5	4250.3	0.88	1.05	0.84	15.54
‘Okapi’	4941 a	3680.6 b	1.38	1260.4	4310.8	4264.5	0.88	0.99	0.74	25.5
‘Orient’	4594.3 ab	3902.6 a	0.82	691.7	4248.5	4234.4	0.87	1.05	0.85	15.05
‘Zarfam’	4221.6 b	3611.3 b	0.79	610.3	3916.5	3904.5	0.74	0.98	0.85	14.45
‘Opera’	3994.6 b	3720 ab	0.37	274.6	3857.3	3854.8	0.72	1	0.93	6.87
No irrigation from flowering stage										
‘Licord’	4841.6 a	3772.3 b	1.64	1069.3	4307	4273.6	0.89	0.96	0.78	22.08
SLMO46	4625 ab	3978 a	0.74	647	4301.5	4289.3	0.89	1.01	0.86	13.98
‘Okapi’	4941 a	4302.6 a	0.96	638.4	4621.8	4610.7	1.03	1.09	0.87	12.91
‘Orient’	4594.3 ab	4041.6 a	0.89	552.7	4318	4309.1	0.9	1.03	0.88	12.02
‘Zarfam’	4221.6 b	3661 b	0.98	560.6	3941.3	3931.3	0.75	0.93	0.86	13.28
‘Opera’	3994.6 c	3791 b	0.38	203.6	3892.8	3891.5	0.73	0.96	0.95	5.09
No irrigation from podding stage										
‘Licord’	4841.6 a	4258 a	1.21	583.6	4549.8	4540.4	1	1.04	0.88	12.05
SLMO46	4625 ab	4127.6 ab	1.08	497.4	4376.3	4369.2	0.93	1.01	0.89	10.75
‘Okapi’	4941 a	4161 ab	1.58	780	4551	4544.2	1.1	1.02	0.84	15.78
‘Orient’	4594.3 ab	4113.6 ab	1.05	480.7	4354	4347.3	0.92	1.01	0.89	10.46
‘Zarfam’	4221.6 b	3863.3 c	0.85	358.3	4042.5	4038.5	0.79	0.95	0.91	8.48
‘Opera’	3994.6 c	3978 c	0.04	16.6	3986.3	3986.3	0.77	0.97	0.99	0.41

Note. Ys – yield of cultivar under stress, Yp – yield of cultivar under irrigated condition, SSI – stress susceptibility index, TOL – tolerance, MP – mean productivity, GMP – geometric mean productivity, STI – stress tolerance index, YI – yield index, YSI – yield stability index.

Table 2. Resistance indices of 6 rapeseed genotypes under stress and non-stress environments for seed yield in 2008–2009

Cultivar	Yp kg ha^{-1}	Ys kg ha^{-1}	SSI	TOL	MP	GMP	STI	YI	YSI	Reduction %
1	2	3	4	5	6	7	8	9	10	11
No irrigation from stem elongation stage										
‘Licord’	3013.9 a	1669 a	1	1344.9	2341.4	2242.8	0.6	1.04	0.55	44.62
SLMO46	2773.2 a	1719 a	0.85	1054.2	2246.1	2183.3	0.57	1.07	0.62	38.01
‘Okapi’	2956 a	1620.4 a	1.01	1335.6	2288.2	2188.5	0.58	1.01	0.55	45.18
‘Orient’	2736.1 a	1435.2 a	1.07	1300.9	2085.6	1981.6	0.47	0.89	0.52	47.54
‘Zarfam’	2601.8 a	1294 a	1.13	1307.8	1947.9	1834.8	0.4	0.8	0.49	50.26
‘Opera’	3219.9 a	1879.5 a	0.93	1340.4	2549.7	2460	0.72	1.17	0.58	41.63

Table 2 continued

1	2	3	4	5	6	7	8	9	10	11
No irrigation from flowering stage										
‘Licord’	3013.9 a	2280.1 a	0.88	733.8	2647	2621.4	0.83	1.08	0.75	24.35
SLMO46	2773.2 a	2043.2 ab	0.96	730	2408.2	2380.3	0.67	0.97	0.73	26.32
‘Okapi’	2956 a	1995.4 ab	1.18	960.6	2475.7	2428.6	0.71	0.95	0.67	32.49
‘Orient’	2736.1 a	2199 ab	0.71	537.1	2467.5	2452.8	0.72	1.05	0.8	19.63
‘Zarfam’	2601.8 a	1627.3 b	1.36	974.5	2114.5	2057.6	0.51	0.77	0.62	37.45
‘Opera’	3219.9 a	2411.2 a	0.91	808.7	2815.5	2786.3	0.93	1.15	0.75	25.11
No irrigation from podding stage										
‘Licord’	3013.9 a	2500 a	1.17	513.9	2756.9	2744.9	0.91	1.01	0.83	17.05
SLMO46	2773.2 a	2328.7 a	1.09	444.5	2550.9	2541.2	0.78	0.94	0.84	16.02
‘Okapi’	2956 a	2578.7 a	0.87	377.3	2767.3	2760.9	0.92	1.04	0.87	12.76
‘Orient’	2736.1 a	2409.7 a	0.81	326.4	2572.9	2567.7	0.79	0.97	0.88	11.93
‘Zarfam’	2601.8 a	2226.1 a	0.99	375.7	2413.9	2406.6	0.69	0.9	0.85	14.44
‘Opera’	3219.9 a	2733.8 a	1.03	486.1	2976.8	2966.9	1.05	1.11	0.85	15.09

Note. Explanation under Table 1.

Table 3. Resistance indices of 6 rapeseed genotypes under stress and non-stress environments for oil yield in 2007–2008

Cultivar	Yp kg ha^{-1}	Ys kg ha^{-1}	SSI	TOL	MP	GMP	STI	YI	YSI	Reduction %
No irrigation from stem elongation stage										
‘Licord’	2187.3 a	1506.1 b	1.59	681.1	1846.7	1815	0.79	0.92	0.69	31.13
SLMO46	2093.2ab	1748.5 a	0.84	344.6	1924.9	1913.1	0.88	1.07	0.83	16.46
‘Okapi’	2227.3 a	1621.2 ab	1.39	606.1	1920.2	1900.2	0.87	0.99	0.73	27.21
‘Orient’	2078.4ab	1750.8 ab	0.8	327.6	1914.6	1907.6	0.88	1.07	0.84	15.76
‘Zarfam’	1889.4 cd	1587.6 ab	0.81	301.7	1738.5	1731.9	0.72	0.97	0.84	15.97
‘Opera’	1753.8 d	1604 ab	0.44	149.7	1678.9	1667.6	0.68	0.98	0.91	8.53
No irrigation from flowering stage										
‘Licord’	2187.3 a	1675.4 bc	1.61	511.8	1931.3	1914.3	0.86	0.96	0.77	23.39
SLMO46	2093.2ab	1746.2 b	1.14	347.06	1919.7	1911.8	0.88	1.00	0.83	16.58
‘Okapi’	2227.3 a	1900.4 a	1.01	326.9	2063.8	2057.3	1.02	1.09	0.85	14.67
‘Orient’	2078.4ab	1785.3 b	0.97	293.1	1931.9	1926.3	0.89	1.02	0.86	14.1
‘Zarfam’	1889.4 cd	1637.8 bc	0.92	251.5	1763.6	1759.1	0.75	0.94	0.87	13.31
‘Opera’	1753.8 d	1696.2 bc	0.23	57.5	1725.01	1724.7	0.72	0.97	0.97	3.28
No irrigation from podding stage										
‘Licord’	2187.3 a	1900.2 a	1.3	287.1	2043.7	2038.7	1	1.04	0.87	13.12
SLMO46	2093.2ab	1850.6 ab	1.15	242.6	1971.9	1968.2	0.93	1.01	0.88	11.59
‘Okapi’	2227.3 a	1851.7 ab	1.67	375.5	2039.5	2030.8	0.99	1.01	0.83	16.86
‘Orient’	2078.4ab	1874.1 ab	0.97	204.3	1976.2	1973.6	0.94	1.02	0.9	9.83
‘Zarfam’	1889.4 cd	1754.4 b	0.7	135	1821.9	1820.6	0.8	0.96	0.93	7.14
‘Opera’	1753.8 d	1747.6 b	0.03	6.21	1750.7	1750.7	0.74	0.95	0.99	0.35

Note. Ys – oil yield of cultivar under stress, Yp – oil yield of cultivar under irrigated condition, SSI – stress susceptibility index, TOL – tolerance, MP – mean productivity, GMP – geometric mean productivity, STI – stress tolerance index, YI – yield index, YSI – yield stability index.

Table 4. Resistance indices of 6 rapeseed genotypes under stress and non-stress environments for oil yield in 2008–2009

Cultivar	Yp kg ha^{-1}	Ys kg ha^{-1}	SSI	TOL	MP	GMP	STI	YI	YSI	Reduction %
No irrigation from stem elongation stage										
'Licord'	1430.6 a	921.8 a	1.12	508.8	1176.2	1148.3	0.81	1.05	0.64	35.56
SLMO46	1165.2 a	810.9 a	0.96	354.3	1130.9	1130.4	0.78	0.93	0.69	30.4
'Okapi'	1340.1 a	726.6 a	1.45	613.5	1033.3	986.7	0.59	0.83	0.54	45.8
'Orient'	1173.6 a	839.8 a	0.9	333.8	1006.7	992.7	0.6	0.96	0.71	28.44
'Zarfam'	1123.7 a	945.8 a	0.5	177.9	1034.7	1030.9	0.65	1.08	0.84	15.83
'Opera'	1414.2 a	991 a	0.94	423.2	1202.6	1183.8	0.86	1.13	0.7	29.92
No irrigation from flowering stage										
'Licord'	1430.6 a	890.1 a	1.44	540.5	1160.3	1128.4	0.78	0.94	0.62	37.78
SLMO46	1165.2 bc	1096.7 a	0.22	68.5	1060.2	1054.9	0.68	1.16	0.94	5.87
'Okapi'	1340.1 abc	933.3 a	1.16	406.8	1136.7	1118.3	0.77	0.99	0.69	30.35
'Orient'	1173.6 bc	1140.3 a	0.1	33.3	1156.9	1156.8	0.82	1.21	0.97	2.83
'Zarfam'	1123.7 c	588 b	1.82	535.7	855.8	812.8	0.4	0.62	0.52	47.67
'Opera'	1414.2 ab	1001.5 a	1.11	412.7	1207.8	1190	0.87	1.06	0.7	29.18
No irrigation from podding stage										
'Licord'	1430.6 a	1104.8 a	1.1	325.8	1267.7	1257.1	0.97	1.09	0.77	22.77
SLMO46	1165.2 bc	955.2 a	0.87	210	1060.2	1054.9	0.68	0.94	0.82	18.02
'Okapi'	1340.1 abc	1182.8 a	0.57	157.3	1261.4	1258.9	0.97	1.16	0.88	11.73
'Orient'	1173.6 bc	869.7 a	1.25	303.9	1021.6	1010.2	0.62	0.85	0.74	25.89
'Zarfam'	1123.7 c	844.3 a	1.2	279.4	984	974	0.58	0.83	0.75	24.86
'Opera'	1414.2 ab	1118.3 a	1.01	295.9	1266.2	1257.5	0.97	1.1	0.79	20.92

Note. Explanation under Table 3.

Table 5. Simple correlation coefficients of stress indices with seed yield of 6 rapeseed cultivars

	Ys kg ha^{-1}	SSI	TOL	MP	GMP	STI	YI	YSI	Reduction %
Yp	0.3ns	0.84**	0.75**	0.87**	0.83**	0.83**	0.39ns	−0.71**	0.71**
Ys	1	−0.05ns	−0.39ns	0.73**	0.77**	0.78**	0.74**	0.44ns	−0.44ns
SSI		1	0.85**	0.57*	0.53*	0.52*	−0.08ns	−0.84**	0.84**
TOL			1	0.33ns	0.27ns	0.26ns	−0.13ns	−0.99**	0.99**
MP				1	0.99**	0.99**	0.66**	−0.28ns	0.28ns
GMP					1	0.99**	0.69**	−0.22ns	0.22ns
STI						1	0.69**	−0.21ns	0.21ns
YI							1	0.17ns	−0.17ns
YSI								1	−1**

Notes. Ys – yield of cultivar under stress, Yp – yield of cultivar under irrigated condition, SSI – stress susceptibility index, TOL – tolerance, MP – mean productivity, GMP – geometric mean productivity, STI – stress tolerance index, YI – yield index, YSI – yield stability index. ns – not significant; * – $P < 0.05$, ** – $P < 0.01$.

The results indicated that there was a positive and significant correlation among Ys and (MP, GMP, YI and STI) and they hence were better predictors of Yp and Ys than TOL, SSI and YSI (Table 5). Farshadfar et al. (2001) believed that most appropriate index for selecting stress-tolerant cultivars is index which has partly high correlation with seed yield under stress and non-stress conditions. The observed relations were consistent with those reported by Fernandez (1992) in mungbean, Farshadfar and Sutka (2002) in maize and Golabadi et al. (2006) in durum wheat. The significant and positive correlation of Yp and SSI, TOL, MP, GMP and STI showed that these criteria indices were more effective in identifying high yielding cultivars under different moisture conditions (Table 5). The results of calculated seed from indirect selection in moisture stress environment would improve yield in moisture stress environment better than selection from non-moisture stress environment. Wheat breeders should, therefore, take into account the stress severity of the environment when choosing an index. STI, GMP and MP were able to identify cultivars producing high yield in both conditions. It is concluded that the effectiveness of selection indices depends on the stress severity supporting the idea that only under moderate stress conditions, potential yield greatly influences yield under stress (Blum, 1996; Panthuwan et al., 2002).

Content of oil yield has the highest importance in production profitability (Robertson, Holland, 2004). Since oil yield was obtained through multiplying oil content by seed yield and also magnitude of changing oil content in modified rapeseed cultivars is low, therefore seed yield has the greatest effect on oil yield. Through breeding and selecting of cultivars for achieving high seed yield, high oil yield can also be achieved. Also, seed yield and oil yield compared to 1000-seed weight and oil content are more affected by environmental conditions (Khoshnazar Parshokohi et al., 2000). Evaluation of indices of MP, GMP and STI for oil yield in different irrigation showed that SLMO45, 'Okapi' and 'Orient' cultivars have the greatest tolerance in the first year but in the second year, 'Licord' and 'Opera' cultivars have the highest tolerance. Also, in TOL and SSI indices, 'Opera' and 'Zarfam' cultivars had least numeral value and the highest tolerance (Tables 3 and 4).

In addition, results of investigation on seed yield in different drought stress and non-stress conditions with drought tolerance indices showed that GMP, STI and MP are best indices for selecting and specifying of rapeseed tolerant cultivars in arid areas. These results completely agreed with Shafazadeh et al. (2004) that aforementioned indices for having positive and significant correlation with seed yield of wheat cultivars at drought stress and non-stress conditions at after flowering stage were an appropriate criterion for recognition of high yield and drought tolerance genotypes.

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Žieminio rapso veislių atsparumo sausrai vertinimas taikant atsparumo ir jautrumo indeksus

A. H. Shirani Rad[1], A. Abbasian[2]

[1]Sėklų ir augalų tyrinėjimo institutas, Karaj, Iranas

[2]Jaunųjų tyrėjų klubo Shahr-e-Qods filialas

Santrauka

Sausra yra rimta problema, turinti didelę įtaką rapsų (*Brassica napus* L.) produktyvumui ir kokybei, tačiau atsparių veislių kūrimą sunkina efektyvių atrankos kriterijų stoka. Tyrimų tikslas – įvertinti keleto atrankos rodiklių tinkamumą indentifikuojant sausrai atsparias veisles esant įvairioms aplinkos sąlygoms. Siekiant įvertinti žieminio rapso veisles taikant jautrumo ir atsparumo rodiklius, 2007–2009 m. Irano Karaj sėklų ir augalų tyrinėjimo institute vykdytas išskaidytų laukelių bandymas trimis pakartojimais. Buvo drėkinama keturiais lygiais: drėkinimas 80 mm išgarinus iš A klasės dirvožemio sluoksnio (kontrolinis variantas); nuo stiebo augimo, žydėjimo ir ankštarų formavimosi tarpsnių pirmosios bei antrosios eilės laukeliuose, auginant šešių veislių ‘Licord’, SLMO64, ‘Okapi’, ‘Orient’, ‘Zarfam’ ir ‘Opera’ rapsus, drėkinimas nebuvo taikomas. Tyrimų rezultatai parodė, kad esant visiems streso lygiams didžiausiu vidutiniu produktyvumu, geometriniu vidutiniu produktyvumu ir atsparumu stresui pasižymėjo veislė ‘Okapi’, o jautriausia ir neatspariausia stresui buvo veislė ‘Opera’. Stipri ir teigiama koreliacija tarp geometrinio vidutinio produktyvumo, atsparumo stresui bei vidutinio produktyvumo ir derliaus esant optimalioms bei sausros sąlygoms parodė, kad šie indeksai geriausiai identifikavo sausrai atsparias veisles. Drėgmės streso indeksų vertinimas parodė, kad geometrinio vidutinio produktyvumo, jautrumo stresui ir vidutinio produktyvumo indeksai yra tinkamiausi nustatant sausrai atsparesnius genotipus. Remiantis šiais rodikliais, sausrai atspariausios buvo veislės ‘Okapi’ ir ‘Opera’. Šie indeksai gali būti naudojami rapsų selekcinėse programose, siekiant nustatyti sausrai atsparias veisles.

Reikšminiai žodžiai: rapsai, drėgmės stresas, drėkinimas, jautrumo ir atsparumo stresui indeksas.