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The effect of drought stress on qualitative and quantitative traits of spring rapeseed (*Brassica napus* L.) cultivars

Amir Hossein SHIRANI RAD[1], Peiman ZANDI[2]

[1]Seed and Plant Improvement Institute
Karaj, Iran
E-mail: shirani.rad@gmail.com

[2]Islamic Azad University, Takestan Branch
Takestan, Iran
E-mail: z_rice_b@yahoo.com

Abstract

In order to evaluate spring rapeseed (*Brassica napus* L.) cultivars subjected to drought stress, the experiments were laid out as a randomized complete block design with split-plot arrangement (4 replications), during 2008–2009 and 2009–2010 cropping seasons at Seed and Plant Improvement Institute of Karaj, Iran. In this research the main factors, allotted to the main plots, consisted of two irrigation regimes including normal irrigation (I) during the total growing period based on 80 mm evaporation from class A pan and water deficit stress (S) as ceased irrigation since the flowering stage until full maturity. Subplots, which consisted of split plots, were devoted to twenty spring rapeseed cultivars. Water deficit stress, caused reduction in plant height, branch plant^{-1}, siliqua plant^{-1}, seed siliqua^{-1}, 1000-seed weight, seed yield, biological yield, oil content, and oil yield while it did not affect harvest index significantly. Correlation coefficient analysis revealed that number of siliquae per plant had the highest correlation with seed yield (r = 0.65, P < 0.01) as compared with other yield components. Among cultivars, 'Hyola 401' (hybrid) produced the highest seed yield (4588 kg ha^{-1}) under normal irrigation, and RGS003 had the maximum seed yield (3577 kg ha^{-1}) and stress tolerance index (STI = 0.952) under water deficit stress conditions. 'Quantum' with the least seed yield in both irrigation patterns (I – 3492 kg ha^{-1} and S – 2948 kg ha^{-1}) and low STI (0.601) had the highest susceptibility to water deficit stress. Based on the result of this study, it can be concluded that RGS003 cultivar had better capability to tolerate drought stress and could produce greater seed yield under stress conditions.

Keywords: *Brassica napus*, water deficit stress, stress tolerance index, seed yield.

Introduction

Rapeseed (*Brassica napus* L.) is one of the most important oilseeds both in Iran and throughout the world with drought stress being one of the main limiting factors of its growth and production in Iran (Moradshahi et al., 2004). Usually, water deficit stress has detrimental effects on many processes in plants, which include reducing photosynthesis, accumulation of dry matter, stomatal exchanges, and protein synthesis that affect their growth stages (Larcher, 2003; Ohashi et al., 2006). Generally, plants respond to water deficit stress through developmental, biochemical and physiological changes and the type of the observed response depends on several factors such as stress intensity (SI), stress duration and genotype (Moradshahi et al., 2004). Nasri et al. (2008) observed that applying drought stress caused a significant reduction in the number of siliquae per plant, the number of seeds per siliqua, 1000-seed weight, seed yield, the seed oil content, and the oil yield of five rapeseed cultivars. Results from experiments conducted by Sinaki et al. (2007) revealed that water deficit stress during the flowering stage until the maturity of 29 rapeseed cultivars resulted in the reduction of seed yield, the biological yield, and the number of siliquae per plant; however, the number of seeds per siliqua was not affected. Also, Zakirullah et al. (2000) observed that under water stress conditions, the number of branches per plant, the number of siliquae in the main stem and the number of seeds per siliqua of drought-sensitive rapeseed lines had a sharp drop, while in drought-tolerant lines this reduction was not significant. The study of Behmaram et al. (2006) on the evaluation of the drought tolerance of spring rapeseed cultivars indicated that the stress tolerance index (STI) could have a better use for evaluating the drought tolerance than the SSI (stress susceptibility index) and TOL (tolerance index). Naeemi et al. (2008), based on stress evaluation indices at the end of growing season, reported that, with consideration of the positive and significant correlation of STI, GMP (geometric mean productivity) and MP (mean productivity) indices with seed yield under desirable and stress conditions, these indices were recognized as suitable criteria for identifying drought stress-tolerant rapeseed cultivars. In fact, identification of drought-tolerant cultivars and developing them are among the main economic goals in the regions where water is considered a limiting factor and the study of morphological and agronomical adaptations of rapeseed to water deficit stress could lead to identifying and developing stress-tolerant cultivars. Concerning the importance of oilseeds cultivation, especially rapeseed in Iran in addition to the growing trend of its cultivated land and limited water resources in the country, this study was undertaken with the purpose of identifying drought-tolerant rapeseed cultivars based on their morphological and agronomical traits and one of the most frequently used drought tolerance indices.

Materials and methods

Site description and soil type. This study was undertaken at the experimental farm of Seed and Plant Improvement Institute, Karaj, Iran (latitude 35°59′ N, longitude 50°75′ E, elevation 1315 m above mean sea level) during the periods 2008–2009 and 2009–2010. This region has a semi-arid climate (354 mm annual rainfall). The climate data of region are demonstrated in Table 1. The soil of the experimental site was a clay loam, with montmorillonite clay mineral, low in nitrogen (0.07–0.08%), low in organic matter (0.44%), alkaline in reaction, phosphorus and potassium content of 3.3 and 175 mg kg^{-1}, respectively, with a pH of 7.8 and EC = 1.70 mmhos cm^{-1}.

Table 1. Meteorological conditions in the experimental period

Month	Year	Average temperature °C minimum	Average temperature °C maximum	Total rainfall mm
October	2008	17.23	22.1	10
	2009	16.58	23.13	8.1
November	2008	10.5	17.13	11.6
	2009	11.7	18.63	37.11
December	2008	7	12.35	26.3
	2009	8	14.45	25.1
January	2009	3.96	10	16.7
	2010	7.55	12.58	21.71
February	2009	7.5	11.38	48.11
	2010	6.31	10.93	47.2
March	2009	8.13	13.93	5.9
	2010	7.6	11.76	33
April	2009	8.76	13.56	46.5
	2010	11	15.33	64.6
May	2009	16	21.13	19.9
	2010	16	21	13.1

Note. Taken from the recording of Irrigation Department in Seed and Plant Improvement Institute.

Agronomic practices. Individual experimental plot consisted of 6 rows, 5 m long and a row spacing of 30 cm using a seeding rate of 7 kg ha^{-1}. The experimental fields were mould-board ploughed and seedbed preparation comprised two passes with a tandem disk. Seeds were planted 1 to 1.5 cm deep at a rate of 100 seeds m^{-2} on 4 October 2008 and 2009. For all treatments, the crop was supplied with the fertilizers at a rate of $N_{150}P_{60}K_{50}$. Nitrogen fertilizer was used in three splits. The first application (1/3 of the total rate) was incorporated and added to soil as the starter fertilizer together with P, K fertilizer (in total rate) at the time of pre-sowing and the second application (2/3 of the total rate) 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. Proper management practices were adopted throughout the growing seasons to ensure good crop growth. Final harvests were carried out on 10 June 2009 and 25 June 2010.

Experimental design and evaluated treatments. The field experiment was split plot based on randomized complete block design (RCBD) with four replications. Two irrigation levels consisting of irrigation after 80 mm evaporation from class A pan as control (I – irrigation during full season) and stopping irrigation from the flowering stage (code 4.5) until the physiological maturity (code 6.9) as water deficit stress (S) were applied in main plots (Sylvester-Bradley, Makepeace, 1984). Subplots which consisted of split application of new spring rapeseed cultivars at 20 levels (‘Sarigol’, ‘Goliath’, ‘Heros’, ‘Comet’, ‘Amica’, SW5001, ‘Cracker Jack’, ‘Eagle’, ‘Wild cat’, ‘SW hot shot’, ‘Ogla’, 19-H, ‘Hyola 401’, ‘Hyola 60’, RGS006, ‘Hyola 420’, RGS003, ‘Option 500’, ‘Hyola 308’ and ‘Quantum’), regarding their reputed differences in yield performance under irrigated and non-irrigated conditions. In each irrigation treatment, 100% of the evaporated water (800 m^3 ha^{-1}) entered the field. The amount of 720 l plot^{-1} water was utilized for the area of each experimental plot (9 m^2). In non-stressed condition (normal irrigation), the number of irrigation applications and amount of irrigation water given over the total growing season were 9 times and 7200 m^3 ha^{-1}, respectively; whereas under non-irrigated condition (water deficit stress), they were 6 times and 4800 m^3 ha^{-1}, respectively. Therefore, compared to the normal conditions, in stress conditions 2400 m^3 ha^{-1} smaller amount of water was applied.

Estimation of traits. At maturity, ten random samples were hand harvested from each experimental unit and the following parameters were determined: plant height, number of branches per plant, number of siliquae per plant, and number of seeds per siliqua (with at least one seed). Main stem length was measured as the plant height. Numbers of siliquae per plant and seeds per siliqua were counted from 50 randomly selected siliquae after hand threshing. The seed yield was measured by harvesting 4.8 m^2 of the central part of each plot at crop full maturity (physiological maturity). The crop was harvested manually in each plot separately and tied into bundles. The bundles were left in the field for drying until constant weight (12% moisture content). The sun-dried bundles were weighed using a precise scale and their biological (aboveground) yields were calculated as kg ha^{-1}. Eight samples of 100 seeds were taken from each seed lot of the experimental units and then weighed. Their average multiplied by 10 recorded 1000-seed weight (TSW). Economic yield divided by biological yield multiplied with 100 gave harvest index (HI) in percent. Oil content was determined by the nuclear magnetic resonance (NMR) in the oilseed research lab of Seed and Plant Improvement Institute, Karaj, Iran. Oil yield was computed multiplying seed yield by oil content. Drought resistance index was calculated applying the following relationship:

(1) Stress tolerance index (STI) = $(Y_p \times Y_s) / (\bar{Y}_p)^2$ (Fernandez, 1993),

where Y_p is the yield of cultivar under irrigated condition (I), Y_s – the yield of cultivar under water deficit stress (S), $\bar{Y}_p$ – the mean yield of all cultivars under non-stress conditions.

Statistical analysis. Data were subjected to analysis of variance (*ANOVA*), using the *SAS* software package and SPSS program for correlation parameter (SAS System, 1996). Duncan’s multiple range test ($P < 0.05$) was applied for mean separation when F values were significant.

Results and discussion

During our investigation, the combined analysis of variance showed that the seed yield and its components including 1000-seed weight, number of siliquae per plant, and number of seeds per siliqua were drastically affected by years of study. This might be attributed to the considerable rainfall increase in the second year of the experiment, especially from March until April (Tables 1 and 2). However, the seed yield was not influenced by year × irrigation as well as year × cultivar interactions.

It is also evident from the data that irrigation had a highly significant effect ($P < 0.01$) on the plant height, number of branches per plant, number of siliquae per plant, number of seeds per siliqua, 1000-seed weight, seed yield, biological yield, oil content, and oil yield; however, the harvest index was not affected by irrigation (Table 2). In terms of the majority of the agronomic traits, except for the biological yield and the harvest index, there was a significant difference between the studied cultivars ($P < 0.01$). Also, the interaction effect of irrigation and cultivar on the number of branches per plant and the number of siliquae per plant was highly significant at the probability level of 1% (Table 2). Usually, fluctuations of plant height are the most conspicuous characteristic of genetic conditions and environmental changes in most plants. In this experiment, the highest plant height (122 cm) was that of normal irrigation (I) treatment, while applying water deficit stress caused the plant height to decrease by 9.4% (Table 3). Reduction in the plant height due to water deficit stress is probably related to decline in photosynthetic products as a result of soil moisture decrease which eventually causes the plant not to reach its genetic potential. Other researchers such as Sadaqat et al. (2003) have also reported a significant decrease in the stem height of rapeseed cultivars under water stress conditions. Among the studied cultivars, 'Amica' and 'SW hot shot' had the highest (136.6 cm) and lowest (99.7 cm) plant height, respectively. Indeed, the mentioned difference between spring rapeseed cultivars in terms of this trait could be caused by their genetic differences (Asgari, Moradi Dalini, 2007).

Table 2. The mean squares of *ANOVA* for plant height, branch plant^{-1}, siliqua plant^{-1}, seed siliqua^{-1}, 1000-seed weight, seed yield, biological yield, oil content, oil yield and harvest index in combined analysis of 2008–2009 and 2009–2010 data

Source of variation	df	Plant height	Branch plant^{-1}	Siliqua plant^{-1}	Seed siliqua^{-1}	1000-seed weight	Seed yield	Biological yield	Oil content	Oil yield	Harvest index
Y	1	53.80ns	34.51**	3385678.1*	79.80**	0.911**	10315397.9*	996574402**	271.5**	786804ns	1200.7*
E_a	6	120.26	0.68	9845.4	30.34	0.197	989814.4	30068334	24.0	270375	86.3
I	1	10593.69**	96.03**	957370.3**	561.80**	11.457**	72588216.9**	1023327847**	119.2**	18617092**	1.6ns
YI	1	210.61ns	0.79ns	388905.1ns	10.15*	0.596**	101527.6ns	3705636ns	2.4**	12305ns	0.9ns
E_b	6	38.64	1.034	6588.9	1.52	0.034	1326731.8	7681995	6.9	215365	88.1
C	19	1431.47**	4.18**	14516.3**	113.75**	1.203**	837496.8**	7669052ns	11.7**	214457**	19.7ns
YC	19	680.80**	3.54ns	18692.5**	90.66**	0.165**	370783.1ns	4522842ns	3.4**	94007ns	22.5ns
IC	19	78.65ns	1.353**	33258.2**	3.70ns	0.052ns	275163.1ns	2596271ns	2.4ns	61475ns	16.4ns
YIC	19	77.07ns	0.987*	27137.9**	4.85ns	0.033ns	226570.3ns	2209513ns	4.1ns	57565ns	21.4ns
Error	228	63.42	0.553	4120.8	4.42	0.065	418280.1	5571228	3.5	89682	14.4
CV (%)	–	6.85	14.72	23.71	10.34	6.34	17.66	16.67	4.09	17.77	14.43

Notes. * – $P < 0.05$, ** – $P < 0.01$, ns – $P > 0.05$; df – degrees of freedom, Y – year effect, I – irrigation effect, C – cultivar effect; E_a – $Error_a$ = rep(Y), E_b – $Error_b$ = rep(YI); YI, YC, IC, YIC represent interaction terms between the treatment factors.

Table 3. Means for plant height (PH), branch plant^{-1} (BP^{-1}), siliqua plant^{-1} (SP^{-1}), seed siliqua^{-1} (SS^{-1}), 1000-seed weight (TSW), seed yield (SY), oil content (OC), oil yield (OY), harvest index (HI) as affected by irrigation treatments in combined analysis of 2008–2009 and 2009–2010 data

Treatments	PH cm	BP^{-1}	SP^{-1}	SS^{-1}	TSW g	SY kg h^{-1}	OC %	OY kg h^{-1}	HI %
Irrigation									
I	122.0 a	5.6 a	325.4 a	21.7 a	4.2 a	4138 a	46.6 a	1927 a	26.4 a
S	110.5 b	4.5 b	216.0 b	19.0 b	3.9 b	3185 b	45.4 b	1444 b	26.3 a
Cultivar									
'Sarigol'	123.8 cd	5.4 bcd	217.9 f	20.8 c	3.9 c-f	3453 cd	46.3 a-f	1604 a-d	25.4 ab
'Goliath'	108.3 h	5.2 cde	297.1 abc	18.3 f	3.9 c-f	3730 a-d	45.1 efg	1685 a-d	28.3 a
'Heros'	118.4 def	5.0 cde	242.5 def	22.5 b	3.9 def	3711 a-d	47.7 a	1770 ab	26.7 a
'Comet'	118.5 def	4.4 fg	301.0 ab	18.2 f	3.8 d-g	3608 a-d	45.4 d-g	1635 a-d	26.9 a
'Amica'	136.6 a	6.1 a	287.2 a-d	25.4 a	3.9 c-f	3932 abc	45. 9 b-f	1804 ab	28.1 a
SW5001	101.8 i	5.1 cde	310.6 ab	17.3 fg	3.9 b-e	3702 a-d	46.0 b-f	1701 abc	25.7 ab
'Cracker Jack'	122.8 cde	5.4 bcd	229.2 ef	20.4 c	3.7 fg	3681 a-d	45.8 b-f	1680 a-d	25.5 ab
'Eagle'	109.4 gh	5.0 cde	313 ab	18.7 def	3.9 c-f	3671 a-d	46.4 a-f	1704 abc	26.5 ab
'Wild cat'	117.5 def	5.5 bc	237.8 def	21.1 bc	3.8 efg	3488 bcd	45.9 b-f	1599 a-d	26.3 ab
'SW hot shot'	99.7 i	4.9 def	288.6 a-d	17.2 fg	3.9 b-e	3563 a-d	46.8 a-d	1668 a-d	25.9 ab
'Ogla'	130.1 b	5.2 cde	243.2 def	20.1 cd	4.0 bcd	3394 cd	46.1 b-f	1565 bcd	25.3 ab
19-H	116.7 ef	5.2 cde	321.6 a	20.0 cde	4.1 bc	4023 ab	45.5 c-g	1827 a	27.1 a
'Hyola 401'	115.1 fg	5.1 cde	241.9 def	21.6 bc	4.5 a	3858 abc	46.6 a-e	1798 ab	26.5 ab
'Hyola 60'	101.1 i	4.6 efg	261.1 b-f	17.8 f	4.5 a	3542 a-d	46.0 b-f	1626 a-d	27.6 a
RGS006	114.8 fg	5.4 bcd	261.1 b-f	24.4 a	4.5 a	3640 a-d	46.1 b-f	1675 a-d	26.7 a
'Hyola 420'	120.6 c-f	4.4 fg	273.4 a-e	21.6 bc	4.1 b	3922 abc	47.0 abc	1853 a	26.2 ab
RGS003	118.5 def	5.3 bcd	281.4 a-e	24.7 a	4.4 a	4068 a	45.2 efg	1839 a	26.7 a
'Option 500'	117.4 def	4.1 g	274.0 a-e	15.8 g	4.5 a	3726 a-d	47.4 ab	1766 ab	27.3 a
'Hyola 308'	108.8 h	5.8 ab	246.8 c-f	22.5 b	3.7 g	3290 d	44.1 g	1458 cd	25.4 ab
'Quantum'	125.0 bc	4.1 g	285.1 a-d	18.5 ef	4.0 b-e	3220 d	44.9 fg	1450 d	23.4 b

Notes. I – normal irrigation (irrigation after 80 mm evaporation from class A pan during full season), S – water deficit stress (stopping irrigation from the flowering until full maturity stage); means in each column followed by the different letters are significantly different ($P < 0.05$) according to Duncan test.

In this study, decreased soil moisture resulted in the reduced number of branches per plant from 5.6 in the control treatment to 4.5 in the water deficit treatment (Table 3). The desired number of branches in the unit of surface is closely related to the soil moisture regime during the plant growth period (Ardell et al., 2001). Reduced number of branches during the shortage of soil moisture has been reported earlier (Sadaqat et al., 2003; Naeemi et al., 2007).

In the present research, the largest and fewest numbers of branches per plant were those of 'Amica' (6.1) and 'Quantum' (4.1), respectively (Table 3). Also, the study of irrigation × cultivar interaction on the number of branches per plant indicated that in both irrigation treatments, 'Amica' was superior to other cultivars, while 'Option 500' under normal irrigation conditions and 'Quantum' under water deficit stress conditions produced the fewest number of branches per plant (Table 4).

Table 4. Means for branch plant^{-1} (BP^{-1}), siliqua plant^{-1} (SP^{-1}), seed siliqua^{-1} (SS^{-1}), 1000-seed weight (TSW), seed yield (SY) as affected by irrigation treatments in combined analysis of 2008–2009 and 2009–2010 data

Cultivars	BP^{-1}		SP^{-1}		SS^{-1}		TSW g		SY kg h^{-1}	
	I	S	I	S	I	S	I	S	I	S
'Sarigol'	5.6 b-h	5.2 d-i	238.1 f-i	197.8 ghi	22.65 c-f	18.90 h-l	4.14 d-h	3.65 l-o	3922 a-f	2984 hi
'Goliath'	5.9 a-e	4.4 i-l	411.8 a	182.4 hi	19.41 g-k	17.21 k-n	4.01 f-k	3.77 k-n	4085 a-e	3375 e-i
'Heros'	5.3 b-i	4.8 g-l	255.3 e-h	229.8 f-i	23.36 b-e	21.55 d-g	4.08 e-j	3.61 l-o	4174 a-d	3248 f-i
'Comet'	5.3 b-i	3.5 m	393.1 ab	208.9 ghi	19.76 g-j	16.58 l-o	4.05 e-k	3.58 mno	4179 a-d	3037 hi
'Amica'	6.5 a	5.7 a-g	299.9 c-f	274.4 d-g	26.74 a	24.11 bc	4.00 f-k	3.80 j-n	4520 a	3344 e-i
SW5001	5.4 a-f	4.4 i-l	423.8 a	197.4 ghi	18.46 i-m	16.23 mno	4.11 d-i	3.77 k-n	3967 a-f	3436 d-i
'Cracker Jack'	5.6 a-h	5.2 d-i	240.1 fgh	218.3 ghi	22.39 c-f	18.45 i-m	3.90 g-l	3.54 no	4237 abc	3126 ghi
'Eagle'	5.9 a-d	4.2 j-m	430.6 a	195.4 ghi	19.41 g-k	17.92 j-n	4.01 f-k	3.76 k-n	4083 a-e	3260 f-i
'Wild cat'	5.7 a-f	5.3 c-i	253.7 e-h	221.8 f-i	22.63 c-f	19.56 g-k	3.90 g-l	3.67 l-o	3863 a-g	3114 ghi
'SW hot shot'	5.7 a-f	4.0 klm	359.0 abc	218.3 ghi	18.48 i-m	15.90 n-o	4.11 f-i	3.76 k-n	4091 a-e	3035 hi
'Ogla'	5.7 a-f	4.7 h-l	254.2 e-h	232.3 f-i	22.56 c-f	17.69 j-n	4.19 d-g	3.84 h-n	3898 a-g	2891 hi
19-H	6.2 ab	4.2 j-m	429.3 a	213.9 ghi	21.70 c-g	18.35 i-n	4.23 def	3.91 g-l	4543 a	3504 c-i
'Hyola 401'	5.4 b-h	4.9 f-k	253.1 e-h	230.8 f-i	23.59 b-e	19.65 g-k	4.62 ab	4.34 cde	4588 a	3127 ghi
'Hyola 60'	5.3 b-i	4.0 l-m	325.9 b-e	196.3 ghi	18.85 h-l	16.70 l-o	4.66 ab	4.32 c-f	4117 a-e	2967 hi
RGS006	5.6 a-h	5.2 d-i	271.5 d-g	250.8 e-h	25.52 ab	23.34 b-e	4.79 a	4.26 c-f	3828 a-g	3452 d-i
'Hyola 420'	5.2 d-i	3.5 m	338.8 bcd	208.0 ghi	22.52 c-f	20.66 f-i	4.40 bcd	3.83 i-n	4470 a	3375 e-i
RGS003	5.6 b-h	5.1 d-i	297.6 c-f	265.2 efg	25.19 ab	24.13 bc	4.54 abc	4.18 d-g	4558 a	3577 b-h
'Option 500'	4.9 f-j	3.4 m	366.6 abc	181.3 hi	17.15 k-n	14.54 o	4.63 ab	4.27 c-f	4315 ab	3137 ghi
'Hyola 308'	6.2 ab	5.4 b-h	256.2 e-h	237.4 f-i	23.75 b-d	21.25 e-h	3.86 h-m	3.43 o	3820 a-g	2761 i
'Quantum'	5.0 e-j	3.3 m	410.2 a	160.0 i	19.33 g-k	17.74 j-n	4.26 c-f	3.64 l-o	3492 c-i	2948 hi

Note. Explanations under Table 3.

The number of siliquae per plant is the most important component of the seed yield in rapeseed (Angadi et al., 2003). In this experiment, the largest number of siliquae per plant (325) was obtained from the normal irrigation and water deficit stress caused a 37% decrease in the said trait compared with the former treatment (Table 3). Furthermore, Daneshmand et al. (2008) reported a 59% decrease in the number of siliquae per plant in rapeseed cultivars exposed to water deficit stress. As a whole, among the seed yield components of the said plant, the number of siliquae per plant showed the highest sensitivity to water deficit stress. Moreover, the exposure to this stress in the flowering and siliqua formation stages resulted in a considerable reduction in the number of siliquae per plant through more severe flower and siliqua abscissions (Sinaki et al., 2007). Usually, when water deficit stress is applied after the flowering stage, it causes the number of siliquae per plant to reduce by shortening the flowering period, the reproductive growth duration, and finally the infertility of some flowers and their abscission (Wright et al., 1996). Among the studied cultivars, 19-H and 'Sarigol' produced the largest and fewest numbers of siliquae per plant, respectively which was due to their genetic potentials (Table 3). In terms of this trait, the cultivars showed different reactions to irrigation levels so that in the normal irrigation 'Eagle' and 19-H and in the water deficit stress 'Amica' and RGS003 produced the largest number of siliquae per plant (Table 4). In this regard, Zakirullah et al. (2000) reported that under water stress conditions, lines of drought-sensitive rapeseeds experienced a sharp drop in the number of siliquae in the main stem; while, in drought-tolerant lines, the reduction was much less. In addition, in the present research, 'Amica' and RGS003 with the largest numbers of siliquae per plant under stress conditions reduced their siliquae less than those of the control irrigation (I) treatment as compared with other cultivars, which was quite a desirable result.

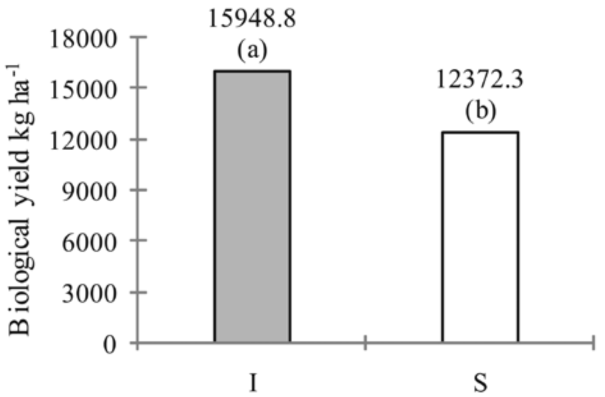
Generally, the number of seeds per siliqua and the TSW are the constituting components of the seed yield in rapeseed (Angadi et al., 2003). Mean comparison results showed that the normal irrigation treatment led to the largest number of seeds per siliqua (21.7) and applying water deficit stress caused a 12% reduction in this trait (Table 3). In an experiment by Daneshmand et al. (2008), it was revealed that the shortage of soil moisture in the water deficit stress treatment declined the number of seeds per siliqua from 25.6 seeds in the control treatment to 21.1 seeds in the water deficit stress treatment. Occurrence of drought stress during the flowering and fertilization stages increased siliqua seedlessness due to insufficient fertility and flower abscission and as a result, it reduced the number of seeds per siliqua. In this research, the largest numbers of seeds per siliqua were those of 'Amica' and RGS003; however, the fewest belonged to 'Option 500' (Table 3). It has been found that the ability of different rapeseed genotypes to form seeds inside siliquae is different and the number of seeds per siliqua is affected by genetic factors (Rao, Mendham, 1991).

Moreover, TSW is one of the most important determining factors of seed yield and the existence of large seeds that filled well, caused this yield to increase.

The highest and lowest weight for TSW is related to the normal irrigation (4.22 g) and water deficit stress (3.85 g) treatments respectively, which showed a significant difference (Table 3). Results of the present experiment in this regard were consistent with those of the earlier researchers (Sadaqat et al., 2003; Sinaki et al., 2007; Nasri et al., 2008). Probably, water deficit stress through disrupting the plant photosynthesis, decreased assimilates synthesis which is necessary for seed filling, and consequently it resulted in seed shrinkage and weight loss. Based on the results given in Table 3, 'Hyola 401', 'Hyola 60' and RGS006 along with 'Option 500' and RGS003 had the highest seed weights, while 'Hyola 308' (hybrid) had the lowest. Our results indicated several reductions in the number of siliquae per plant (37%), the number of seeds per siliqua (12%), and TSW (9%) due to water deficit stress which tended to decline in the seed yield from 4137.5 kg ha^{-1} to 3184.9 kg ha^{-1}. This finding was consistent with the reports of Zakirullah et al. (2000) and Sinaki et al. (2007). Among the studied cultivars, RGS003 with a mean value of 4068 kg ha^{-1} and 'Quantum' with a mean value of 3220 kg ha^{-1} produced the highest and lowest seed yields, respectively (Table 3). In addition, RGS003 due to having a large number of seeds per siliqua and a high TSW had the highest seed yield, while 'Quantum' due to having the fewest number of branches per plant, the fewest number of seeds per siliqua, and a lower TSW had the lowest seed yield (Table 3). Means comparison of the seed yield showed that in the plots under normal irrigation conditions, although 'Hyola 401' (hybrid) had the fewest number of siliquae per plant, by having a high TSW; it produced the highest seed yield among the studied cultivars (Table 4). Also, of the studied cultivars, RGS003 by producing the largest number of seeds per siliqua and a high TSW along with 19-H due to its having the largest number of siliquae per plant, had a high and similar yield compared with the 'Hyola 401' (hybrid). On the other hand, in the normal irrigation treatment, despite producing the largest number of siliquae per plant, 'Quantum' had the lowest seed yield among the studied cultivars. In the water deficit stress (S) treatment, RGS003 with larger number of siliquae per plant, seeds per siliqua, and a higher TSW than other cultivars produced a much higher seed yield, while the 'Hyola 308' (hybrid) had the lowest seed yield among the studied cultivars (Table 4). In general, the reaction of crops and their evaluation for an optimum yield under different environmental conditions depend on their ability to use the said conditions. This would be possible through regulating yield components and the interaction of genotype with the environment when desirable and undesirable conditions occur in each stage of plant growth and development (Entz, Flower, 1990).

In this research, the highest biological yield was obtained from the normal irrigation (15948 kg ha^{-1}), while water deficit stress led to a 22% decrease in the said trait (Fig. 1). Also, in a study conducted by Faraji et al. (2009) the dry land farming (without irrigation) treatment resulted in a 21% reduction of the dry matter in rapeseed cultivars as compared with the normal irrigation treatment. Moreover, the effect of cultivar on the biological yield was not significant (Table 2).

The results indicated that there was a positive and highly significant correlation among seed yield in both stressed (Y_s) and non-stressed (Y_p) conditions with STI (Figs 2 and 3). Farshadfar et al. (2001) believed that the most appropriate index for selecting stress-tolerant cultivars is an index which has partly high correlation with seed yield under stress and non-stress conditions. The observed relations coincided with those reported by Fernandez (1993) on mungbean, Farshadfar and Sutka (2002) on maize, Golabadi et al. (2006) on durum wheat and Shirani Rad and Abbasian on rapeseed (2011). The significant and positive correlation of STI with Y_p (r = 0.087, $P < 0.001$) and Y_s ($r = 0.086$, $P < 0.001$) showed that this criteria index was effective in identifying high-yielding cultivars under different moisture conditions. STI has been earlier found effective in identifying cultivars that perform well under both stress and non-stress conditions (Fernandez, 1993; Porch, 2006). A higher STI value is an indicator of higher tolerance to drought stress (Fernandez, 1993). Based on this index, RGS003 and 19-H were identified as superlative and 'Quantum' and 'Hyola 308' (hybrid) as the weakest cultivars in respect to drought stress tolerance (Table 5).



Note. Means not sharing a common letter (a, b) are significantly different ($P < 0.05$).

Figure 1. Effect of irrigation patterns (I – normal irrigation and S – water deficit stress) on biological yield

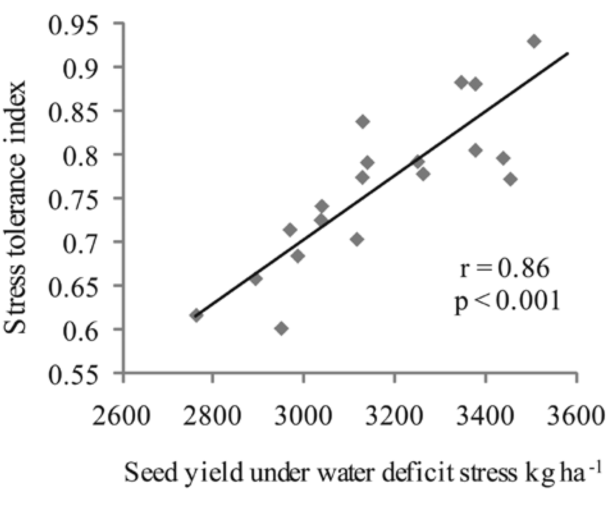


Figure 2. The relationship between seed yield under water deficit stress conditions (Y_s) and stress tolerance index (STI) (n = 20)

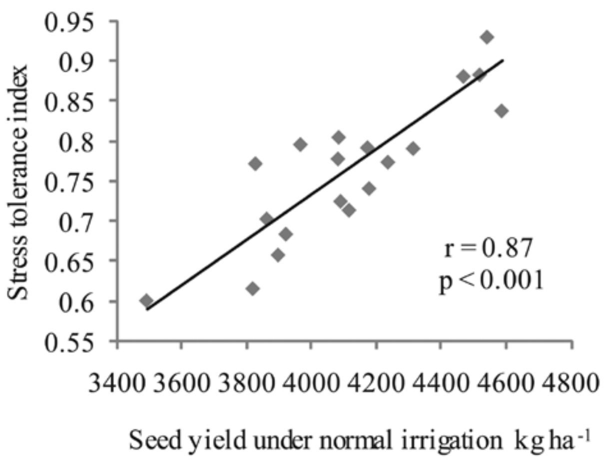


Figure 3. The relationship between seed yield under normal irrigation conditions (Y_p) and stress tolerance index (STI) (n = 20)

In this study, applying water deficit stress reduced the seed oil percentage (oil content) and the oil yield by 2.6% and 25%, respectively in comparison with the normal irrigation treatment (Table 3), which was in conformity with the results of Naeemi et al. (2007). Obtained results showed that the seed oil yield in comparison with the oil content was more affected by the shortage of soil moisture, which had been caused by a much more control of the oil content over genetic factors and the oil yield being more affected by the seed yield variations relative to the oil content.

The results of simple correlation between oil yield, oil content, and seed yield in Table 6 revealed that oil yield was highly correlated with the seed yield (r = 0.99, P < 0.01) in comparison with the oil content (r = 0.66, P < 0.01) which was consistent with the results of this research. Furthermore, Valadiyani and Tajbakhsh (2007) reported that advanced rapeseed cultivars had a higher oil yield in terms of seed yield. Of all the studied cultivars, the highest and lowest oil content percentages were related to 'Heros' (47.56%) and the 'Hyola 308' (hybrid) (44.13%) respectively; while, the 'Hyola 420' (hybrid) and RGS003 due to their high seed yields had the highest oil yields as well (Table 3).

Table 5. Evaluation of spring rapeseed cultivars with stress tolerance index (STI)

Cultivars	Origin	STI	Cultivars	Origin	STI
'Goliath'	Denmark	0.805	19-H	Pakistan	0.930
'Heros'	Germany	0.792	'Hyola 60'	Australia	0.714
'Eagle'	Sweden	0.778	RGS006	Germany	0.772
'Wild cat'	Sweden	0.703	'Hyola 308'	Canada	0.616
'Comet'	Italy	0.741	'Quantum'	Canada	0.601
'Amica'	Germany	0.883	RGS003	Germany	0.952
SW5001	Sweden	0.796	'Hyola 420'	Canada	0.881
'Cracker Jack'	Sweden	0.774	'Option 500'	Germany	0.791
'SW hot shot'	Sweden	0.725	'Sarigol'	Germany	0.684
'Ogla'	Germany	0.658	'Hyola 401'	Canada	0.838

Note. Higher values of STI for a cultivar indicate greater stress tolerance and higher yield potential.

Table 6. A matrix of simple correlation coefficients (r) for the estimated traits in rapeseed cultivars

Trait	PH	BP^{-1}	SP^{-1}	SS^{-1}	TSW	SY	BY	OC	OY	HI
PH	1	0.491**	0.334*	0.599**	0.208ns	0.483**	0.533**	0.300 ns	0.485**	−0.033ns
BP^{-1}		1	0.612**	0.669**	0.249ns	0.639**	0.635**	0.267 ns	0.619**	0.128ns
SP^{-1}			1	0.178ns	0.418**	0.652**	0.689**	0.403**	0.651**	0.026ns
SS^{-1}				1	0.283ns	0.523**	0.507**	0.139ns	0.498**	0.130ns
TSW					1	0.610**	0.560**	0.502**	0.627**	0.203ns
SY						1	0.933**	0.565**	0.992**	0.337*
BY							1	0.495**	0.922**	−0.001ns
OC								1	0.661**	0.114ns
OY									1	0.323*
HI										1

Notes. PH – plant height, BP^{-1} – branch plant^{-1}, SP^{-1} – siliqua plant^{-1}, SS^{-1} – seed siliqua^{-1}, TSW – 1000-seed weight, SY – seed yield, BY – biological yield, OC – oil content, OY – oil yield, HI – harvest index; ns – not significant, * – P < 0.05, ** – P < 0.01.

Harvest index is one of the main physiological indexes and a criterion for the mobilization efficiency of assimilates produced in plants to the seeds. In this research, harvest index showed non-significant difference between normal irrigation and water deficit stress treatments (Table 3), the reason of which was the plant biomass affected by the latter treatment; however, this sharp drop was equal to the reduction occurred in the plant's reproductive organs. In other words, the effect of water deficit stress on the seed and biological yield was the same. Moreover, in terms of the harvest index, the studied cultivars did not differ significantly (Table 3). The results in Table 6 revealed that, among the seed yield components, the number of siliquae per plant was highly correlated with the seed yield (r = 0.65, P < 0.01); while the lowest positive and significant correlation was that of the number of seeds per siliqua (r = 0.52, P < 0.01) and was less important among the seed yield components of rapeseed. These results are consistent with those of Angadi et al. (2003).

Conclusion

The present study indicated that RGS003 due to having a large number of seeds per siliqua and a high 1000-seed weight (TSW) had the highest seed yield (3577 kg ha^{-1}) and stress tolerance index (STI) (0.952) among the water-deficit assessed cultivars. However, in the normal irrigation, 'Hyola 401' (hybrid) owing to its relatively large number of seeds per siliqua and a high TSW, produced the highest seed yield (4588 kg ha^{-1}). On the other hand, RGS003 in addition to tolerating the water deficit stress had a high genetic potential for producing seed yield under normal irrigation conditions. Also, 'Quantum' which had the lowest seed yield (3492 kg ha^{-1}) in the normal irrigation, a low yield under water deficit stress (2948 kg ha^{-1}) and a low STI (0.601) was identified as a cultivar with the highest sensitivity to water deficit stress.

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Sausros sukelto streso įtaka vasarinio rapso (*Brassica napus* L.) veislių kokybinėms ir kiekybinėms savybėms

A. H. Shirani Rad[1], P. Zandi[2]

[1]Karaj sėklų ir augalų tyrimo institutas, Iranas
[2]Irano islamiškojo Azado universiteto Takestano filialas

Santrauka

2008–2009 ir 2009–2010 m. vegetacijos laikotarpiais Karaj sėklų ir augalų tyrimo institute (Iranas) atlikti tyrimai, siekiant įvertinti vasarinio rapso (*Brassica napus* L.) 20 veislių atsaką į sausros sukeltą stresą. Bandymas įrengtas taikant išskaidytų laukelių atsitiktinių blokų schemą, keturiais pakartojimais. Svarbiausius veiksnius, tyrinėtus pagrindiniuose laukeliuose, sudarė du drėkinimo režimai – normalus drėkinimas (I) visą vegetacijos laikotarpį, paremtas 80 mm išgaravimu iš A klasės podirvinio klodo, ir drėgmės trūkumo sukeltas stresas (S), kai nebuvo drėkinta nuo žydėjimo iki pilnos brandos tarpsnio. Dėl drėgmės trūkumo sukelto streso sumažėjo augalų aukštis, šakų ir ankštarų skaičius ant augalo, sėklų skaičius ankštaroje, 1000-čio sėklų masė, biologinis ir sėklų derliai, aliejingumas bei aliejaus derlius, tačiau šis stresas esmingai nepaveikė derliaus indekso. Koreliacijos koeficientų analizė parodė, kad ankštarų skaičius ant augalo labiausiai koreliavo su sėklų derliumi ($r = 0{,}65$, $P < 0{,}01$), palyginti su kitais derliaus komponentais. Esant normaliam drėkinimui, hibridinės veislės 'Hyola 401' rapsai davė didžiausią sėklų derlių (4588 kg ha^{-1}), o esant drėgmės streso sąlygoms didžiausią derlių (3577 kg ha^{-1}) davė ir didžiausią streso tolerancijos indeksą (STI = 0,952) turėjo veislės RGS003 rapsai. Veislės 'Quantum' rapsai davė mažiausią sėklų derlių esant abiem drėkinimo sąlygoms (I – 3492 kg ha^{-1} bei S – 2948 kg ha^{-1}), turėjo mažiausią STI (0,601) ir buvo jautriausi drėgmės trūkumo sukeltam stresui. Remiantis tyrimų rezultatais galima daryti išvadą, kad veislės RGS003 rapsai geba geriau toleruoti sausros sukeltą stresą ir esant drėgmės streso sąlygoms gali duoti didesnį sėklų derlių.

Reikšminiai žodžiai: *Brassica napus*, drėgmės trūkumo sukeltas stresas, streso tolerancijos indeksas, sėklų derlius.