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Response of agronomic characteristics of oilseed rape (*Brassica napus* L.) to drought stress

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Abstract
Climate change may contribute to drought stress and limit crop production. The oilseed rape (*Brassica napus* L.) cultivation area has declined due to drought stress. Identification of high-yielding and tolerant varieties could be regarded as a solution to this problem. Twelve oilseed rape genotypes were planted under drought stress and normal conditions in Lishtar, Gachsaran, Iran, using a randomized complete block design with three replications in 2017. A considerable decline in the pods per plant (76%), pod length (20%), grain yield (80%), biomass (73%), harvest index (37%), plant height (34%), seeds per pod (41%) and branches per plant (41%) of genotypes was observed in the evaluated genotypes of the oilseed rape as the consequence of drought stress. In general, grain yield, biomass, and pods per plant had a very high sensitivity to moisture reduction. The significant direct effect of the pod number and 1000-seed weight on the grain yield showed that these characteristics can be used to select the promising genotypes to increase the grain yield of oilseed rape under normal conditions. Under drought stress conditions, branch number per plant, pod length, and seeds per pod had a significant direct effect on grain yield. Increasing these traits and reducing the plant height and shortening the growth period may improve the grain yield of the oilseed rape. Hyola401, RGS003, and Hyola308, showed the highest grain yield under both drought stress and normal conditions among the evaluated oilseed rape genotypes. They may be regarded as the promising varieties to be planted in the conditions of the experimental site or similar areas.

Keywords: Direct effect; Drought; Oilseed rape; Path analysis

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Introduction

Climate changes and warm temperatures may contribute to drought by making periods with low precipitation and enhancing evaporation from the soil. High temperature and drought are the main factors leading to the difference between the potential and actual yield of crops. Seed yield is affected by several genetic and environmental factors, complicating the selection of desired plant genotypes (Clarke *et al.* 1992). Identification of stress-tolerant and early maturing genotypes is regarded as practical solution for climate change. This can be achieved by understanding the physiological basis of plants` response to stress conditions (Blum 2017).

Water deficit can reduce plant height and branch number per plant in oilseed rape cultivars (Shirani Rad *et al.* 2010). Drought stress in the reproductive stage decreases the pods per plant (Nielsen 1997; Shirani Rad *et al.* 2010), seeds per pod (Nielsen 1997; Shirani Rad *et al.* 2010), seed weight (Nielsen 1997; Shirani Rad *et al.* 2010), grain yield (Shirani Rad *et al.* 2010) and biomass (Shirani Rad *et al.* 2010) of oilseed rape.

Selection for grain yield in plants could be conducted by indirect selection for its components. Path analysis can be used to understand the importance of the direct and indirect effects of these components (Wright 1934). A significant direct effect of the number of pods per plant and the branch number per plant on the grain yield of oilseed rape was observed using the path analysis (Hashemi *et al.* 2010). In another study, the number of pods per plant, the number of primary branches, and the number of pods per the main raceme (stem) had the highest direct effects on the grain yield per plant in oilseed rape (Lu *et al.* 2011).

This study aimed to determine the effects of drought stress on different characteristics of oilseed rape, identify the contribution of most critical characteristics to grain yield under normal and drought conditions, and recognize drought-tolerant cultivars.

Materials and Methods

In this experiment 12 oilseed rape genotypes were planted during the 2016-2017 growing season in Lishtar with UTM: 454297, 3367430-39R, Gachsaran, Kohgilouyeh and BoyerAhmad province, Iran under drought stress (rainfed) and normal (well-watered) conditions separately. The experimental design in each condition was a randomized complete block design with three replications. Plots were prepared in five rows of 4 meters in length with a 30 cm distance between the rows, and a 5 cm space between plants in rows. Strip irrigation and rainfed (dryland farming) conditions were used for the normal and stress experiments, respectively. Genotypes were planted in both experiments after the first adequate precipitation in November 2016 (Table 1).

Characteristics measurement

The early growth vigor was recorded observationally from one (Min. growth) to nine (Max.) at the 4-leaf growth stage, based on the plant height and canopy. From each plot, 10 plants were randomly selected, and plant height, pod length, branch number per plant, pods per plant, and seeds per pod were recorded. Grain yield and biomass of each plot were measured for an area of two m^2.

Correlation coefficients and path analysis

Pearson correlation coefficients were calculated among the characteristics for both drought stress and normal conditions. Direct and indirect effects of yield components on grain yield were also calculated in both conditions by path analysis. using the IBM SPSS Amos (Version 23).

Data analysis

IBM SPSS (Version 23) statistical software was used for data analysis. Duncan's multiple range test at the 0.05 probability level of significance was used for means comparison. The combined analysis of variance was used to analyze the data of the two experiments after Bartlett's test assessment. Path analysis was carried out using the IBM SPSS Amos (Version 23) software.

Results and Discussion

Comparing genotypes under normal and drought stress conditions

In normal conditions, genotypes were significantly different in the plant height, branch number, pod length, seeds per pod, 1000-seed weight, days to flowering, days to maturity, grain yield, growth vigor, harvest index, and canopy temperature (Table 2). The genotypes were not significantly different in pod number, oil and protein percentage, biomass, and SPAD index in normal conditions. The highest grain yield in normal conditions belonged to Hyola308, Hyola401, and RGS003 genotypes, which were only significantly different from Okapi, Opera, and SLM-046 among other genotypes (Table 2). These three

Table 1. Rainfall (mm) distribution in the experimental site in 2016- 2017

October	November	December	January	February	March	April	May	Total effective rainfall (> 5 mm)
20	39.5	110	3	7	70	47	6	299.5

Table 2. Means of the oilseed rape genotypes for the studied traits under normal conditions

Genotypes	Plant height (cm)	Branch number	Pod number	Pod length	Seed per pod	Oil (%)	Protein (%)	1000-seed weight	Days to flowering
Zarfam	160.8 abc	7 b	186 a	5.9 cd	19 abc	30.8 a	16.1 a	2.57 bc	129 cd
SLM-046	168.3 ab	6 b	135 a	5.4 cde	15 bc	28.5 a	15.8 a	2.43 bc	153 b
RGS003	124.5de	15 a	217 a	6.9 ab	22 bc	29.0 a	14.4 a	3.00 abc	100 e
Karaj3	157.2 a-d	7 ab	188 a	5.2 cde	17 abc	27.0 a	14.2 a	2.33 c	145 b
Opera	132.4 cde	7 ab	134 a	4.9 de	12 c	27.7 a	15.1 a	3.03 abc	169 a
Karaj2	162.1 abc	9 ab	178 a	5.7 cd	18 abc	29.9 a	14.3 a	2.90 abc	142 bc
Hyola401	108.1 e	12 ab	165 a	7.3 a	25 a	28.5 a	16.1 a	3.70 a	91 e
Sarigol	135.7 b-e	9 ab	205 a	6.1 bc	20 abc	31.5 a	15.0 a	2.60 bc	124 d
NAFIS	172.7 a	8 ab	175 a	5.6 cd	15 bc	30.1 a	14.3 a	2.43 bc	150 b
Okapi	129.9 cde	8 ab	82 a	4.5 e	12 ca	31.6 a	16.2 a	2.33 c	169 a
Hyola308	117.8 e	9 ab	211 a	7.6 a	28 a	28.6 a	15.8 a	2.90 abc	90 e
Modena/q3	162.7 abc	7 ab	192 a	5.5 cde	15 bc	29.6 a	15.3 a	3.23 ab	144 b

Means with at least one common letter in each column are not significantly different based on Duncan's multiple range test at the 5% probability level

Table 2 Continued

Genotypes	Days to maturity	Biomass (kg ha^{-1})	Yield (kg ha^{-1})	Harvest index (%)	Growth vigor	Canopy temperature	SPAD
Zarfam	162 c	8733.3 a	1686.7 ab	19.3 a-d	5 ab	25.2 ab	50.0 a
SLM-046	185 ab	6891.7 a	610.4 bc	8.8 ef	8 a	26.5 a	53.0 a
RGS003	132 d	10975.0 a	2460.2 a	23.2 abc	8 a	23.0 ab	44.4 a
Karaj3	181 b	7550.0 a	1338.5 ab	17.7 bcd	7 a	23.3 ab	48.1 a
Opera	190 ab	5075.0 a	312.0 cd	7.0 ef	1 b	23.0 ab	47.8 a
Karaj2	183 ab	9000.0 a	1017.0 abc	12.1de	8 a	23.2 ab	53.0 a
Hyola401	131 d	8783.3 a	2671.3 a	30.7 ab	8 a	20.6 b	47.1 a
Sarigol	157 c	7066.7 a	1855.5 ab	26.7 ab	8 a	23.4 ab	47.5 a
NAFIS	183 ab	8108.3 a	842.7 abc	10.5 de	7 a	24.0 ab	54.9 a
Okapi	194 a	5375.0 a	115.7 d	2.4 f	6 a	24.2 ab	53.1 a
Hyola308	127 d	8533.3 a	2711.6 a	31.8 a	8 a	21.3 b	46.0 a
Modena/q3	182 ab	7841.7 a	1059.9 abc	13.5 cde	6 a	22.7 ab	54.8 a
CV (%)	2.64	3.16	6.44	4.52	20.39	7.26	7.76

Means with at least one common letter in each column are not significantly different based on Duncan's multiple range test at the 5% probability level

genotypes also had high branch number, pod length, seeds per pod, 1000-seed weight, biomass, harvest index, and growth vigor, and low plant height, days to flowering, and days to maturity. However, they were not significantly different from some other genotypes concerning these characteristics (Table 2).

There were significant differences among the genotypes under drought stress conditions based on the plant height, branch number, pod length, seeds per pod, 1000-seed weight, days to flowering, days to maturity, biomass, grain yield, harvest index, growth vigor, and the SPAD index. The genotypes were not significantly different for pod number, seed oil and protein percent, and canopy temperature (Table 3). Under drought stress conditions Zarfam had the highest grain yield followed by Hyola401, RGS003,

Table 3. Means of the oilseed rape genotypes for the studied traits under drought stress conditions

Genotypes	Height (cm)	Branch number	Pod number	Pod length (mm)	Seed per pod	Oil (%)	Protein (%)	1000- seed weight(g)	Days to flowering
Zarfam	97.5 ab	6 ab	68 a	bcd	13 abc	31.3 a	14.2 a	2.1 b	150 abc
SLM-046	86.6 ab	4 ab	15 a	3.7 abc	5 cd	31.3 a	15.7 a	2.1 b	165 ab
RGS003	67.9 b	5 ab	57 a	6.0 abc	14 abc	28.6 a	15.0 a	2.0 b	120 cde
Karaj3	104.2 ab	5 ab	22 a	3.5 d	5 cd	28.2 a	14.0 a	2.4 b	158 ab
Opera	71.4 ab	3 b	15 a	3.6 cd	4 d	29.7 a	14.3 a	2.5 ab	170 a
Karaj2	98.1 ab	5 ab	44 a	4.0 bcd	9 a-d	27.8 a	15.0 a	2.1 b	166 ab
Hyola401	64.8 b	8 ab	55 a	5.9 a-d	18 ab	29.0 a	15.2 a	3.5 a	106 de
Sarigol	120.2 a	10 a	82 a	6.1 ab	14 abc	28.3 a	15.5 a	1.9 b	136 bcd
Nafis	103.3 ab	6 ab	37 a	3.7 bcd	6 cd	28.8 a	14.5 a	2.1 b	167ab
Okapi	70.4 ab	2 b	11 a	4.6 a-d	8 bcd	28.5 a	14.9 a	2.4 ab	154 ab
Hyola308	56.8 b	3 b	34 a	6.4 a	21 a	30.2 a	15.1 a	2.8 ab	96 e
Modena/q3	92.2 ab	4 ab	55 a	4.5 a-d	11 a-d	30.1 a	14.4 a	2.6 ab	162 ab
CV (%)	19.59	5.40	22.85	17.53	5.44	4.47	7.98	15.12	7.75

Means with at least one common letter in each column are not significantly different based on Duncan's multiple range test at the 5% probability level

Table 3 Continued

Genotypes	Days to maturity	Biomass (kg ha^{-1})	Yield (kg ha^{-1})	Harvest index (%)	Growth vigor	Canopy temperature	SPAD
Zarfam	170 ab	2683.3 ab	533.3 a	12.4 abc	6 ab	24.9 a	49.2 abc
SLM-046	181 a	1291.7 bc	76.9 c	6.1 bc	7 ab	25.2 a	51.5 abc
RGS003	147 bcd	2875.0 ab	409.3 a	15.8 ab	6 ab	22.8 a	44.8 bc
Karaj3	186 a	2458.3 ab	109.1 c	4.6 c	9 a	25.4 a	56.3 a
Opera	188 a	883.3 c	89.1 c	11.9 abc	2 b	26.1 a	52.4 ab
Karaj2	185 a	1533.3 abc	100.7 c	7.2 bc	8 a	25.5 a	53.0 ab
Hyola401	140 cd	3416.7 ab	444.6 a	17.0 ab	7 ab	23.3 a	55.7 a
Sarigol	159 abc	3433.3 a	370.7 a	13.0 abc	6 ab	23.4 a	43.5 c
Nafis	187 a	1475.0 bc	102.3 c	8.7 abc	6 ab	25.3 a	49.7 abc
Okapi	173 ab	1591.7 abc	62.7 c	4.5 c	6 ab	23.8 a	52.5 ab
Hyola308	126 d	1808.3 abc	342.8 ab	20.1 a	6 ab	22.5 a	45.1 bc
Modena/q3	183 a	2183.3 abc	141.9 bc	6.6 bc	8 a	24.1 a	49.9 abc
CV (%)	5.80	4.32	10.26	5.97	26.55	7.96	5.89

Means with at least one common letter in each column are not significantly different based on Duncan's multiple range test at the 5% probability level

Sarigol, and Hayola308. The variety Hayola308 had the highest pod length (6.4 cm), followed by Sarigol, RGS003, and Hyola401. Hayola308 and Hyola401 also highest seeds per plant, 1000-seed weight, and harvest index, and also the lowest plant height, days to flowering, and days to maturity. The highest branch number and biomass belonged to Sarigol and Hyola401. The variety Hyola401 also had the highest SDAD value under drought stress conditions (Table 3).

Combined analysis of variance

The main effect of irrigation regimes was significant on plant height, branch number per plant, pod number, pod length, seeds per pod, oil percent, 100-seed weight, days to flowering, biomass, grain yield, and harvest index. Nevertheless, there was no significant difference between irrigation conditions for protein percent, days to maturity, early growth vigor, canopy temperature, and SPAD index (Table 4). A sharp decline in pods per plant (76%), and pod length (about 20%) was seen under drought stress conditions as compared to normal conditions. In addition, the number of seeds per pod was reduced (41%) due to drought stress. The reduction in seeds per pod may be related to the decline in pod length

Table 4. The mean comparison of irrigation conditions for the studied traits of the oilseed rape

Drought	Height (cm)	Branch number	Pod number	Pod length (mm)	Seed per pod	Oil (%)	Protein (%)	1000- seed weight (g)	Days to flowering
Normal	144.35a	8.67a	172.35a	5.88a	18.17a	29.40a	15.20a	2.79a	133.83b
Drought tress	86.12b	5.08b	41.38b	4.73b	10.72b	29.33b	14.81a	2.37b	145.92a

Means with at least one common letter in each column are not significantly different based on Duncan's multiple range test at the 5% probability level

Table 4 Continued

Drought	Days to maturity	Biomass (kg ha^{-1})	Yield (kg ha^{-1})	Harvest index (%)	Growth vigor	Canopy temperature	SPAD
Normal	167.33a	7827.8a	1390.1a	16.96a	6.7a	23.4a	49.98a
Drought tress	168.64a	2136.1b	277.68b	10.7b	6.6a	24.4a	50.30a

Means with at least one common letter in each column are not significantly different based on Duncan's multiple range test at the 5% probability level

due to drought stress. Kalantar Ahmadi *et al.* (2015) also reported a decline in pods per plant and seeds per pod under limited water deficit stress. Under drought stress conditions, the grain yield and biomass of genotypes decreased significantly by 80 and 73%, respectively. The harvest index also decreased by 37% under the drought stress. In addition, plant height was significantly reduced (34%) under drought stress conditions. Jensen *et al.* (1996) reported grain yield reduction under high evaporative demand in oilseed rape. Shirani Rad *et al.* (2010) reported such declines in the grain yield and plant height due to the adverse effect of terminal drought stress on the oilseed rape genotypes under study. The severity of the decline in the above-mentioned characteristics indicates that the environmental conditions affect these traits, leading to their lower heritability. Also, a 41% decrease in the branch number per plant due to stress conditions indicates the high sensitivity of the studied genotypes to environmental conditions. Shabani *et al.* (2010) and Shirani Rad *et al.* (2010) observed a decline in the number of branches per plant under water-deficit stress conditions. Also, the 1000-seed weight of the genotypes in the drought stress conditions was significantly lower (15%) than that in the normal conditions (Table 4). Similar results were reported by Kalantar Ahmadi *et al.* (2015).

According to the combined analysis of variance, there were significant differences among the rapeseed genotypes for the plant height, branch number per plant, pod number per plant, pod length, seeds per pod, 100-seed weight, biomass, and early growth vigor in the average of two irrigation conditions (Table 5). The shortest plant height belonged to Hyola401and Hyola308. The varieties Hyola308 and Hyola401 had the highest number of seeds per pod. Hyola401 also showed the highest 1000-seed weight followed by Modena/q3, Hyola308, and Opera. The highest number of branches per plant (about 10) belonged to the RGS003, Hyola401, and Sarigol genotypes. RGS003 and Sarigol also showed the highest pods per plant. In terms of pod length, Hyola308, Hyola401, RGS003, and Sarigol had higher values than other oilseed rape genotypes, averaged over the two irrigation conditions. The biomass of RGS003 and Hyola401 was highest among the tested oilseed rape genotypes (Table 5).

The genotype × environment interaction was not significant for any of the evaluated characteristics

Table 5. Mean comparison of oilseed rape genotypes for the studied traits based on the results of the combined analysis of variance

Genotypes	Height (cm)	Branch number	Pod number	Pod length (mm)	Seed per pod	Protein (%)	1000-seed weight (g)	Biomass (kg ha^{-1})	Growth Vigor
Zarfam	129.2ab	6.2abc	127.0ab	5.4bcd	16.0b-e	15.1a	2.3ab	5708.3ab	5.7a
SLM-046	127.4abc	5.3abc	74.7ab	4.5d	10.2fg	15.8a	2.3ab	4091.7abc	7.3 a
RGS003	96.2d	9.8a	136.9a	6.5ab	18.0abc	14.7a	2.5ab	6925.0a	7.0 a
Karaj3	130.7ab	6.2abc	105.3ab	4.4d	11.2d-g	14.1a	2.4ab	5004.2ab	8.0 a
Opera	101.9bcd	5.0bc	74.7ab	4.2d	7.8g	14.7a	2.8ab	2979.2c	1.7b
Karaj2	130.1ab	7.0abc	111.0ab	4.8cd	13.7c-f	14.6a	2.5ab	5266.7ab	8.0 a
Hyola401	86.5d	9.8a	110.2ab	6.6ab	21.8ab	15.6a	3.6ab	6100.0a	7.7 a
Sarigol	128.0abc	9.7ca	143.5a	6.1abc	16.8a-d	15.2a	2.2b	5250.0ab	7.0 a
Nafis	138.0a	7.0abc	106.2ab	4.6d	10.2fg	14.4a	2.3b	4791.7abc	6.7 a
Okapi	100.2cd	4.8c	46.7b	4.5d	10.0fg	15.5a	2.4ab	3483.3bc	6.3 a
Hyola308	87.3d	6.0abc	122.6ab	7.0a	24.5a	15.5a	2.8ab	5170.8ab	7.3 a
Modena/q3	127.5abc	5.7abc	123.7ab	5.0cd	13.2c-g	14.9a	2.9a	5012.5ab	7.0 a

Means with at least one common letter in each column are not significantly different based on Duncan's multiple range test at the 5% probability level

indicating that the differences among the oilseed rape genotypes under the conditions of this experiment were mainly stable in normal and drought-stress environments.

Correlation coefficients

Under both normal and drought stress conditions, a positive and significant correlation of grain yield with the pod number, pod length, seeds per pod, harvest index, and biomass was observed. However, there was a significant negative relationship between yield and the number of days to flowering and maturity under both conditions (Table 6). The correlation coefficients of grain yield with the branch number and SPAD index were only significant under normal conditions. Grain yield did not significantly correlate with plant height, early growth vigor, and 1000-seed weight under both conditions. Plant height did not significantly correlate with the grain yield and biomass in both the drought stress and normal conditions. Perhaps the reason behind the lack of such a significant correlation was the growth habit of oilseed rape and its high branching habit. Diepenbrock (2000) in a review paper concluded that oilseed rape yield is a function of plant density and pods per plant. He also indicated that seed number per pod has a positive correlation with pod length and suggested that pod length can be useful for indirect selection of the grain yield in plant breeding. According to Hashemi *et al.* (2010), the number of branches per plant, pods per plant, and pod length had significant correlations with the grain yield in oilseed rape. Also, Lu *et al.* (2011) reported that the number of primary branches, number of pods on the main raceme, and number of seeds per pod made significant contributions to seed yield per plant. The relationship of seed weight with the grain yield is not stable in oilseed rape. In our experiment, there was no significant correlation between grain yield and 1000-seed weight. However, Hashemi *et al.* (2010) observed a significant positive correlation between these traits in an F2 population, while Lu *et al.* (2011) and Marjanović-Jeromela *et al.* (2011) reported a negative correlation between seed weight and grain yield per plant. It seems that the relationship of the seed weight with the grain yield depends on several factors such as the type of germplasm and environmental conditions.

Table 6. Correlation coefficients among the oilseed rape traits under normal (above diagonal) and drought stress (below diagonal) conditions

Trait	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1		-0.62*	-0.01	-0.55	-0.54	-0.53	0.58*	0.67*	-0.06	-0.55	-0.54	-0.08	-0.38	0.75**
2	0.56		0.42	0.67*	0.58*	0.53	-0.70*	-0.73**	0.67*	0.67*	0.55	0.40	-0.01	-0.61*
3	0.38	0.75**		0.67*	0.67*	0.25	-0.69*	-0.63*	0.75**	0.75**	0.74**	0.37	-0.41	-0.44
4	-0.34	0.36	0.60*		0.96**	0.56	-0.98**	-0.97**	0.72**	0.95**	0.91**	0.56	-0.28	-0.62*
5	-0.40	0.28	0.57	0.93**		0.46	-0.97**	-0.94**	0.68*	0.96**	0.95**	0.60*	-0.16	-0.65*
6	-0.62*	-0.09	-0.15	0.24	0.43		-0.53	-0.52	0.34	0.49	0.46	0.02	-0.27	-0.31
7	0.54	-0.24	-0.36	-0.91**	-0.92**	-0.49		0.98**	-0.74**	-0.99**	-0.95**	-0.59*	0.22	0.67*
8	0.56	-0.20	-0.36	-0.93**	-0.93**	-0.42	0.99**		-0.67*	-0.97**	-0.93**	-0.48	0.14	0.76**
9	0.19	0.77**	0.79**	0.68*	0.61*	0.15	-0.58*	-0.53		0.74**	0.60*	0.57	-0.41	-0.31
10	-0.12	0.54	0.74**	0.74**	0.75**	0.19	-0.69*	-0.68*	0.78**		0.97**	0.54	-0.19	-0.71**
11	-0.49	0.25	0.44	0.81**	0.81**	0.35	-0.85**	-0.86**	0.41	0.73**		0.50	-0.18	-0.71**
12	0.36	0.25	0.17	-0.02	0.11	-0.03	-0.04	0.02	0.34	-0.03	-0.35		-0.23	-0.04
13	-0.28	-0.55	-0.80**	-0.60*	-0.46	0.41	0.33	0.38	-0.64*	-0.56	-0.29	-0.24		-0.42
14	-0.04	-0.18	-0.52	-0.64*	-0.47	0.45	0.39	0.48	-0.24	-0.36	-0.52	0.23	0.70*	

Traits: 1) Plant height, 2) Branch number, 3) Pod number, 4) Pod length, 5) Seeds per Pod, 6) 1000-seed weight, 7) Days to flowering 8) Days to maturity, 9) Biomass, 10) Seed yield, 11) Harvest index, 12) Growth vigor, 13) Canopy temperature (before flowering), and 14) SPAD index; *, and **: significant at the 0.05 and 0.01 probability levels, respectively

Path coefficients analysis

As shown in Figures 1 and 2, path coefficients determine the relationship between yield and the other evaluated characteristics directly or indirectly. Under normal conditions, the direct effects of pod number and 1000-seed weight on grain yield were significant (0.201 and 0.112, respectively) (Figure 1). However, the correlation coefficient of 1000-seed weight on grain yield (0.49) was not significant but that of pod number with grain yield (0.75) was significant (Table 6). Although the branch number per plant in normal conditions showed a positive and significant coefficient correlation (0.67) with grain yield (Table6), the direct effect of this characteristic on grain yield was only 0.126 and was not statistically significant (Figure 1). It seems that the pod number per plant and 1000-seed weight were the components of the grain yield in oilseed rape under normal conditions in this study, however, they exert some of their effects indirectly through other characteristics.

Under drought stress conditions, the direct and indirect effects of the traits with grain yield were different from the normal conditions (Figures 1 and 2). The pod number per plant has had a non-significant direct effect (0.025) on the grain yield, a different situation from normal conditions. So, the existence of a correlation between two variables does not necessarily mean that there is a cause and effect relationship between the two variables and the selection based on correlation coefficients can lead to an inefficient selection strategy (Vu *et al.* 2019).

Unlike normal conditions, seeds per pod, pod length, and branch number showed significant direct effects on the grain yield under drought stress conditions (Figure 2) and were regarded as the major contributing traits to the grain yield of oilseed rape when drought was imposed. In other words, when seeds per pod, pod length, and branch number go up by one standardized unit, the grain yield goes up by 0.382, 0.344, and 0.286 standard units, respectively,

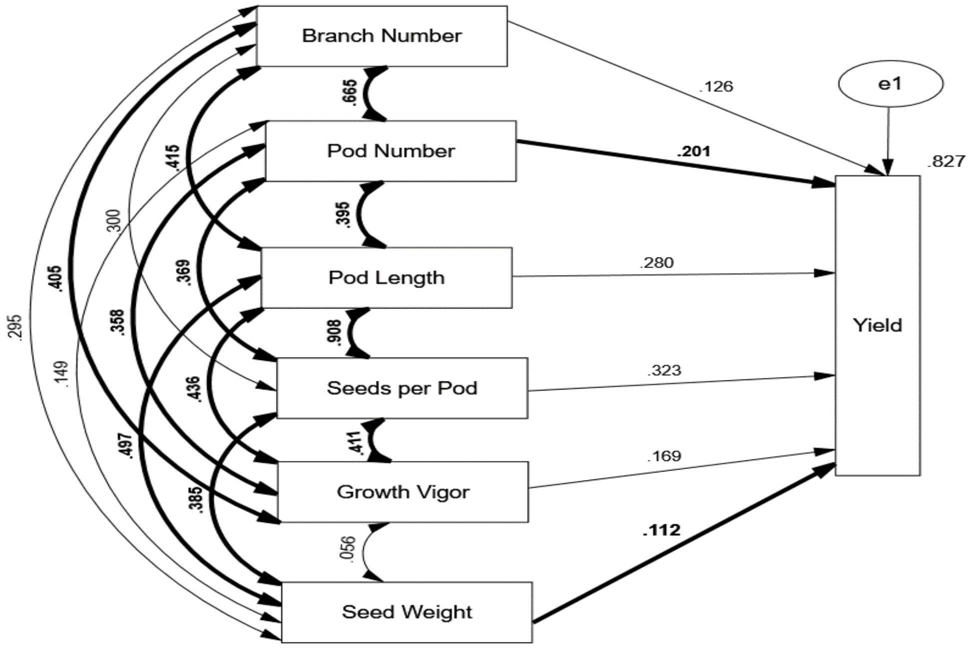

Figure 1. The interrelationship between the studied characters of the oilseed rape (double-headed arrows indicate simple correlations, and single-headed arrows indicate direct effects) using path analysis under normal conditions (boldface arrows are significant at $p \leq 0.05$)

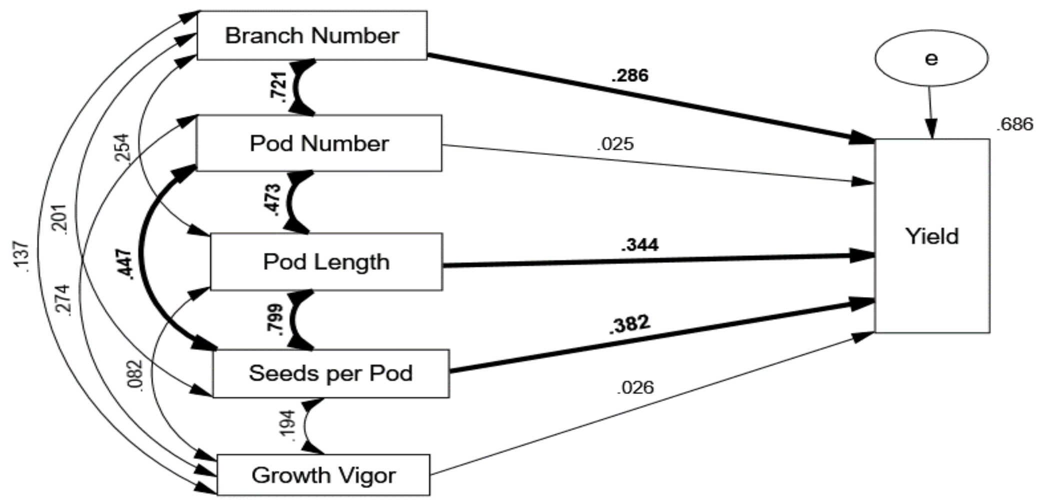

Figure 2. The interrelationship between the studied characters of the oilseed rape (double-headed arrows indicate correlations, and single-headed arrows indicate direct effects) using path analysis under drought stress conditions (boldface arrows are significant at $p \leq 0.05$)

in addition to any indirect effect of these characteristics on grain yield (Kline 2005). Indirect selection will not be better than direct selection unless the correlation between the traits is strong, and the narrow-sense heritability of the unselected characteristic is not higher than that of the selected one. Therefore, indirect selection should not be used unless the preferred trait is complicated or expensive to assess or is sex-limited (Kearsey and Pooni 1998).

Conclusion

In general, grain yield, biomass, and pods per plant had a very high sensitivity to moisture reduction, while early growth vigor did not decrease significantly. The slight decrease in the early growth vigor is due to the absence of stress on plants at this growth stage. Also, drought stress decreased plant height, branch number, pod length, seeds per pod, oil percentage, 1000-seed weight, and harvest index of the oilseed rape genotypes in this study. Therefore, drought has a detrimental effect on the grain yield of the oilseed rape, and breeding for drought-tolerance varieties can alleviate part of the negative effects of the drought on this plant.

The direct effect of the pod number and 1000-seed weight on the grain yield showed that these characteristics could be used to select the promising genotypes to increase the yield of oilseed rape under normal conditions. Under drought-stress conditions, more branch numbers per plant, pod length, and seeds per pod could be considered to select for the high-yielding oilseed rape genotypes. Based on the conditions of this study, increasing these traits and reducing the plant height and shortening the growth period are recommended to improve grain yield in oilseed rape, especially under drought stress conditions.

Hyola401, RGS003, and Hyola308, had the highest grain yield among the evaluated oilseed rape genotypes in both drought stress and normal conditions and may be suitable to use under the conditions of the experimental site and other similar areas.

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Conflict of Interest

The authors declare that they have no conflict of interest with any organization concerning the subject of the manuscript.

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واکنش ویژگی‌های زراعی کلزا (*Brassica napus* L.) به تنش خشکی

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چکیده

تغییرات آب و هوایی ممکن است موجب تنش خشکی شود و تولید محصول را محدود کند. سطح کشت کلزا (*Brassica napus* L.) به دلیل تنش خشکی کاهش یافته است. شناسایی ارقام پرمحصول و متحمل می‌تواند به عنوان راه حلی برای رفع این مشکل در نظر گرفته شود. دوازده ژنوتیپ کلزا تحت شرایط تنش خشکی و نرمال در لیشتر گچساران در قالب طرح بلوک‌های کامل تصادفی با سه تکرار در سال ۱۳۹۶ کشت شدند. کاهش قابل توجه تعداد خورجین در بوته (۷۶٪)، طول خورجین (۲۰٪). عملکرد دانه (۸۰٪)، بیوماس (۷۳٪)، شاخص برداشت (۳۷٪)، ارتفاع بوته (۳۴٪)، تعداد دانه در خورجین (۴۱٪) و تعداد شاخه در بوته (۴۱٪) در ژنوتیپ‌های مورد ارزیابی کلزا به عنوان پیامد تنش خشکی مشاهده شد. به طور کلی عملکرد دانه، بیوماس و تعداد خورجین در بوته حساسیت بسیار بالایی به کاهش رطوبت داشتند. اثر مستقیم معنی‌دار تعداد خورجین در بوته و وزن هزار دانه بر عملکرد دانه نشان داد که از این ویژگی‌ها می‌توان برای انتخاب ژنوتیپ‌های امید بخش برای افزایش عملکرد دانه کلزا در شرایط نرمال استفاده کرد. در شرایط تنش خشکی، تعداد شاخه در بوته، طول خورجین و تعداد دانه در خورجین اثر مستقیم معنی‌داری بر عملکرد دانه داشتند. افزایش این صفات و کاهش ارتفاع بوته و کوتاه کردن دوره رشد می‌تواند باعث بهبود عملکرد دانه کلزا شود. Hyola401، RGS003 و Hyola308 بالاترین عملکرد دانه را در هر دو شرایط تنش خشکی و شرایط نرمال در بین ژنوتیپ‌های کلزای مورد ارزیابی نشان دادند و می‌توان آن‌ها را به عنوان واریته‌های مناسب برای کاشت در شرایط محل آزمایش یا مناطق مشابه در نظر گرفت.

واژه‌های کلیدی: اثر مستقیم؛ تجزیه علیت؛ خشکی؛ کلز