Agronomic Evaluation of Rapeseed Varieties (*Brassica napus* L.) in Response to Late-Season Water Deficit Stress

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Summary

Drought is a wide spread limiting problem seriously influencing rapeseed (*Brassica napus* L.) growth, production and quality, mostly in dryland regions. However, identification and development of resistant varieties is prohibited by destitute of effective selection criteria. The aim of this study was to evaluate the prevention possibility of rapeseed varieties against terminal-season water deficit stress through selecting suitable varieties. Thirty-four rapeseed varieties were tested in a split plot design based on randomized complete block design (RCBD) with four replications for two years (2005- 2006 and 2006-2007) at Seed and Plant Improvement Institute of Karaj, Iran. Two irrigation levels consisting of irrigation after 80 mm evaporation from class “A” pan during full growing season as normal irrigation (I) and water deficit stress (S) by restricting watering from the flowering phase until full maturity were established in main plots, and subplots were devoted to split application of varieties. Water deficit stress caused noticeable decrease in plant height, silique plant^{-1}, seed silique^{-1}, 1000-kernel weight, seed yield, oil percentage, oil yield and harvest index. There were significant positive correlations between seed yield and yield-related components. Meanwhile, the highest correlation was recorded for number of seeds per siliqua ($r= 0.64$; $P<0.01$), suggesting that late-season water deficit stress could be used in selecting drough tolerant varieties. Among varieties, ‘Sunday’ produced the highest seed yield (4938 kg ha^{-1}) and oil yield (2317 kg ha^{-1}) in normal irrigation, and ‘ORW20-3002’ had the highest seed yield (2348 kg ha^{-1}) and oil yield (1000 kg ha^{-1}) in water deficit stress conditions. Accordingly, ‘ORW20-3002’ and ‘Sunday’ can be reported as varieties with sustainable productivity in stress and non-stress conditions.

Key words

oil yield, rapeseed, seed yield , water deficit stress

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Introduction

Drought is one of the most widespread abiotic stresses experienced by crops, and it is becoming an increasingly severe problem in many regions of the world that can significantly affect plant yield in arid and semi-arid regions (Petcu et al., 2007; Petcu et al., 2009). However, in the areas with insufficient rainfall, regulated irrigation as a most efficient crop management measure can increase and stabilize crop yield (Chiriþã et al., 1999). Iran is generally considered as an arid country and its derivative draught stress is among the most important and common environmental stresses that have limited our agricultural production and have reduced the efficiency of using semi-arid regions (Moradshahi et al., 2004; Seyedmohammadi et al., 2013).

Rapeseed (*Brassica napus* L.) is a major oil-producing crop, and the global production of rapeseed oil was estimated to be over 64.3 million tons during 2012 to 2013, which is now the second leading source of the vegetable oil supply in the word (FAO, 2014). The ability of rapeseed in terms of germination, growth and development at low temperatures has placed this crop among the few oily seeds that are cultivable as an autumnal cultivation in temperate climates even in cold regions (Kimber and McGregor, 1995). Water deficit stress for the autumnal cultivation of rapeseed in cold and cold-temperate regions usually occurs during the late growth and development period (during late spring and early summer). It seems that the best way to cope with drought stress is application of suitable farming operations and use of cultivars that are more tolerant of drought (Ahmadi and Javidfar, 2000).

According to the latest research results, water deficit could have a deleterious effect on rapeseed; however, this effect depends on the genotype with higher water use efficiency (Petcu et al., 2009), the growth and development stage and the plant's adaptation to drought (Kimber and McGregor, 1995).

Generally, the number of siliqua per plant, number of seeds per siliqua and also seeds weight are considered the yield components of rapeseed (Angadiet al., 2003). As a whole, drought stress causes a significant decrease in the rapeseed yield (Jensen et al., 1996). Although water shortage reduces this yield in many development stages, the negative effects of stress during flowering and siliqua development are quite apparent (Sinaki et al., 2007). Water deficit stress in the flowering stage until the end of the seed filling period/ stage seriously affects the seed yield and its relevant components. Drought stress decreases the seed yield mainly through reducing the number of siliquae per plant (Pasban Eslam et al., 2000). It has been found that supplying enough water during flowering and early siliqua development stages, when the number of siliquae and seeds is determined, has a vital role (Ma et al., 2006). On the other hand, shortage of water in the flowering stage, due to its negative effect on siliqua formation and seed size, reduces the seed yield (Johnston et al., 2002). However, some researchers reported that under water deficit stress conditions, the seed size of this plant increases as a compensatory response to the decreased number of seeds and siliquae, which is accompanied by the increasing in the seeds' glucosinolate content (Jensen et al., 1996).

In a study conducted in Karaj region, it was observed that irrigation based on 50 mm evaporation from class A pan in rapeseed produced the highest seed yield. Increasing irrigation intervals from 100 mm up to 150 mm evaporation from class A pan showed a significant decrease in the seed yield and revealed that the most sensitive stages of plant growth in terms of water shortage are flowering and seed filling stages (Daneshmand et al., 2007). In a survey on the effect of soil moisture treatments in the early/ late vegetative growth and flowering stages of rapeseed cultivars showed that soil moisture stress significantly reduced the number of siliquae per plant, the number of seeds per siliqua and the seed yield. The lowest number of siliquae and seeds per siliqua of the plants exposed to stress were those of the flowering stage. Seed weight loss was also more noticeable in water stress treatments applied during late growth periods (Hashem et al., 1998). A study by Kajdi and Pocsai (1993) on the effects of irrigation on 21 rapeseed cultivars showed that, as irrigation frequency increased, the seed yield increased as well. Indeed, they noticed the high seed yield only in the cultivars with high levels of erucic acid and glucosinolate. Moreover, it has been reported that drought or heat stress during flowering and seed filling stages could stop the flowering and caused decrease of seed formation, oil percentage and the seed yield to decrease (Walton et al., 1999; Johnston et al., 2002).

Based on meteorological data collected over the last 10 years (data not shown), in Karaj and similar regions of Iran relatively good rainfalls occur in March, April and May and provide plant water requirements in the shoot-formation stage. In order to save more irrigation water for the last irrigations during flowering, siliqua formation and seed-filling stages that coincides with the early irrigations of spring farming and the lack of sufficient irrigation water for both spring and autumn cultivations, halt in irrigation in these stages causes three times of saving irrigation water compared with usual conditions. Therefore, with sporadic precipitations (April 21 to May 21) taken into consideration, stresses to which plants are exposed during these stages are not of severe ones. If cultivars could be selected in a way that produce an acceptable economic yield in less watering condition and are more stress tolerant under the stress intensity conditions, they would be practically very useful for developing rapeseed cultivation in such regions.

Considering the fact that water shortage endangers the development of cultivation areas and a successful production of rapeseed in the semi-arid areas, this research was conducted with the purpose to identify which rapeseed genotypes could produce the highest yield and the least amount of damage in regions with their drought stress at the end of the season.

Materials and methods

Site description and soil type

This study was laid out at the experimental farm of Seed and Plant Improvement Institute, Karaj, Iran (latitude 35°48′ N, longitude 50°57′ E, elevation 1321 m above mean sea level) during the periods of 2005–2006 and 2006–2007. This region has a semi-arid climate (243 mm mean annual rainfall over the past 30 years, mainly in late autumn and early spring) (Table 1). The soil of experimental site was clay loam, with montmorillionite 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)		Total rainfall (mm)	Average relative humidity (%)	
		minimum	maximum		minimum	maximum
October	2005	10.68	25.03	1.8	20	67
	2006	13.1	24.72	67.1	29	76
November	2005	4.2	14.06	28.5	34	73
	2006	3.5	13.6	18.7	42	83
December	2005	0.9	10.79	16.3	43	81
	2006	-2.67	4.81	34	53	88
January	2006	-3.94	3.71	79.5	59	84
	2007	-3	6.77	14.1	41	81
February	2006	1.16	12.25	34.3	38	66
	2007	1.3	9.7	36.7	43	76
March	2006	4.42	17.68	33.8	22	63
	2007	2.74	12	72.9	44	82
April	2006	10.43	23.2	28.7	27	63
	2007	9.3	19.6	108.3	37	75
May	2006	13.16	28.16	9.2	29	88
	2007	13.2	27.55	16.9	25	70
June	2006	19.13	35.03	0	12	50
	2007	16.6	33.47	12.6	19	71

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

Agronomic practices

Individual experimental plot consisted of six rows (5 m long) with 30 cm row spacing and 7 kg/ha seeding rate. The experimental fields were mould-board ploughed and seedbed preparation comprised of two passes with a tandem disk. Seed planting depth was 1 to 1.5 cm at a rate of 100 seeds m^{-2} on 10 October 2005 and 2006. For all treatments, the crop was supplied with the $N_{15}P_{60}K_{50}$ fertilizer. Nitrogen fertilizer was used in three splits. The first application (⅓ 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 (⅔ 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. 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 12 June 2006 and 24 June 2007.

Experimental design and applied treatments

The field experiment was split plot based on randomized complete block design (RCBD) with four replications. Two irrigation levels, 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 and Makepeace, 1984). Subplots were consisted of split application of rapeseed varieties at 34 levels ('Ebonite', 'Elite', 'Talent', 'Olpro', 'Sinatra', 'Sahara', 'Celsius', 'Sunday', 'Modena', 'Geronimo', 'Opera', 'ARC-5', 'ARC-2', 'ARG-91004', 'Milena', 'Dexter', 'SLM046', 'Zarfam', 'Okapi', 'Talaye', 'Licord', 'Herkules', 'Vectra', 'G.K.Helena', 'G.K.Olivia', 'G.K.Gabriella', 'Orient', 'RN*3304', 'N.K.Bilbao','ORW201-3001', 'ORW20-3002', 'RG4504', 'Dante' and 'Frederic'). These varieties were selected according to their reputed differences in yield performance under irrigated/non-irrigated conditions and as main cultivars of Karaj region.

Estimation of traits

Almost 10 days before rapeseed maturity, ten random samples were hand harvested from each experimental plot and the following measurements were carried out: plant height, number of siliquae per plant (empty siliquae were ignored in the counting process), and number of seeds per siliqua. Main stem height was measured at physiological maturity stage. Numbers of siliquae per plant and seeds per siliqua were counted from 40 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 physiological maturity. The manually harvested crops were left in the field for a week until drying to a constant weight (12% moisture content). The sun-dried samples were weighed using a precise scale and their biological (aboveground) yields were calculated as kg/ha. Five samples of 100 seeds were taken from each seed lot of the experimental units and then weighed. Their average multiplied by 10 and recorded as 1000-kernel weight (TKW). Economic yield divided by biological yield multiplied by 100 gave harvest index (HI) in percent. Oil percentage was determined by the nuclear magnetic resonance (mq20 NMR Analyzer, Brunker, Germany) in the oilseed research lab of Seed and Plant Improvement Institute, Karaj, Iran. Oil yield was calculated through multiplying seed yield by oil percentage.

Statistical analysis

Data were subjected to the *SAS* statistical software package (SAS institute, 2004) for analysis of variance (*ANOVA*), and SPSS program for correlation parameter. Duncan's multiple range test ($P<0.05$) was employed for mean comparisons when *F* values were significant.

Results and discussion

Compound analysis of variance indicated that all evaluated traits were highly significantly ($P<0.01$) influenced by the year effect (Table 2); this could be attributed to a considerable rainfall increase in the second year of experiment compared to

Table 2. The mean squares of *ANOVA* for plant height, siliqua plant^{-1}, seed siliqua^{-1}, 1000-kernel weight, seed yield, oil percentage, oil yield and harvest index in combined analysis of 2005–2006 and 2006–2007 data

Source of variation	df	Plant height	Siliqua plant^{-1}	Seed siliqua^{-1}	1000-kernel weight	Seed yield	Oil percentage	Oil yield	Harvest index
Y	1	231767.4**	288475.6**	15656.36**	67.906**	76490700.1**	6306**	37433862.8**	3242.4**
Rep(Y)	6	77.984	20.2	6.066	0.087	9744.11	1.849	4156.2	4.875
I	1	57721.20**	18404.71**	3629.356**	16.709**	459057857.2**	735.653**	101882122.3**	3026.8**
YI	1	4494.2**	362.71**	3.12 ns	0.001**	8496850.4**	252.73**	6567452.2**	8.323*
Error	6	55.90	5.159	1.986	0.159	2953.12	7.145	6982.3	0.835
V	33	652.24**	3310.39**	33.687**	1.211**	1514689.26**	26.676**	372647.4**	275.985**
YV	33	2140.27**	3162.9**	26.982**	1.096**	0.288 ns	21.937**	32902.6**	1.021 ns
IV	33	93.85**	56.79**	4.758**	0.014 ns	1916869.42**	1.871 ns	397636.6**	186.908**
YIV	33	90.565**	56.79**	4.785**	0.014 ns	0.287 ns	3.621 ns	14542.9**	0.952 ns
Error	396	23.651	17.24	1.114	0.028	15909.68	3.469	6376.03	3.504
CV (%)	–	4.54	5.77	4.77	4.41	4.66	4.35	6.75	8.17

* – $P < 0.05$, ** – $P < 0.01$, ns – $P > 0.05$; df – degrees of freedom, Y – year effect, I – irrigation effect, V – variety effect; YI,YV, IV, YIV represent interaction terms between the treatment factors.

the first year, especially from March 21 until June 20 (Table 1). Irrigation treatment had a drastically significant effect on all measured traits including plant height, number of siliquae per plant, number of seeds per siliqua, 1000-kernel weight, seed yield, seed oil percentage, seed oil yield and harvest index. In addition, assessed varieties had significant differences in terms of all measured traits (Table 2). Studies have shown that rapeseed is very sensitive to soil moisture stress from the stem formation stage onward because even a mild moisture stress causes a significant decrease in the yield and total dry matter production (Daneshmand et al., 2007). Usually, water deficit stress occurs when the amount of water that enters a plant is less than the water that is lost through parts of plant, especially from the leaves. This might be due to the excessive water loss, reduced water uptake or both. Generally, the decline in the osmotic potential or the total water potential along with losing turgidity, stomatal closure and reduced growth are the special signs of water stress. In cases where water stress intensity is high, it would be resulted in a drastic reduction in photosynthesis, disrupted physiological processes, stunted growth and ultimately drying and the death of a plant (Kramer and Boyer, 1995).

Individual effects of irrigation and variety, along with their interaction on the plant height (PH) become significant at the probability level of 1% (Table 2). Normal irrigation (I–control) with a mean value of 117.5 cm was significantly superior to the stopped irrigation treatment (S–water deficit stress) from the flowering stage until full maturity stage (69.9 cm) (Table 3). Hoogenboom et al. (1987) stated that drought stress affects the longitudinal growth of stem through decreasing the number of nodes and the length of internodes. Moreover, Birun Ara et al. (2011) reported that, at the stem elongation stage, drought stress reduces the plant height and decreases the leaf surface to its lowest limit. Decreased plant height due to drought stress could be attributed to the disruption of photosynthesis by dehydration, a decrease in the amount of assimilates to be delivered to the growing parts of a plant and finally, failure to reach a full genetic potential. Also, in terms of PH, the tested varieties were placed in different statistical groups in a way that 'Geronimo' with an average height of 118 cm and 'Orient' with an average height of 92.6 cm showed the highest and lowest plant heights, respectively (Table 3). Means comparison results of the interaction between the irrigation and variety treatments showed that the tested varieties were placed in different statistical groups at different irrigation levels so that 'Ebonite' with a mean value of 129.3 cm under normal irrigation conditions (I) had the tallest plant height, while 'Licord' with a mean value of 81.19 cm under water deficit stress (S) had the lowest plant height. As a whole, 'Ebonite' under normal irrigation conditions and 'Geronimo' (109.5 cm) under water deficit stress had the highest values pertaining to PH (Table 4).

Depending on environmental, climatic and genetic diversities, changes in the seed yield components usually cause the seed yield to vary. In general, yield components are among the characteristics that determine a crop's yield potential. The number of siliquae per plant (SP^{-1}) can be considered as one of the important components of the yield (Seyedmohammadi et al., 2013) because siliquae contain seeds and at the early seed filling stages they participate in the growth and development of seeds through photosynthesis process. In the present study, the number of siliquae per plant was significantly affected by the irrigation treatment (Table 2). Mean comparison results revealed that normal irrigation with a mean value of 77.82 was significantly superior to the drought stress treatment (66.19) (Table 3). Other reports have also been presented based on the negative effect of drought stress during the siliqua formation stage on the number of siliquae per plant (Sinaki et al., 2007). Wright et al. (1996) demonstrated that a drastic decrease in the number and the dry weight of siliquae resulted from siliqua and flower abscission, a problem that is more apparent in more intensive stresses. Moreover, in terms of this trait, the tested varieties were placed in different statistical groups in a way that 'Ebonite' with a mean value of 107.9 and 'Orient' with a mean value of 43.52 had the highest and the lowest number of siliquae per plant, respectively (Table 3). Mean comparison results of the interaction between irrigation and variety showed that at different irrigation levels, the studied varieties were placed in different statistical groups in terms of the said trait so that under normal irrigation conditions, 'Ebonite' (113.3) had the highest number of siliquae per plant, while under water deficit stress from the flowering stage onward 'Orient' had the lowest number of siliquae per plant

Table 3. Means for plant height (PH), siliqua plant^{-1} (SP^{-1}), seed siliqua^{-1} (SS^{-1}), 1000-kernel weight (TKW), seed yield (SY), oil percentage (OP), oil yield (OY), harvest index (HI) as affected by irrigation treatments in combined analysis of 2005–2006 and 2006–2007 data

Treatments	PH (cm)	SP^{-1}	SS^{-1}	TKW (g)	SY (kg ha^{-1})	OP (%)	OY (kg ha^{-1})	HI (%)
Irrigation								
I	117.5 a	77.82 a	24.73 a	3.97 a	3626 a	43.93 a	1616 a	25.28 a
S	69.9 b	66.19 b	19.56 b	3.62 b	1788 b	41.61 b	751 b	20.56 b
Variety								
'Ebonite'	117.5a	107.9a	23.29d	3.66i-l	2805ijk	43.25d-g	1241fgh	24.53c-f
'Elite'	109.2d-h	95.1c	23.14d	3.89ef	3168b	42.96d-i	1395b	24.27d-g
'Talent'	113.7bc	85.59e	23.06de	3.56j-m	2910fgh	42.65d-i	1269efg	33.34a
'Olpro'	112.4d-e	86.91de	21.08ijk	3.63i-m	2891ghi	42.88d-i	1265efg	19.82mn
'Sinatra'	112.9bcd	89.56d	23.19d	3.73ghi	3043cd	43.97a-d	1372bc	23.74e-h
'Sahara'	104.6i-m	74.52h	21.77g-j	3.67ijk	3022cde	41.40ij	1279def	32.16a
'Celsius'	106.5g-k	97.29bc	20.61klm	3.50m	2908fgh	41.03d-g	1280def	23.37f-i
'Sunday'	105.4h-l	73.21h	20.97jkl	3.87ef	3458a	45.35a	1603a	32.67a
'Modena'	107.8f-j	75.39gh	22.96def	3.89ef	2777jk	42.82d-i	1224f-i	25.86bc
'Geronimo'	118a	78fg	21.97gh	4.11bc	2494mn	43.13 d-g	1105lm	20.28lm
'Opera'	104.3i-m	64.11lm	24.75a	3.99cde	2711kl	42.53 d-i	1176h-k	25.81bc
'ARC-5'	112.2b-e	65.51klm	21.92ghi	3.72ghi	2798ijk	43.59b-e	1248fg	24.89cde
'ARC-2'	108.1f-i	65.95j-m	22.21fg	4.02cd	2778jk	42.99d-h	1220f-i	22.28ij
'ARG-91004'	111.1c-f	70.31i	23.62cd	3.53lm	2588m	43.95a-d	1163i-l	22.61hij
'Milena'	106.6g-k	52.85r	23.69bcd	3.14o	2528m	44.85abc	642i-l	20.54klm
'Dexter'	115.4ab	75.68gh	22.09g	3.83fg	2999c-f	43.33c-f	832cd	26.03bc
'SLM046'	105.7h-l	65.18klm	21.03jk	4.10bc	2738jkl	42.94d-i	618ghi	26.72b
'Zarfam'	110.4c-g	63.45mn	20.10mn	4.31a	2566m	43.37c-f	1139jkl	23.08g-j
'Okapi'	108.7e-h	68.36ijk	22.30efg	3.61i-m	2678l	43.23d-g	1182hij	19.49mno
'Talaye'	94.8n	56.91pq	22.31efg	3.81fgh	2014s	40.73j	837r	21.64jkl
'Licord'	95.2n	58.34opq	19.86mn	4.03cd	2327pq	41.41ij	979opq	17.59pq
'Herkules'	92.9n	56.62pq	20.23lmn	3.84fg	2425no	39.34k	947pq	21.75jk
'Vectra'	108.1f-i	66.96jkl	19.06o	4.22ab	2574m	40.94j	1053mn	19.47mno
'G.K.Helena'	111.6b-f	79.78f	22.10g	3.53klm	2815hij	42.07e-j	1209ghi	25.53bcd
'G.K.Olivia'	101.0m	59.50op	19.73no	3.30n	2265qr	41.91f-g	972pq	19.39mno
'G.K.Gabriella'	108.1f-i	75.81gh	21.16h-k	4.02cd	2954d-g	40.77j	1220f-i	20.04mn
'Orient'	92.6n	43.52s	21.79g-j	3.67ijk	2880ghi	41.42hij	1207ghi	24.72c-f
'RN*3304'	103.9j-m	70.28i	23.59cd	3.93def	2936efg	43.91a-d	1325cde	24.86cde
'N.K.Bilbao'	107.5f-j	60.78no	24.44ab	3.69hij	3052c	43.86a-d	1366bc	22.12ij
'ORW201-3001'	111.4c-f	98.98b	23.62cd	3.56j-m	2390op	42.68d-i	1037no	18.34opq
'ORW20-3002'	112.7b-e	76.46gh	21.53g-j	3.66i-l	2573m	42.73d-i	1117kl	18.34opq
'RG4504'	109.0d-h	55.43qr	21.72g-j	3.56j-m	2207r	44.97ab	1220nop	18.33opq
'Dante'	102.0lm	68.82ij	24.35abc	4.30a	2516mn	43.47b-f	1117kl	18.61nop
'Frederic'	103.2klm	65.32klm	23.68bcd	4.19ab	2261qr	41.72g-j	952q	16.98q

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.

(35.8). Among all tested varieties, under both irrigation treatment conditions, 'Ebonite' produced the highest number of siliquae per plant (Table 4).

Furthermore, the number of seeds per siliqua (SS^{-1}) is also considered as one of the determining elements of the seed yield in rapeseed (Angadi et al., 2003; Shirani Rad and Zandi, 2012). In fact, the more the number of seeds per siliqua, the larger the sink capacity for the photosynthetic products produced by a plant, which leads to increased yield as well. Mendham et al. (1984) found that increased number of seeds per siliqua is a key factor for the yield increase in new varieties. In this research, the number of seeds per siliqua was considerably ($P<0.01$) influenced by irrigation treatments and also by the interaction effects of irrigation and variety. Normal irrigation with a mean value of 24.73 was significantly superior to water deficit stress treatment which had a mean value of 19.56 (Tables 2, 3). These results coincide with the observations of Ma et al. (2006) and Shirani Rad and Zandi (2012) who reported that drought stress reduces the number of seeds per siliqua. In terms of this trait, examined varieties were placed in different statistical groups in a way that 'Opera' (24.75) and 'Vectra' (19.06) had the highest and lowest number of seeds per siliqua, respectively (Table 3). Mean comparison results revealed that the studied varieties were put in different statistical groups at different irrigation levels in such a way that in the normal irrigation conditions 'Opera' produced the highest number of seeds per siliqua (27.3); whereas, under applied water deficit stress 'Vectra' had the lowest number of seeds per siliqua (16.6). In general, the highest number of seeds per siliqua under both irrigation treatments (I and S) was of 'Opera' (I–27.3) and 'Dante' (S–22.4) (Table 4). It seems that soil moisture stress has the greatest effect on the fertilization of flowers and causes severe flower abscission, which finally leads to a reduced number of siliquae per plant and a decrease in the number of seeds per siliqua. During our investigation, no compensation

Table 4. Means for plant height (PH), siliqua plant^{-1} (SP^{-1}), seed siliqua^{-1} (SS^{-1}), 1000-kernel weight (TKW), seed yield (SY), oil percentage (OP), oil yield (OY), harvest index (HI) as affected by interaction effect of irrigation treatments with different rapeseed varieties in combined analysis of 2005–2006 and 2006–2007 data

Varieties	PH cm		SP^{-1}		SS^{-1}		TKW g		SY kg ha^{-1}		OP %		OY kg ha^{-1}		HI %	
	I	S	I	S	I	S	I	S	I	S	I	S	I	S	I	S
'Ebonite'	129.3a	105.8opq	113.3a	102.6c	26.1a-e	20.5q-u	3.801n-v	3.513yz	3909f	1700w-z	43.94c-o	42.55g-w	1750def	732wxy	25.48h-k	23.59k-p
'Elite'	119.9d-i	98.46s-y	100.8cd	89.4g	26.6ab	19.7u-x	4.085e-j	3.693s-y	4503b	1753v-y	44.05b-n	41.87n-x	2047b	743vwx	31.88cd	16.65z
'Talent'	126.9ab	100.5q-v	97.4de	73.8m-p	27.1a	19.1v-z	3.744q-w	3.378z	4152cd	1669yz	43.73c-q	41.56p-z	1838d	700xyz	38.96b	27.71fg
'Olpro'	120.9c-h	103.9o-s	93.5efg	80.3h-l	23.8jk	18.3z	3.784o-w	3.479z	3984ef	1797v-y	44c-n	41.76n-y	1773de	757vwx	22.43o-t	17.21z
'Sinatra'	121.3b-g	104.5o-r	94.2ef	84.9h	25.4b-h	21.0o-t	3.932i-q	3.526xyz	4508b	1581z	45.11a-e	42.84e-t	2057b	686xyz	32.08cd	15.40z
'Sahara'	116.2g-k	93.1yz	79.2jkl	69.8p-u	24.8f-k	18.8w-z	3.874k-t	3.461z	4628b	1416z	42.38i-x	40.43v-z	1980bc	578z	41.76a	22.56n-s
'Celsius'	118.8e-i	94.2w-z	101.8c	92.8fg	23.7kl	17.5z	3.696s-y	3.309z	3981ef	1831t-w	44.5b-k	41.56p-z	1790de	769vwx	24.94i-l	21.80o-v
'Sunday'	114.7i-l	96.1u-z	78.3klm	68.1r-v	23.8k	18.1z	4.025e-l	3.71s-y	4938a	1979s	46.29ab	44.41b-k	2317a	889stu	42.20a	23.15l-q
'Modena'	116.4g-k	99.3r-x	79.7i-l	71.1o-t	26.3abc	19.6u-y	4.026e-l	3.725r-x	4094de	1459z	44.21b-m	41.44q-z	1834d	614z	33.45c	18.28yz
'Geronimo'	126.4abc	109.5l-o	84.3hi	71.7n-t	24.8f-k	19.1v-z	4.298a-d	3.916j-r	3209l	1778v-y	44.52b-j	41.73n-y	1457kl	753vwx	22.22o-t	18.34yz
'Opera'	115.6g-k	93.0yz	69.4q-v	58.8z	27.3a	22.2mno	4.196c-g	3.775p-w	3576hi	1846s-w	43.69c-r	41.38r-z	1582hij	770vwx	30.32de	21.30q-w
'ARC-5'	122.8b-f	101.7p-u	70.6p-t	60.4z	24.8f-k	19.1v-z	3.864k-u	3.581w-z	3774g	1821t-x	44.87a-g	42.31j-x	1718ef	778vwx	24.99i-l	24.79i-m
'ARC-2'	122.6b-f	93.57xyz	74.7m-p	57.2z	25.1c-i	19.3v-z	4.205b-f	3.845l-u	3609h	1947stu	44.46b-k	41.51q-z	1625gh	816uvw	23.96j-o	20.59r-x
'ARG-91004'	125.0a-d	97.13t-z	80.1i-l	60.5z	26.5ab	20.7p-u	3.684t-y	3.372z	3281kl	1894s-v	45.28a-d	42.62f-w	1509ijk	816uvw	23.17l-q	22.06o-u
'Milena'	121.0c-g	92.22z	58.6z	46.6b	26.1a-e	21.2n-r	3.269z	3.005z	3612h	1444z	45.79abc	43.91c-o	1680fg	642z	15.27z	25.81g-j
'Dexter'	126.0abc	104.9o-r	83.2hij	68.1r-v	24.9e-k	19.2v-z	3.994h-n	3.66u-z	4036def	1963st	44.73a-h	41.93m-x	1830d	832tuv	24.73i-n	27.34fgh
'SLM046'	115.1ijk	96.29u-x	70.6p-t	59.7z	23.9jk	18.2z	4.316a-d	3.891j-s	4010ef	1466z	44.35b-l	41.53p-z	1803de	618z	32.30cd	21.13q-w
'Zarfam'	120.2d-i	100.5q-v	67.4s-w	59.5z	22.7lm	17.5z	4.466a	4.158d-h	3450ij	1681xyz	44.68a-i	42.05l-x	1564hij	715xyz	23.25l-q	22.92l-q
'Okapi'	117.8fg	99.54r-w	75.9lmn	60.8yz	24.4g-k	20.2r-v	3.775p-w	3.445z	3544hi	1813u-y	44.38b-l	42.08l-x	1595hi	770vwx	21.68p-v	17.31z
'Talaye'	104.7o-r	84.96z	61.4yz	52.4z	24.7f-k	19.9s-w	3.983h-o	3.629v-z	2548o	1481z	41.94m-x	39.52yz	1085q	589z	20.60r-x	22.69m-r
'Licord'	109.2mno	81.19z	62.4xyz	54.3z	21.8m-p	17.9z	4.213b-e	3.841l-u	2766n	1889s-v	42.67f-v	40.15xyz	1197op	763vwx	17.59z	17.60z
'Herkules'	99.47r-w	86.50z	60.6yz	52.6z	22.1mno	18.4yz	4.001g-n	3.671t-z	3346jk	1503z	40.29w-z	38.39z	1350mn	579z	25.93g-j	17.58z
'Vectra'	118.1f-j	98.16s-y	70.5p-t	63.4w-z	21.5m-q	16.6z	4.39ab	4.048e-k	2994m	2153qr	40.71t-z	41.16s-z	1212o	894stu	20.34s-y	18.59xyz
'G.K.Helena'	118.3e-j	104.8o-r	85.0h	74.6m-p	24.2h-k	20.0s-w	3.685t-y	3.384z	3511hi	2119r	43.65c-r	40.48u-z	1552hij	865stu	24.37i-m	26.30ghi
'G.K.Olivia'	101.0m	87.41z	63.3w-z	55.7z	21.5m-q	18.0z	3.524xyz	3.084z	3023m	1497z	43.31d-s	40.51u-z	1332n	612z	19.39mno	19.42w-z
'G.K.Gabriella'	108.1f-i	97.24t-z	80.6h-l	71.0o-t	22.5m	19.8t-w	4.179c-h	3.858k-u	2616h	2292p	42.17k-x	39.36z	1536h-k	905st	20.04mn	19.78v-y
'Orient'	92.65n	82.95z	51.2z	35.8z	25.1d-j	18.5xyz	3.807n-v	3.531xyz	3491hi	2269pq	42.54h-w	40.31w-z	1498jkl	917st	24.72c-f	22.09o-u
'RN*3304'	103.9j-m	94.88v-z	75.8l-o	64.7v-z	25.7b-f	21.5m-q	4.173d-h	3.697s-y	4273c	1600z	45.12a-e	42.7f-v	1956c	694xyz	24.86cde	20.56r-x
'N.K.Bilbao'	107.5f-j	96.29u-z	66.8t-x	54.7z	27.0a	21.9m-p	3.953i-p	3.434z	3950f	2153qr	44.91a-f	42.81e-u	1801de	930rs	22.12ij	21.92o-v
'ORW201-3001'	111.4c-f	99.36r-x	107.2b	90.8fg	25.5b-g	21.7m-p	3.705s-y	3.411z	2981m	1800v-y	43.85c-p	41.51q-z	1323n	751vwx	18.34opq	17.54z
'ORW20-3002'	112.7b-e	101.4p-u	82.9h-k	70.0p-u	24.1ijk	18.9v-z	3.811m-v	3.51yz	2761n	2384p	43.85c-p	41.61o-z	1234o	1000r	18.34opq	19.82v-y
'RG4504'	109.0d-h	102.8p-t	60.0z	50.8z	24.3g-k	19.1v-z	3.716r-x	3.414z	2999m	1416z	46.76a	43.18d-s	1421lm	619z	18.33opq	16.72z
'Dante'	102.0lm	97.41t-z	72.3n-s	65.3u-y	26.3abc	22.4mn	4.47a	4.129d-i	3503hi	1528z	44.63a-j	42.31j-x	1581hij	652yz	18.61nop	14.03z
'Frederic'	103.2klm	94.91v-z	72.9n-r	67.8z	26.3a-d	21.1o-s	4.367abc	4.011f-m	2632o	1891s-v	42.31j-x	41.12s-z	1126pq	777vwx	16.98q	16.44z

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.

process was observed between the number of siliquae per plant and the number of seeds per siliqua during the stress treatment (Table 3). This compensatory response exists in Indian mustard (*Brassica juncea* (L.) Coss), but it was not observed in rapeseed (Wright et al., 1995).

Individual effects of irrigation and variety on 1000-kernel weight (TKW) at the probability level of 1% were significant; nevertheless, the TKW remained unaffected by their interaction (Table 2). Normal irrigation with a mean value of 3.97 g was superior to water deficit stress, which gave a mean value of 3.62 g (Table 3). Decreased TKW due to drought stress was probably because of a decline in the production of assimilates (source strength reduction) and their allocation to seeds. In addition, water deficit stress during seed filing might have decreased the possibility for the remobilization of such matters and consequently it resulted in seed shrinkage and weight loss. This finding was consistent with the reports of Daneshmand et al. (2007) and Shirani Rad and Zandi (2012). The tested varieties were placed in different statistical groups in a way that 'Zarfam' with a mean value of 4.31 g and 'Milena' with a mean value of 3.14 g showed the highest and lowest TKW, respectively (Table 3). Mean comparison results showed that the assessed varieties were in different statistical groups in terms of the said trait at different irrigation levels in such a way that under normal irrigation conditions, 'Dante' produced the highest TKW (4.47 g), while 'Milena' under water stress conditions had the lowest value (3.005 g). To sum up, the highest TKW values belonged to 'Dante' (I – 4.47) and 'Zarfam' (S – 4.158) varieties for both applied irrigation regimes (Table 4).

Result indicated that simple effects of irrigation, variety, and interaction on the seed yield (SY) became effective at the probability level of 1% (Table 2). Normal irrigation during full growing season with a mean value of 3626 kg ha^{-1} was significantly superior to the water-deficit stress treatment by the mean value of 1788 kg ha^{-1}. Furthermore, among the tested varieties, the most (3458 kg ha^{-1}) and the least (2014 kg ha^{-1}) SY belonged to 'Sunday' and 'Talaye', respectively (Table 3). Means comparison results showed that the exprimental varieties were placed in different statistical groups in a way that the highest SY (4938 kg ha^{-1}) was obtained by 'Sunday' in plots with normal irrigation conditions and the lowest (1416 kg ha^{-1}) value was achieved by both 'Sahara' and 'RG4504' in the conditions of water deficit stress. Among all treatment combinations, normal irrigation × 'Sunday' and water deficit stress × 'ORW20-3002' interactions resulted in the highest SY (Table 4). In their study on "the effects of irrigation treatments on the yield of two rapeseed varieties", Poma et al. (1999) observed that under water deficit conditions, seed yield and the entire yield components decreased as well. These findings indicate that water deficit stress reduces both source strength and sink capacity (the amount of seeds per siliqua decreased due to post-flowering water stress, Table 4). In fact, water deficit stress decreased photosynthesis and its products in leaves (being a primary site of photosynthesis). As a result, the amounts of photosynthetic products transferred from the leaves are also decreased. The water pressure potential (ψ_p) in phloem, as a sap-transfer agent through phloem, decreased as well; therefore, less photosynthetic products were transferred and finally, it caused seed formation and the yield to decrease (Taiz and Zeiger, 2006).

Seed oil percentage (OP) was highly affected by varieties and different irrigation levels; however, it did not contribute by their interactions (Table 2). Normal irrigation with a mean value of 43.93% was considerably superior to stopped irrigation conditions with a mean value of 41.61%. Indeed, late-season water stress led to seeds containing less oil compared with normal irrigation (Abbasian and ShiraniRad, 2011). It is also recognized that the highest (45.35%) and lowest (39.34%) OP were those of 'Sunday' and 'Herkules', respectively (Table 3). Moreover, the interaction's output detected that 'RG4504' in plots subjected to normal irrigation treatment produced the highest OP (46.76%). By contrast, water deficit stress resulted in producing the least OP in 'Herkules' variety (38.39%). It can be concluded that the highest OP was recorded in 'RG4504' (for column I) and 'Sunday' (for column S) as shown in Table 4.

Seed oil yield (OY) showed significant differences due to different irrigation levels and varieties in a way that normal irrigation (1616 kg ha^{-1}) was statistically superior to the water deficit stress (751 kg ha^{-1}). It may highlight the contribution of normal irrigation conditions in producing a higher seed yield (Tables 2, 3). In a similar study, it was observed that applying drought stress caused a significant reduction in the number of siliquae per plant, number of seeds per siliqua, TKW, seed yield, seed oil percentage and the oil yield of five rapeseed varieties (Moghanni Nasri et al., 2006), a finding which was in complete conformity with the results of the present study. Besides, the tested varieties were located in different statistical groups in a way that 'Sunday' with a mean value of 1603 kg ha^{-1} and 'Talaye' with a mean value of 837 kg ha^{-1} had the highest and lowest OY, respectively (Table 3). Regarding the mean values presented based on the interactions, it is evident that 'Sunday' and 'G.K.Olivia' generated the highest (2317 kg ha^{-1}) and lowest (612 kg ha^{-1}) OY as a result of stressed (water deficit stress) and non-stressed (normal irrigation) treatments. Furthermore, the highest values in both stressed/non-stressed conditions were linked to 'ORW20-3002' and 'Sunday' varieties, respectively (Table 4).

The recorded data indicated highly statistically significant differences in harvest index (HI) with respect to different irrigation levels, varieties and their interactions. Normal irrigation treatment with a mean value of 25.28% was noticeably superior to water deficit stress, which had a mean value of 20.56%. Moreover, the tested varieties were stood in different statistical groups in such a way that 'Talent' and 'Licord' had the highest (33.34%) and lowest (17.59%) HI values, respectively (Tables 2, 3). 'Dante' with 14.03% amount was the most sensitive variety to stopping the irrigation from flowering stage in terms of HI than other varieties; however, 'Sunday' gave more value (42.2%) under normal irrigation conditions. In addition, the highest HI was recorded in both irrigation treatments for 'Sunday' (I) and 'Talent' (S) varieties (Table 4). Usually, under drought and water deficit conditions, seed yield and the HI can be suitable indices for studying the genotype tolerance to water deficit (Sanchez et al., 1998). Yahyavi Tabriz and Sadrabadi Haghighi (2004) stated that decreased HI in the limited irrigation treatment during the flowering stage of rapeseed is mainly due to the reduced number

Table 5. A matrix of simple correlation coefficients (*r*) for the estimated traits in rapeseed varieties

Trait	PH	SP^{-1}	SS^{-1}	TKW	OP	OY	SY	HI
PH	1	0.84**	0.84**	0.57**	0.78**	0.66**	0.58**	0.42*
SP^{-1}		1	0.75**	0.47*	0.68**	0.54**	0.45*	0.39^{ns}
SS^{-1}			1	0.63**	0.81**	0.72**	0.64**	0.49*
TKW				1	0.51**	0.51**	0.47*	0.33^{ns}
OP					1	0.69**	0.53**	0.41*
OY						1	0.97**	0.67**
SY							1	0.67**
HI								1

PH – plant height, SP^{-1} – siliqua $plant^{-1}$, SS^{-1} – seed $siliqua^{-1}$, TKW – 1000-kernel weight, OP – oil percentage, OY – oil yield, SY – seed yield, HI – harvest index; ns – not significant, * – $P < 0.05$, ** – $P < 0.01$.

of seeds per siliqua. Although number of studies (Daneshvar, 1997; Razmi and Ghasemi, 2007) indicated a reduced HI under drought stress conditions, Ehdaie and Waines (1993) and Bolanos (1995) presented contradictory reports based on increased harvest index under severe drought stress conditions.

The correlation coefficient between traits in different growth stages are displayed in Table 5. Plant height, oil percentage and the number of seeds per siliqua separately, were highly significantly correlated (for all relations $r= +$, $P<0.01$) by the rest of traits except for harvest index that only showed a significant positive correlation ($P<0.05$). Regarding the oil yield, correlation study showed an outstanding significant positive association ($P<0.01$) among seed oil yield and the other characteristics. Harvest index had great positive correlation with oil yield ($r= 0.67$; $P<0.01$). Great positive correlation was due to its indirect effect by seed yield in each plant. Similar correlation was observed for harvest index and seed yield. The experiments done by Chango and McVetty (2001) and Ali et al. (2003) represented that harvest index had a significant correlation with seed yield. By contrast, Abbasian and Shirani Rad (2012) reported negative correlation that was inconsistent with our result. Thousand-kernel weight and the number of siliquae per plant had a greatly significant positive correlation with the number of seeds per siliqua, seed oil percentage, plant height and the oil yield ($P<0.01$). The results indicated that among the seed yield components, the number of seeds per siliqua had the greatest ($r = 0.64$; $P<0.01$) ;while, the number of siliquae per plant ($r = 0.45$; $P<0.05$) and thousand-kernel weight ($r = 0.47$; $P<0.05$), respectively had the weakest influence on seed yield so that they were identified as less important factors among seed yield components. In this regard, Angadi et al. (2003), Abbasian and Shirani Rad (2011), and Shirani Rad and Zandi (2012) reported that siliqua number per plant had the greatest correlation with seed yield than seed number per siliqua. Hence, positive and significant correlation between the seed yield and these traits shows that seed yield variations are in line with changes in these traits. Thus, a decrease in each one of these traits, as a criterion for rapeseed yield improvement, through occurrence of water deficit stress will severely affect the seed yield (Daneshmand et al., 2007). Therefore, screening rapeseed varieties based on these traits might be more useful under water deficit stress conditions. According to our investigation, seed yield in plant had the most positive direct effect on oil yield ($r = 0.97$; $P<0.01$). The same finding was also reported by Shirani Rad and Zandi (2012).

Conclusions

The estimated traits including the number of siliquae per plant, number of seeds per siliqua, 1000-kernel weight (TKW), seed oil percentage, seed oil yield, seed yield and the harvest index (HI) were significantly affected by irrigation treatments. Of course, the effect of irrigation on varieties was different and varieties showed different reactions to water stress. In the conditions of normal irrigation and under the conditions of stopping the irrigation from the flowering till maturity stage 'Sunday' as well 'ORW20-3002' produced the greatest seed and oil yields. On the other hand, varieties had completely significant differences in terms of all evaluated traits. After all, under normal irrigation conditions, 'Ebonite' was the superior variety and had the highest number of siliquae per plant; 'Opera' had the highest seeds number per siliqua; 'RG4504' had the highest seed oil percentage; 'Dante' had the highest TKW and 'Sunday' had the highest seed yield, oil yield and HI. Furthermore, in response to withholding irrigation from the flowering stage, 'Geronimo' was distinguished as the highest plant; 'Ebonite' had the highest number of siliquae per plant; 'Danite' had the highest number of seeds per siliqua; 'Zarfam' had the highest TKW; 'Sunday' had the highest seed oil percentage; 'Talent' had the highest HI and 'ORW20-3002' had the highest seed yield and oil yield. Finally, with consideration of the results of this research, 'Sunday' can be recommended for cultivation in cold and temperate regions of Iran where there is no irrigation water shortage and less rainfall from 20th February onwards, while 'ORW20-3002' can be considered suitable for those cold and temperate regions which have the said problems.

References

Abbasian A., Shirani-Rad A.H. (2011). Investigation the Response of Rapeseed Cultivars to Moisture Regimes in Different Growth Stages. J Cent Eur Agric 12(2): 353-366.

Ahmadi M.R., Javidfar, F. (2000). Evaluation and drought tolerance improvement methods in oil species of Brassica genus, 1st ed, AREEO Press,Karaj,Iran, pp140 (in Persian)

Ali N., Javidfar F., Jafarieh Yazdi E., Mirza M.Y. (2003). Relationship among yield components and selection criteria for yield improvement in winter rapeseed. Pakistan J Botan 35: 167-74.

Angadi S.V., Cutforth H.W., McConkey B.G., Gan Y. (2003). Yield adjustment by canola grown at different plant populations under semiarid conditions. *Crop Sci* 43: 1358-1366.

Birun Ara A., Shekari F., Hassanpouraghdam M.B., Khorshidi M.B., Esfandyari E. (2011). Effects of water deficit stress on yield, yield components and phenology of canola (*Brassica napus* L.) at different growth stages. J Food Agric Environ 9(3-4):506-509.

Bolanos J. (1995). Physiological basis for yield differences in selected maize cultivars from central America. Field Crops Res 42(2):69-80.

Chango G., McVetty P.B.E. (2001). Relationship of physiological characters to yield parameters in oilseed rape. Canadian J Plant Sci 81: 1-6.

Chiriþã V., Crãciun M., Crãciun I., Condei G., Fluieraºu V. (1999). Ionic interactions in maize grown under water stress conditions. Rom Agric Res 11-12:65-74.

Daneshmand A.R., Shirani-Rad A.H, Noormohammadi Gh., Zarei Gh., Daneshian J. (2007). Effect of water stress and different levels of nitrogen fertilizer on seed yield and its components, nitrogen uptake and water use and nitrogen utility efficiency in two rapeseed (*Brassica napus* L.) cultivars. Iranian Journal of Crop Science 8(4-32):323-342 (in Persian)

Daneshvar M.(1997).Effect of different irrigation regimes on growth, grain yield and its components of grain sorghum (*Sorghum bicolor* L.) cultivars under Isfahan conditions. Ph.D. dissertation. Dep. Of Agrononomy, Faculty of Agriculture, *Isfahan* Univ. of Technology, *Isfahan* , Iran (in Persian)

Ehdaie B.,Waines J.G.(1993).Variation in Water-Use Efficiency and Its Components in Wheat: I. Well-Watered Pot Experiment. Crop Sci 33:294-299.

Food and Agriculture Organization of the United Nations (FAO), (2014). Global Information and Early Warning System on food and agriculture(GIEWS), Food Outlook (May, 2014). Rome, Italy,186 http://www.fao.org/giews/english/fo/index.htm (Last accessed: 15 June 2014)

Hashem A., Amin Majumdar M.N., Hamid A. Hossain M.M. (1998). Drought Stress Effects on Seed Yield, Yield Attributes, Growth, Cell Membrane Stability and Gas Exchange of Synthesized *Brassica napus L. J* Agron *Crop* Sci 180(3):129-136.

Hoogenboom G., Peterson C.M., Huck M.G.(1987). Shoot growth rate of soybean as affected by drought stress. Agron J 79(4):598-607.

Jensen C.R., Mogensen V.O.,Mortensen G., Fieldsend J.K., Milford G.F.J., Andersen M.N., Thage J.H.(1996). Seed glucosinolate oil and protein contents of field Grown rape (*Brassica napus* L.) affected by soil drying and evaporative demand. Field Crops Res 47(2-3):93-105.

Johnston A.M., Tanaka D.L., Miller P.R., Brandt S.A., Nielsen D.C., Lafond G.P., Riveland N.R. (2002). Oilseed crops for semiarid cropphng systems in the Northern Great Plains. Agron J 94(2): 231-240.

Kajdi F., Pocsai K.(1993). Az öntözés hatása a repcefajták termık épességére,fehérjetartalmára, valamint fehérjehozamára/The effect of irrigation on the yield potential , protein yield. Acta Agronomica Óváriensis 35(1):65-72.

Kimber D.S., McGregor D.I.(1995). Brassica Oilseeds Production and Utilization.Willingford, UK,CABI, 394

Kramer P.J., Boyer J.S. (1995). Water Relations of Plants and Soils.1st ed. Academic Press. New York, 495

Ma Q., Niknam S.R., Turner D.W. (2006). Responses of osmotic adjustments and seed yield of Brassica napus and B. juncea to soil water deficit at different growth stages. Aust J Agric Res 57(2): 221-226.

Mendham N.J., Russell J., Buzza G.C.(1984).The contribution of seed survival to yield in new Australian cultivars of oil-seed rape (*Brassica napus* L.). J Agric Sci 103(2):303-316.

Moghanni Nasri M., Heidari Sharif Abad H., Shirani-Rad A.H., Majidi Hervan E., Zamanizadeh H.R. (2006). Performance of the effect water stress on physiological characters of rapeseed cultivars. J Agric Sci (IAU) 1:127-134 (in Persian)

Pasban Eslam B., Shakiba M.R., Neyshabori M.R., Moghaddam M., Ahmadi M.R.(2000). Evaluation of Physiological Indices as a Screening Technique for Drought Resistance in Oilseed Rape. Pakistan Acad Sci J 37(2): 143-152.

Petcu E., Schitea M., Badea D. (2007). The behavior of some Romanian alfalfa genotypes to salt and water stress. Rom Agric Res 24:51-54.

Petcu E., Schitea M., Cîrstea V.E. (2009). The effect of water stress on cuticular transpiration and its association with alfalfa yield. Rom Agric Res 26:53-56.

Poma I., Venezia G., Gristina L.(1999). Rapeseed (*Brassica napus* L. var. *Oleifera* D.C.) ecophysiological and agronomical aspects as affected by soil water availability. In: Proc 10th International Rapeseed Congress, 27-29 September, The Regional Inst. Ltd, Canberra,Australia, pp7 http://regional.org.au/au/gcirc/2/201.htm (Last accessed: 12 January 2011)

Razmi N., Ghasemi M. (2007). Effect of different irrigation regimes on growth, grain yield and its components of grain sorghum (*Sorghum bicolor* L.). Iran J Crop Sci 9(2):169-183 (in Persian)

SAS institute (2004). SAS/STAT users guide. Ver. 9.1. ,SAS Institute Inc., Cary,NC, USA

Sanchez F.J., Manzanares M., de Andres E.F., Tenorio J.L., Ayerbe L.(1998). Turgour maintenance, osmotic adjustment and soluble sugars and praline accumulation in 49 pea cultivars in response to water stress. Field Crops Res 59(3): 225-235.

Seyedmohammadi N.S., Allahdadi I., Seyedmohammadi S.A., Sarafraz E. and Shirani-Rad A.H. (2013). Some physiological and morphological responses of canola varieties (*Brassica Napus* L.) to different amounts and intervals between irrigations. Rom Agric Res 30:1-6.

Sinaki J.M., Majidi Heravan E., Shirani-Rad A.H., Noormohammadi Gh., Zarei Gh. (2007). The effects of water deficit during growth stages of canola (*Brassica napus* L.). Am Eurasian J Agric Environ Sci 2(4): 417-422.

Shirani-Rad A.H., Zandi P. (2012). The effect of drought stress on qualitative and quantitative traits of spring rapeseed (*Brassica napus* L.) cultivars. Žemdirbystė=Agriculture 99(1): 47-54.

Sylvester-Bradley R., Makepeace R.J.(1984). A code for stages of development in oilseed rape (*Brassica napus* L.). Aspects Appl Biol 6: 398-419.

Taiz L., Zeiger E. (2006). Plant physiology. 4th ed. Sinauer Associates, Inc. Publishers. Sunderland, Massachusetts,USA,764.

Walton G., Mendham N., Robertson M., Potter T.(1999). Phenology, Physiology and Agronomy. In: Proc 10th International Rapeseed Congress. 27-29 September, The Regional Inst. Ltd,Canberra, Australia, pp 6 http://www.regional.org.au/au/gcirc/canola/ (Last accessed: 25 Febreuary 2012)

Wright P.R., Morgan J.M., Jessop R.S.(1996). Comparative adaptation of canola (*Brassica napus*) and Indian mustard (*Brassica juncea*) to soil water deficits: Plant water relations and growth. Field Crops Res 49(1):51-64.

Wright P.R., Morgan J.M., Jessop R.S., Cass A. (1995). Comparative adaptation of canola (*Brassica napus*) and Indian mustard (*Brassica juncea*) to soil water deficits: yield and yield components. Field Crops Res 42(1):1-13.

Yahyavi Tabriz Sh., Sadrabadi Haghighi R. (2004). Effect of irrigation on yield and yield component of three spring canola cultivars under environmental of Tabriz. Iranian Journal of Field Cops Res 1: 305-313 (in Persian)

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