EFFECTS OF POTASSIUM APPLICATION ON THE CROP TRAITS, QUALITY, AND YIELD OF RAPESEED CULTIVARS AT LATE-SEASON DROUGHT STRESS

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Abstract

In order to reduce the damage caused by late-season drought stress on rapeseed plant, a split plot factorial experiment was implemented in a complete randomized block design with three replications in Iran (Karaj) for two years (2014-2016). Treatments were application and non-application of potassium sulphate, and irrigation at three levels of normal irrigation (control), cessation of irrigation from flowering and silique stages onwards, which were assigned as factorial to main plots. Five winter rapeseed cultivars, namely Opera, L72, KR1, GKH3705, GKH0224, and Neptune, were placed in sub-plots. In the interaction of cultivars on the canopy temperature, L72 had the lowest average canopy temperature (30.93 °C). The interaction of potassium sulfate × irrigation × cultivar on seed oil yield and glucosinolate content was significant at 1% level. The promising L72 line is recommended with the highest oil yield (2961 kg/ha) and a standard high glucosinolates content with potassium sulfate application and normal irrigation. The same line contained the highest total chlorophyll content at all irrigation levels. Opera cultivar is also recommendable with the highest oil yield (2281 and 1618 kg/ha at cessation of irrigation from the silique and flowering stages onwards, respectively) with potassium sulfate application at late-season drought stress and having standard glucosinolate levels.

Keywords; Rapeseed, potassium sulfate, fatty acid composition, late-season drought stress.

Introduction

Drought is the most important factor limiting the growth of plants and crops around the world, particularly in arid and semi-arid zones (Sun et al., 2013). The highest yield reductions in plants have been reported as a result of abiotic stresses such as drought and lack of soil nutrients (Bery *et al.*, 2000). Currently, rapeseed oil, along with other species of Brassica, accounts for the second largest oil production among oilseeds after soybeans (Scarth and Tung, 2006). On the other hand, low concentrations of saturated fatty acids in canola oil compared to other vegetable oils caused canola oil to be considered as a useful edible oil (Scarth and Tung, 2006). The environment plays an important role in determining the oil content in rapeseed. Irrigation can increase the amount of seed oil, while flooding and drought stress can reduce it (See and Walton, 2004). As rapeseed has a relatively high nutritional requirement, the use of nutrients (e.g., potassium sulfate) can play an important role in increasing production and its quality to achieve optimal grain yield, oil content, and optimal grain protein, and to reduce the adverse effects of drought stress in rapeseed. Recent studies indicate that growth restriction in 60% of arable lands results from a lack of mineral elements (Cakmak, 2002). Nasri et al. (2008) reported an increase in the amount of fatty acids and a decrease in the quality of seed oil with rising drought stress intensity.

Potassium plays an important physiological role in the cell ubder adverse environmental conditions, and its high levels improve plant tolerance (Weiss, 2001; Cakmak, 2005). Potassium consumption has been reported to increase rapeseed yield by 15-25% with and without moisture stress (Sharma, 2002). Under potassium deficiency, plant susceptibility increases to environmental stresses (Cakmak, 2002). Along with the direct effect of drought caused by declined water availability in the growing environment of the plant. It is also important to maintain and balance soil nutritional elements, and such an element as potassium plays important roles in the control of water losses from plants (Sardanz and Uelas, 2008). Researchers believe that drought stress can affect the reproductive mechanisms determining rapeseed yield, such as flower and silique formation, seed number per silique, and grain filling, but the intensity of this effect is a function of genotype, stress duration, climatic conditions, and growth stages (Sinki *et al.* 2007; Faroug *et al.* 2008). The fatty acid composition of rapeseed oil includes 7% saturated fatty acids, 66% monounsaturated fatty acids, and 27% polyunsaturated fatty acids, with significantly different composition of fatty acids in seed oil among rapeseed cultivars (Kadivar *et al.*, 2010). The quality of rapeseed oil is mainly determined by the amounts of oleic, linoleic, and erucic fatty acids and is greately influenced by environmental conditions (Engalbert *et al.*, 2013) and the type of cultivar (Nasr *et al.*, 2006; Javidfar *et al.*, 2007). High amounts of natural potassium in soil cannot be used for plants and crops (Ashley *et al.*, 2006), and deficiency and imbalance of minerals increase the adverse effects of environmental stress, particularly water deficit, in arid and semi-arid zones. Therefore, the aim of this study was to investigate the role of potassium sulfate in reducing the adverse effects of different late-season drought stress intensities on the quantitative and qualitative traits in the promising winter cultivars and lines of rapeseed.

Materials and Methods

The effect of K2SO4 application on morphological, qualitative traits, and yield of rapeseed cultivars in late-season drought stress was investigated a split plot factorial experiment in a complete randomized block design with three replications in Karaj region (Iran) located at 35° 49′ N and 51° 6′ E with an altitude of 1313 m above sea level in the crop years 2014-15 and 2015-16. According to the average 30-year meteorological data of Karaj Meteorological Agency, the average annual rainfall is 33 mm in the region and precipitation occurs mainly in late autumn and early spring. The meteorological figures and the soil profile of the study site during the two crop years are presented in Figure 1 and Table 1, respectively.

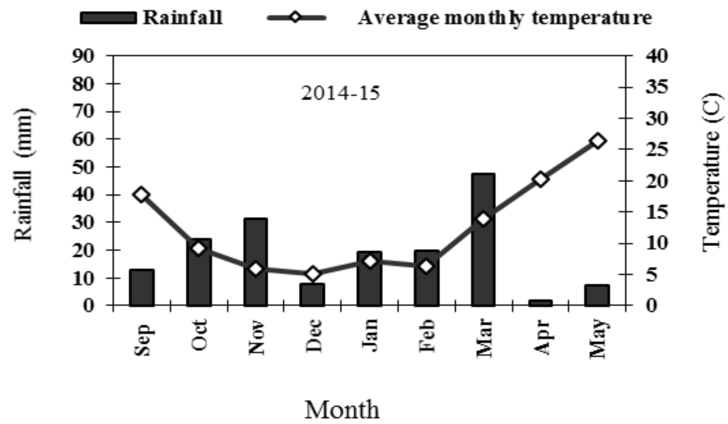

Figure 1. Average temperature and rainfall changes at the meteorological station in Karaj region, Iran (2014-16 crop years)

Table 1. Physicochemical properties of the study site soil at depths of 0-30 and 30-60 cm in 2014-16 crop years

Year	Soil Depth (cm)	Soil texture	Soil pH	Organic carbon (%)	EC (ds.m-1)	Total Nitrogen (%)	Pava. (ppm)	Kava. (ppm)	Sand (%)	Clay (%)	Silt (%)
2014-15	0-30	Loam-Clay	7.4	0.95	1.47	0.08	14.5	207	26	29	45
	30-60	Loam-Clay	6/9	0.98	1.28	0.09	15.4	168	27	26	47
2015-16	0-30	Loam	7.6	0.54	1.55	0.07	12.9	275	41	25	34
	30-60	Loam	7.8	0.47	1.15	0.08	8.6	162	39	26	35

In this study, two K2SO4 levels of without application and application at 100 kg/ha, and irrigation at three levels of conventional irrigation (control), cessation of irrigation from flowering and silique stages onwards were as factorial and the main factors. Winter rapeseed cultivars, namely Opera, L72, KR1, GKH3705, GKH0224, and Neptune were as sub-factors.

Each experimental plot consisted of six lines of 6 m long with 3 cm spacing, and two side lines were considered as margins. The plants on the planting lines were 5 cm apart. The fertilizers used based on soil test were ammonium phosphate (150 kg/ha) and potash sulfate (150 kg/ha) as a base concurrent with seedbed preparation, and urea as 150 kg/ha (100, 150, and 100 kg in the three-leaf, stem, and budding stages, respectively) as the top-dress. All operations related to growing, except irrigation, were carried out uniformly and according to local customs. Irrigation cycle was considered based on 80 mm of evaporation from Class A evaporation pan, and the amount of water consumed per irrigation was 80% of evaporated water. The amount of water flowing into the experimental farm was measured with a counter.

To determine the grain yield, the plants in an area of 4.8 m2 were surface-cut separately from each experimental plot and then weighed and calculated with an accurate balance. The canopy temperature was measured using an infrared thermometer with an emissivity index of 0.99. Stomatal resistance was measured with a pyrometer (DELTA-T DEVICES-Cambridge). Seed oil content was determined by selection of a seed sample (5 g) per plot by the use of an NMR (Nuclear Magnetic Resonance) system (International Standard ISO 5511., 1992). Seed oil yield (kg/ha) was calculated through multiplying oil content by seed yield. Gas chromatography method was used to measure fatty acids in seed oil (Azadmard-Damirchi et al., 2005). Grain glucosinolate levels were measured by a spectrophotometer (Harinder et al., 2007).

After assuring the experimental assumptions, the homogeneity of experimental variances per year was determined using the Bartlett test, followed by composite analysis of variance by SAS statistical software (version 9/1). Mean values were compared by the least significant difference (LSD) test. Average interactions were compared by the least Least-Squares Means (LSMEANS) test. Excel software was used to draw the graphs.

Results and discussion

The effect of year was significant on seed oil yield and content (%) (Table 3). The irrigation levels and K2SO4 had significant effects on the seed oil yield, seed oil content, and glucosinolate levels (Table 3). The cultivars were significantly different in terms of seed yield, seed oil content, and glucosinolate levels (Table 3). Significant effects of irrigation × cultivar interaction were observed on seed oil yield, seed oil content, and glucosinolate levels (Table 3). The interaction of irrigation × K2SO4 × cultivar was significant on seed oil yield and glucosinolate levels (Table 3). Palmitic acid content was significantly influenced by the year, irrigation, cultivar, and K2SO4 (Table 2).

Table 2. Composite ANOVA for the studied traits of rapeseed cultivars under the influence of K2SO4 and irrigation in a two-year experiment

		Mean of squares				
Treatment	df	Palmitic acid	Total chl.	Canopy T.	Silique L.	Leaf proline
Year	1	8·2955**	1·18074**	35·122**	85·5037**	1267·30**
Year × replication	4	0·1339	0·01524	0·352	3·5905	16·21
Irrigation	2	33·5626**	0·04504**	246·228**	159·0643**	1624·3273·28**
Year × irrigation	2	0·2437 ns	0·02494 ns	0·590 ns	0·6759 ns	32·28**
K2SO4	1	1·5083*	0·51920**	13·350**	7·9733**	73·99**
K2SO4 × year	1	0·0158 ns	0·00020 ns	0·085 ns	0·0133 ns	0·27 ns
K2SO4 × irrigation	2	0·0369 ns	0·00053 ns	0·069 ns	0·0008 ns	0·14 ns
K2SO4 × irrigation × year	2	0·0790 ns	0·00327 ns	0·126 ns	0·0014 ns	2·70 ns
Error I	20	0·2351	0·01803	1·458	0·7828	1·85
Cultivar	5	0·8961**	0·31174**	7·120**	4·6109**	42·63**
Cultivar × year	5	0·0302 ns	0·00010 ns	0·013 ns	0·0323 ns	0·40 ns
Cultivar × irrigation	10	0·1949 ns	0·06423**	1·42 ns	0·9326 ns	8·91**
Cultivar × irrigation × year	10	0·0372 ns	0·00260 ns	0·066 ns	0·0126 ns	2·16**
Cultivar × K2SO4	5	0·0066 ns	0·00142 ns	0·044 ns	0·0103 ns	0·16 ns
Cultivar × K2SO4 × year	5	0·0120 ns	0·00030 ns	0·001 ns	0·0026 ns	0·04 ns

Cultivar × K2SO4 × irrigation	10	0·0108 ns	0·00183 ns	0·024 ns	0·0270 ns	0·27*
Cultivar × K2SO4 × irrigation× year	10	0·0060 ns	0·00085 ns	0·018 ns	0·0034 ns	0·08 ns
Error II	120	0·1458	0·01511	1·09	0·56	0·79
COV (%)		7·85	8·64	3·33	11·56	5·29

Ns: non-significant; * and ** significant at levels 0.05 and 0.01, respectively

Table 3. Composite ANOVA for the studied traits of rapeseed cultivars under the influence of K2SO4 and irrigation in a two-year experiment of mean squares

		Mean of squares				
SOV	df	Seed oil (%)	No. of seeds per silique	1000-seed weight	Seed oil yield	Seed glucosinolate
Year	**1**	**9·0733****	**479·12****	**77·412****	**7132960***	**14·36 ns**
Year × replication	**4**	**0·3045**	**2·84**	**0·318**	**403417**	**13·85**
Irrigation	**2**	**140·1183****	**1146·44****	**69·373****	**30687107****	**961·68****
Year × irrigation	**2**	**0·2116 ns**	**6·71 ns**	**5·927****	**50767 ns**	**3·67 ns**
K2SO4	**1**	**8·4688****	**52·51****	**3·382****	**1498666****	**45·99****
K2SO4 × year	**1**	**0·0242 ns**	**0·08 ns**	**0·247 ns**	**1223 ns**	**0·28 ns**
K2SO4 × irrigation	**2**	**0·0796 ns**	**0·07 ns**	**0·014 ns**	**7682 ns**	**0·16 ns**
K2SO4 × irrigation × year	**2**	**0·0115 ns**	**0·10 ns**	**0·010 ns**	**119 ns**	**0·05 ns**
Error I	**20**	**0·2957**	**2·10**	**0·234**	**70190**	**1·42**
Cultivar	**5**	**4·3867****	**31·59****	**1·709****	**804627****	**23·79****
Cultivar × year	**5**	**0·0214 ns**	**0·15 ns**	**0·059 ns**	**659 ns**	**0·12 ns**
Cultivar × irrigation	**10**	**0·8966****	**6·67****	**0·430****	**180237****	**5·68****
Cultivar × irrigation × year	**10**	**0·0213 ns**	**0·04 ns**	**0·056 ns**	**1013 ns**	**0·13 ns**
Cultivar × K2SO4	**5**	**0·0051 ns**	**0·05 ns**	**0·007 ns**	**1257 ns**	**0·07 ns**
Cultivar × K2SO4 × year	**5**	**0·0179 ns**	**0·01 ns**	**0·012 ns**	**1451 ns**	**0·03 ns**
Cultivar × K2SO4 × irrigation	**10**	**0·0098 ns**	**0·04***	**0·009 ns**	**4254****	**0·22****
Cultivar × K2SO4 × irrigation× year	**10**	**0·0484 ns**	**0·01 ns**	**0·010 ns**	**825 ns**	**0·01 ns**
Error II	**120**	**0·1572**	**2·04**	**0·14**	**56485**	**0·58**
COV (%)		**0·89**	**6·88**	**9·52**	**11·91**	**5·35**

Silique length

Significant differences in the reaction of cultivars to irrigation treatments with and without the use of K2SO4 indicate a positive effect of potassium in the improvement of this trait (Table 2). Comparison of mean simple effect of K2SO4 revealed that potassium led to a 6.3% increase in silique length, with averages of 6.7 cm and 6.3 cm with and without the use of K2SO4, respectively. A comparison of the average simple effect of irrigation indicated that different levels of irrigation were located in different statistical groups in terms of the mentioned trait, and silique length declined significantly under drought stress. The highest (7.9 cm) the lowest (5 cm) average silique length were recorded in normal irrigation (control) and cessation of irrigation, respectively, from the flowering stage onwards. A comparison of the average simple effect of cultivar suggested that different the experimental cultivars belonged to different statistical groups in terms of this trait, with average silique lengths of 6.9, 6.8, and 6.7 cm in L72, Neptune, and Opera cultivars, respectively. Consumption of K2SO4 in L72, Neptune, and

Opera cultivars increased the silique length more effectively than in KR1, GKH3705, and GKH0224 cultivars, indicating that the former three cultivars are more reactive to potassium levels than the latter three cultivars. Wright *et al*. (1996), for example, reported that irrigation increased silique area and size. Adequate moisture and genetic traits of rapeseed could effectively optimize this trait. Some researchers believe that rapeseed cultivars with higher and larger siliques are superior to those that have smaller siliques but produce more siliques (Trabuee and Reynard, 1999). This is an inheritable trait in different cultivars and depends on genetic factors, but this genetic trait is sometimes affected by environmental conditions such as water deficit and nitrogen consumption (Trabui and Reynard, 1999).

Number of seeds per silique

According to ANOVA results, simple effects of year, K2SO4, irrigation, and cultivar, and the double interaction of irrigation × cultivar were significant at 1% level, but the triple interaction of K2SO4 × irrigation × cultivar was significant at 5% level (Table 3). Elevated stress intensity led to decreased number of seeds per silique. A comparison of average numbers of seeds per silique by the LSMEANS test showed that the highest amount of this trait was observed in normal irrigation treatment (control) among the irrigation levels in all studied cultivars with and without application of K2SO4; number of seeds per silique dropped significantly in cessation of irrigation treatments. L72 line attained the highest average number of seeds per silique (26.9) with K2SO4 application in normal irrigation conditions, and this trait was uppermost in Opera cultivar (22.6 and 18.6) in late-season drought stress (irrigation interruption from silique and flowering stages onwards). The studied cultivars were significantly different in terms of the number of seeds per silique with no K2SO4 application and normal irrigation (control), and Opera cultivar contained the highest average number of seeds per silique under cessation of irrigation from silique and flowering stages (21.6 and 17.5, respectively). Similar to the number of silique per plant, the use of K2SO4 had an increasing effect on the number of seeds in, with significant reductions in the number of seeds per silique and the number of silique per plant with no consumption of K2SO4 compared to its consumption. These results correspond to those of Sharma and Koohad (2006), Yadava *et al.* (2009), and Zaman Khan *et al.* (2004) who reported that increasing potassium fertilizer not only increased grain yield, but also elevated the number of silique per plant and the number of seeds per silique. Under extreme stress conditions of this experiment (cessation of irrigation from flowering onwards), the ability of the source (leaves) to absorb photosynthates decreased due to reduced resource activity period along with the acceleration of their aging and, consequently, a reduction in the current photosynthesis. These factors, along with the infertility of pollen grains and abortion of grains, resulted in decreased number of seeds in silique in the main stem and shoots, and the number of seeds in silique. Irrigation interruption from the reproductive growth stage caused photosynthesis reduction followed by the allocation of less photosynthates to the flowers, which reduced the number of fertile flowers. Continued water deficit was associated with declined number of seeds formed per silique. The allocation of assimilates to grains decreases under stress conditions, along with abortion of some seeds (Fayaz *et al.*, 2007). Ma *et al.* (2006) also observed decreased number of seeds in rapeseed silique as a result of drought stress.

1000-seed weight

A comparison of the averages of simple effect of K2SO4 on 1000-seed weight showed a positive effect of potassium on increasing this trait. Potassium generally caused a 7.8% elevation of 1000-seed weight compared to no use of this element. The averages of this trait were 4.1 g and 3.8 g with and without application of K2SO4, respectively (Fig. 2), which indicates the potential for weight gain under environmental and managerial conditions. A comparison of mean interaction of irrigation × cultivar by the LSMEANS test revealed that the cultivars investigated in normal irrigation (control) and cessation of irrigation from the silique stage onwards had no significant difference in terms of 1000-seed weight, with the highest average values of 3.3 and 3.2 g in Opera and L72 cultivars, respectively in cessation of irrigation treatment (Fig. 3). In addition to genetic factors, environmental conditions in the last stages of growth can also be effective in differences between cultivars. In general,

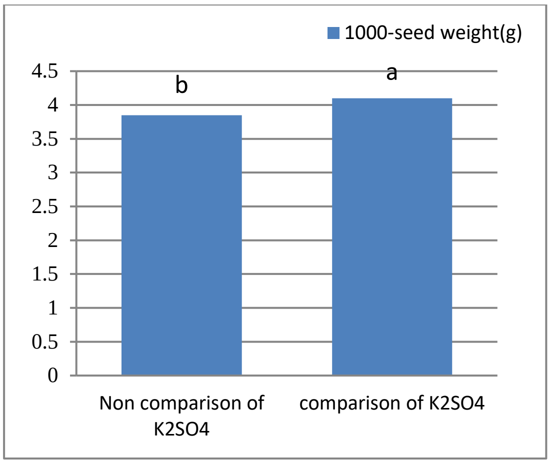

Fig. 2. A comparison of K2SO4 simple effect on 1000-seed weight (vertical bars indicate LSD)

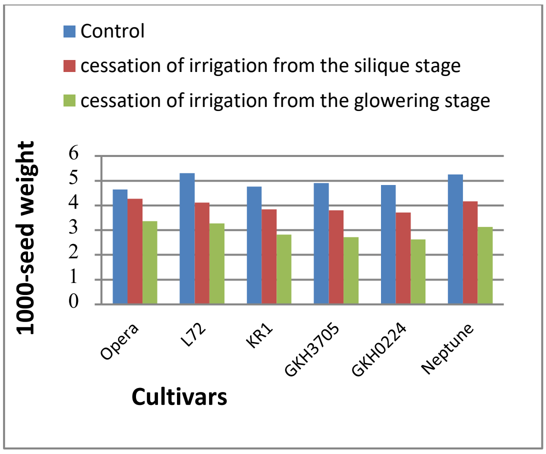

Fig. 3. A comparison of irrigation × cultivar interaction on 1000-seed weight (vertical bars indicated LSD

grain weight is a function of the rate and duration of grain filling, which is provided by two sources of current photosynthesis and remobilizotion of assimilates in the plant. Zaman Khan *et al.* (2004) also reported a significant increase in 1000-seed weight under the influence of potassium consumption. Potassium deficiency in the plant leads to premature leaf fall, the process of which accelerates during seed filling, causing yellowing of leaves and premature aging of the plant. This phenomenon causes grain weight loss due to disturbed transfer of substances to the grain (Azizi, 1998; Scott, 1992). Grain weight is generally affected by the length of the period between pollination and ripening (Faraji, 2009). Drought stress during flowering stage might have caused seed wrinkling and weight loss by disruption of plant photosynthesis and, consequently, with a reduction in the synthesis of assimilates necessary for seed filling. On the other hand, the reduced 1000-seed weight in the cessation of irrigation from the silique stage could have caused by the simultaneous seed growth with the time of stress application and disrupted transfer of assimilates produced before flowering to seeds. Under drought stress conditions, stomatal closure and decreased photosynthetic rate will lead to the production of smaller seeds, resulting in decreased 1000-seed weight of rapeseed (Sedaghat *et al.*, 2003).

Seed oil yield

The reactions of cultivars to irrigation treatments were significantly different with and without application of K2SO4 (Table 3). The highest average seed oil yields belonged to L72 line (2961 kg/ha) with K2SO4 application and conventional irrigation (control), Opera cultivar (2281 kg/ha) with cessation of irrigation from the silique stage onwards, and Opera and L72 cultivars (1618 and 1581, respectively) with cessation of irrigation from flowering stage onwards. L72 line (2838 kg/ha) without K2SO4 application and conventional irrigation (control) and Opera cultivar with cessation of irrigation from silique and flowering stages onwards (2123 and 1499 kg/ha, respectively) contained the highest seed oil yields (Table 3). Accordingly, potassium increased the seed oil yield of cultivars at all irrigation levels in comparison to the treatment without K2SO4 application. The highest positive effects of potassium were observed in GKH0224 cultivar with cessation of irrigation from silique and flowering stages onwards with averages of 9.5% and 14.2%, respectively. Zaman Khan et al. (2004) also confirmed an increase in seed oil yield with the application of K2SO4.

Total chlorophyll content (TCC) at the silique stage

ANOVA table results showed significant simple effects of year, K2SO4, irrigation, and cultivar as well as the interaction of irrigation × cultivar on TCC at a level of 1% (Table 2). Mean TCC values were significantly different in treatments with (1.47 mg/g leaf wet weight) and without (1.37 mg/g leaf wet weight) K2SO4 application (Fig. 4). A comparison of mean interaction of irrigation × cultivar by the LSMEANS test revealed that TCC values were uppermost in L72 line (1.94 mg/g leaf wet weight) with conventional irrigation (control), Opera, Neptune, and L72 (1.55, 1.51, and 1.48 mg/g leaf wet weight, respectively) with cessation of irrigation from the silique stage onwards, and Opera, L72, and Neptune (1.17, 1,13, and 1.10 mg/g leaf wet weight, respectively) with cessation of irrigation from flowering stage onwards (Fig. 4). In general, the promising L72 line contained the highest TCC at all different irrigation levels. A reason for the higher TCC in the promising L72 line in cessation of irrigation treatments could be a high concentration of carotenoids, which also play a protective role (Jalil et al., 2007). According to Sheen and Schachtmann's (2004), TCC reduction under stress conditions arises from the acceleration of leaf aging due to a hormonal disorder and remobilizotion of substances, in particular nitrogen, to seeds. Chlorophyll content in plants is one of the important factors in maintaining photosynthetic capacity (Jiang and Huang, 2001), and leaf chlorophyll is one of the most important indicators of environmental stress on plants. Measurement of chlorophyll contents, as a representative of the whole photosynthesis complex, reflects the potential for photosynthesis.

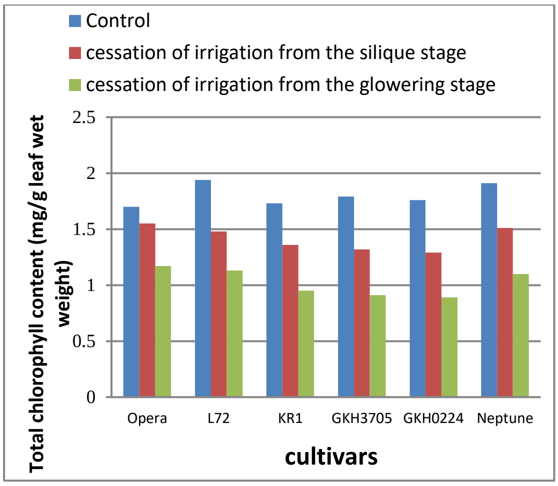

Fig. 4. A comparison of irrigation × cultivar interaction on total chlorophyll content (vertical bars indicated LSD)

Seed oil content (SOC)

Mean SOC with a 0.9% increase by K2SO4 consumption was significantly different from the treatment without K2SO4 application (Fig. 5), which is in line with a reported increase in rapeseed oil content with potassium consumption (Afaridi *et al.* 2002).

A comparison of mean irrigation × cultivar interaction by the LSMEANS test showed that the uppermost SOC averages were recorded in L72 and Neptune (46.2% and 46%, respectively) with conventional irrigation (control), Opera, Neptune, and L72 (44.7, 44.6, and 44.4%, respectively) with cessation of irrigation from the silique stage onwards, and Opera, L72, and Neptune (43.3, 43.2, and 43%, respectively) with cessation of irrigation from flowering stage onwards (Fig. 6). In this regard, Sinki *et al.* (2007) reported that drought stress at late growing season led to declined SOC.

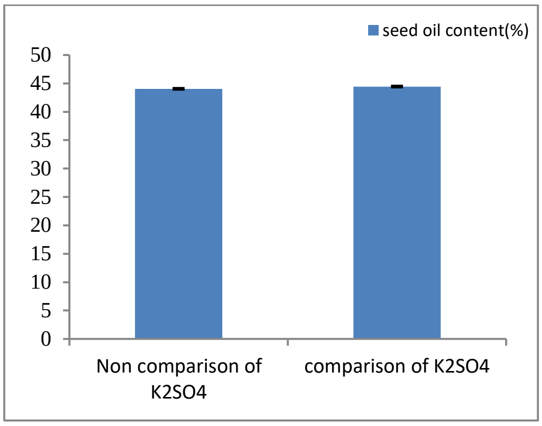

Fig. 5. A comparison of K2SO4 simple effect on seed oil content (vertical bars indicated LSD)

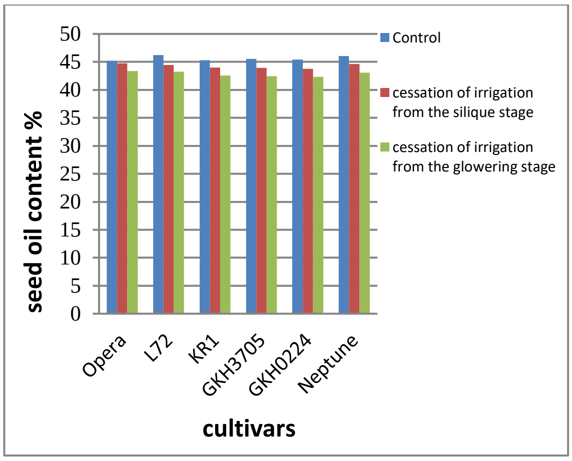

Fig. 6. A comparison of irrigation × cultivar interaction on seed oil content (vertical bars indicated LSD)

Table 4: A comparison of average interaction of K2SO4 × Irrigation × cultivar on the studied traits

K2SO4 application	Irrigation	Cultivar	Seed oil yield
K2SO4 non-application	K2SO4 application	2333c	2333c
		2838a	2838a
		2400c	2400c
		2502abc	2502abc
		2458bc	2458bc
		2780ab	2780ab

	LSD (0.05)		0.71
	Cessation of irrigation from the silique stage onwards	2123a	2123a
		2035abc	2035abc
		1818abc	1818abc
		1762bc	1762bc
		1700c	1700c
		2064ab	2064ab
	LSD (0.05)		2.12
	Cessation of irrigation from the flowering stage onwards	1499a	1499a
		1394ab	1394ab
		1156bc	1156bc
		1111bc	1111bc
		1057c	1057c
		1358abc	1358abc
	LSD (0.05)		1.40
K2SO4 application	Control	2562b	2562b
		2961a	2961a
		2616ab	2616ab
		2720ab	2720ab
		2684ab	2684ab
		2908ab	2908ab
	LSD (0.05)		0.55
	Cessation of irrigation from the silique stage onwards	2281a	2281a
		2178ab	2178ab
		1951ab	1951ab
		1921ab	1921ab
		1862b	1862b
		2222ab	2222ab
	LSD (0.05)		2.41
	Cessation of irrigation from the flowering stage onwards	1618a	1618a
		1581a	1581a
		1317abc	1317abc
		1262bc	1262bc
		1208c	1208c
		1533ab	1533ab
	LSD (0.05)		1.54

Means with at least one similar letter per column are not significantly different at 5% level.

Palmitic acid

The composition of fatty acids is the most important factor in the economic use of oilseeds. According to composite ANOVA results, the simple effects of year, irrigation, and cultivar were significant at 1% level, and the simple effect of K2SO4 was significant at 5% level (Table 2). A comparison of mean simple K2SO4 effect on palmitic acid yielded values of 4.9 and 4.7% in treatments with and without K2SO4 application, respectively. A comparison of the average simple effect of irrigation showed that different levels of irrigation were located in different statistical groups in terms of this trait. The highest (5.4%) and the lowest (4.1%) average levels of palmitic acid were measured in normal irrigation (control) and cessation of irrigation from flowering stage onwards, respectively. Based on a comparison of average simple effects of cultivars, the studied cultivars were in different statistical groups in terms of the mentioned trait, with L72, Neptune, and Opera containing the highest average levels of palmitic acid (5.02, 5, and 4.98, respectively).

Leaf proline content (LPC) at the silique stage

Based on composite ANOVA results, the simple effects of year, K2SO4, irrigation, and cultivar, and the interaction of year × irrigation, irrigation × cultivar, and year × irrigation × cultivar were significant at 1% level, and the interaction of K2SO4 × irrigation × cultivar was significant at 5% level (Table 2). According to a comparison of averages by the LSMEANS test, the lowest LPC in all the cultivars was observed in conventional irrigation treatment in both application and non-application of K2SO4, and cessation of irrigation increased LPC significantly. Non-application of K2SO4 with normal irrigation resulted in the highest average amount of LPC (13.9 µM/g leaf wet weight) in Opera cultivar. However, the cultivars did not differ significantly in terms of LPC under late-season drought stress (cessation of irrigation from the silique and flowering stages onwards). With the application of K2SO4 at all irrigation levels, LPC was not significantly different in the cultivars and were in the superior statistical groups. Overall, LPS increased with increasing intensity of stress (cessation of irrigation from the flowering stage onwards), which corresponds to those of Ma et al. (2004) and Sharma and Koohad (2006) who found increased proline synthesis under severe stress. Stress-induced proline accumulation may be due to decreased proline oxidation or its glutamate-induced synthesis or elevated protease activity (Ingram and Bartels, 1996). Proline play a quite clear role in the stability of cell membranes due to the scavenging of reactive oxygen species (Ashraf and Foolad, 2007).

Glucosinolate levels

The cultivars responded differently to irrigation treatments with and without application of K2SO4 in terms of seed glucosinolate levels, which increased with raising irrigation intervals in stress treatments (Table 5). The application of K2SO4 and normal irrigation (control) resulted in the lowest average amounts of glucosinolate in L72 line (8.9 µM/g of meal), Opera, Neptune, and L72 (12.6, 9.12, and 13.1 µM/g of meal, respectively) with cessation of irrigation from the silique stage onwards, and Opera and L72 (1.16 and 16.5 µM/g of meal, respectively) with cessation of irrigation from the flowering stage onwards (Table 5). However, conditions of non-application of K2SO4 with normal irrigation (control), cessation of irrigation from the silique stage onwards, and cessation of irrigation from the flowering stage onwards led to the lowest average seed glucosinolate levels in L72 and Neptune (9.4 and 9.7 µM/g of meal, respectively), Opera and Neptune (13.4 and 13.7 µM/g of meal, respectively), and Opera cultivar (17.2 µM/g of meal), respectively (Table 5).

Therefore, the amounts of glucosinolate were at standard limits (< 30 µM/g of meal) in both application and non-application of K2SO4 at all irrigation levels, and the use of K2SO4 reduced the amounts of glucosinolate compared to non-application conditions. The hybrid GKH3705, the promising L72 line, and Opera had the most positive reducing effects of potassium on glucosinolate levels in normal irrigation, cessation of irrigation from the silique stage onwards, and cessation of irrigation from the flowering stage onwards with 11.5%, 7%, and 6.3%, respectively (Table 4). Increased glucosinolates levels reduce the quality and nutritional value of rapeseed grain meal (Sulisbury *et al.*, 1987), which is affected by hereditary and environmental factors (Fieldsend *et al.*, 1991).

Table 5. Comparison of mean interaction of K2SO4 × irrigation × cultivar on some studied traits

K2SO4 application	Irrigation	Cultivar	Glucosinolates (µM/g of meal)
K2SO4 non-application	K2SO4 application	Opera	34.12 a
		L72	9.48b
		KR1	11.92a
		GKH3705	11.36a
		GKH0224	11.58a
		Neptune	9.76b
	LSD (0.05)		1.06
	Cessation of irrigation from the silique stage onwards	Opera	13·49c
		L72	14.10bc

		KR1	15.31ab
		GKH3705	15.65a
		GKH0224	15.91a
		Neptune	13.79c
	LSD (0.05)		1.3
	Cessation of irrigation from the flowering stage onwards	Opera	23·17c
		L72	64·17bc
		KR1	87·18a
		GKH3705	99·18a
		GKH0224	13·19a
		Neptune	88·17abc
	LSD (0.05)		1.25
K2SO4 application	Control	Opera	11.03a
		L72	8.91c
		KR1	10.72a
		GKH3705	10.01ab
		GKH0224	10.44a
		Neptune	9.13bc
	LSD (0.05)		1.05
	Cessation of irrigation from the silique stage onwards	Opera	12.64b
		L72	13.16b
		KR1	14.42a
		GKH3705	14.72a
		GKH0224	15.00a
		Neptune	12.95b
	LSD (0.05)		1.05
	Cessation of irrigation from the flowering stage onwards	Opera	16.18c
		L72	16.54c
		KR1	18.13ab
		GKH3705	18.35a
		GKH0224	18.57a
		Neptune	16.89bc
	LSD (0.05)		1.28

Means with at least one similar letter per column are not significantly different at 5% level.

Canopy temperature

Significant simple effects of year, K2SO4, irrigation, and cultivar were observed based on ANOVA results at a level of 1% (Table 2). In comparison to its non-application, the use of K2SO4 caused an adjusted and dropped temperature, with average canopy temperatures of 31.1 and 31.6 °C with and without application of K2SO4, respectively. Significant canopy temperature differences between irrigation levels showed that this trait was lowermost (with an average of 29.5 °C) in control irrigation, and cessation of irrigation reduced the canopy temperature significantly. The highest average canopy temperature (33.2 °C) was observed during the late-season drought stress with cessation of irrigation from the flowering stage onwards. Significant differences in the response of cultivars to canopy temperatures showed that L72, Neptune, and opera cultivars with average levels of 30.93, 30.98, and 31.13 C, respectively, attained the lowest canopy temperatures.

Conclusion

The use of K2SO4 at different irrigation levels had a positive effect on all the traits examined in this study and the cultivars responded differently to the application of K2SO4. The most positive effect of potassium application on glucosinolate levels was noticed in the promising L72 line with cessation of irrigation from the silique stage onwards. In addition, the promising KR1 line presented the most positive effect of K2SO4 application on seed oil yield among other cultivars with cessation of irrigation from the flowering stage onwards.

Referneces

Afridi, M. Z., Jan, M. T., & Shad, A. A. (2002). Some aspects of NPK nutrition for improved yield and oil contents of canola. Asian J Plant Sci, 5, 507-509.

Ashley, M. K., Grant, M., & Grabov, A. (2006). Plant responses to potassium deficiencies: a role for potassium transport proteins. Journal of experimental botany, 57(2), 425-436.

Ashraf, M., & Foolad, M. R. (2007). Improving plant abiotic-stress resistance by exogenous application of osmoprotectants glycine betaine and proline. Environ. Exp. Bot, 59, 206-216.

Azizi, M., M. H. Rashedmohasel, A. Kocheky, A. Rahimian and M. Azizi, M., M. H. Rashedmohasel, A. Kocheky, A. Rahimian and M. R. Ahmady. 1999. Effect of different irrigation regimes and potassium fertilizer on Agronomy, Physiological and Biochemical Characteristics of Soybean. Ph.D. thesis. Ferdowsi University of Mashhad. pp .85.

Bray, E. A. (2000). Response to abiotic stress. Biochemistry and molecular biology of plants, 1158-1203.

Cakmak, I. (2005). The role of potassium in alleviating detrimental effects of abiotic stresses in plants. Journal of Plant Nutrition and Soil Science, 168(4), 521-530.

Cakmak, I. (2005). The role of potassium in alleviating detrimental effects of abiotic stresses in plants. Journal of Plant Nutrition and Soil Science, 168(4), 521-530.

Damirchi, S. A., Savage, G. P., & Dutta, P. C. (2005). Sterol fractions in hazelnut and virgin olive oils and 4, 4′-dimethylsterols as possible markers for detection of adulteration of virgin olive oil. Journal of the American Oil Chemists' Society, 82(10), 717-725.

Enjalbert, J. N., Zheng, S., Johnson, J. J., Mullen, J. L., Byrne, P. F., & McKay, J. K. (2013). Brassicaceae germplasm diversity for agronomic and seed quality traits under drought stress. Industrial Crops and Products, 47, 176-185.

Farooq, M., Wahid, A., Kobayashi, N., Fujita, D. B. S. M. A., & Basra, S. M. A. (2009). Plant drought stress: effects, mechanisms and management. In Sustainable agriculture (pp. 153-188). Springer, Dordrecht.

Fayaz, F., NADERI, D. M., & SHIRANI, R. A. (2007). Evaluation of drought stress effects on yield and yield components of advanced Rapeseed varieties at Esfahan region.

Fieldsend, J. K., Murray, F. E., Bilsborrow, P. E., Milford, G. F. J., & Evans, E. J. (1991). Glucosinolate accumulation during seed development in winter sown oilseed rape (B. napus). In Proceedings of 8th International Rapeseed Congress (pp. 686-694).

Harinder, P.S.Makkar, Siddhuraju, P., Klaus Becker. 2007. Plant secondary metabolites, Hummana Press, 58-60

ISO 5511:1992, Oilseeds-Determination of oil content-Method using continuous-wave low-resolution nuclear magnetic resonance spectrometry (Rapid method).

Ingram, J., & Bartels, D. (1996). The molecular basis of dehydration tolerance in plants. Annual review of plant biology, 47(1), 377-403.

[16] Jaleel, C. A., Manivannan, P., Sankar, B., Kishorekumar, A., Gopi, R., Somasundaram, R., & Panneerselvam, R. (2007). Water deficit stress mitigation by calcium chloride in Catharanthus roseus: Effects on oxidative stress, proline metabolism and indole alkaloid accumulation. Colloids and Surfaces B: Biointerfaces, 60(1), 110-116.

Javidfar, F., F. Reipley, H. Zeinaly, S. Abdmishani, A.A. Shah Nejat Boushehri, R. Tavakol Afshari, B.Alizadeh and E. Jafarieh. 2007. Heritability of fatty acids composition in sping oilseed rape(Brassica napus L.). Journal of Agriculture and Science. 17(3): 57-64.

Jiang, Y., & Huang, B. (2001). Osmotic adjustment and root growth associated with drought preconditioning-enhanced heat tolerance in Kentucky bluegrass. Crop Science, 41(4), 1168-1173.

Kadivar, S., Ghavami, M., Gharachorloo, M., & Delkhosh, B. (2010). Chemical evaluation of oil extracted from different varieties of colza.

Khan, H. Z., Malik, M. A., Saleem, M. F., & Aziz, I. (2004). Effect of different potassium fertilization levels on growth, seed yield and oil contents of canola (Brassica napus L.). Int. J. Agric. Biol, 6(3), 557-559.

Ma, Q., Niknam, S. R., & Turner, D. W. (2006). Responses of osmotic adjustment and seed yield of Brassica napus and B. juncea to soil water deficit at different growth stages. Australian Journal of Agricultural Research, 57(2), 221-226.

Nasr, N., Khayami, M., HEYDARI, R., & JAMEEI, R. (2006). Genetic diversity among selected varieties of Brassica napus (Cruciferae) based on the biochemical composition of seeds.

Nasri, M., Zahedi, H., Moghadam, H. T., Ghooshci, F., & Paknejad, F. (2008). Investigation of water stress on macro elements in rapeseed genotypes leaf (Brassica napus). American Journal of Agricultural and Biological Sciences, 3(4), 669-672.

Sadaqat, H. A., Tahir, M. H. N., & Hussain, M. T. (2003). Physiogenetic aspects of drought tolerance in canola (Brassica napus). International Journal of Agriculture and Biology, 5(4), 611-614.

Sardans, J., & Peñuelas, J. (2008). Drought changes nutrient sources, content and stoichiometry in the bryophyte Hypnum cupressiforme Hedw. growing in a Mediterranean forest. Journal of Bryology, 30(1), 59-65.

Scarth, R., & Tang, J. (2006). Modification of Brassica oil using conventional and transgenic approaches. Crop science, 46(3), 1225-1236.

Scott, D. A., Proctor, J., & Thompson, J. (1992). Ecological studies on a lowland evergreen rain forest on Maracá Island, Roraima, Brazil. II. Litter and nutrient cycling. Journal of Ecology, 705-717.

Sharma, H. C. (2002). More potash is needed for high yield and quality of oilseeds crops in India. Indian J. Agric.

Sharma, K. D., & Kuhad, M. S. (2006). Influence of potassium level and soil moisture regime on biochemical metabolites of Brassica species. Brassica Journal, 8, 71-74.

Shin, R., & Schachtman, D. P. (2004). Hydrogen peroxide mediates plant root cell response to nutrient deprivation. Proceedings of the National Academy of Sciences, 101(23), 8827-8832.

Sinaki J, Majidi Heravan ME, Shirani Rad AH, Noormohammadi GH and Zarei GH, 2007. The effects of water deficit during growth stages of canola. American Eurasian Journal Agricultural Biological Science 2:417- 422

Si, P., & Walton, G. H. (2004). Determinants of oil concentration and seed yield in canola and Indian mustard in the lower rainfall areas of Western Australia. Australian Journal of Agricultural Research, 55(3), 367-377.

Salisbury, P., Sang, J., & Cawood, R. (1988). Genetic and environmental factors influencing glucosinolate content in rapeseed in southern Australia. In 7th International Rapeseed Congress/convened under the patronage of Stanislaw Zieba; by the Plant Breeding and Acclimatization Institute under the auspices of the Group Consultatif International de Recherche sur le Colza. Poznan.: Panstwowe Wydawnictwo Rolnicze i Lesne, 1988..

Sun, X. P., Yan, H. L., Kang, X. Y., & Ma, F. W. (2013). Growth, gas exchange, and water-use efficiency response of two young apple cultivars to drought stress in two scion-one rootstock grafting system. Photosynthetica, 51(3), 404-410.

Triboi-Blondel, A. M., & Renard, M. (1999, September). Effects of temperature and water stress on fatty acid composition of rapeseed oil. In 10th International Rapeseed Congress (pp. 26-29).

Yadav, S. S., Singh, S., Tikoo, A., & Yadava, J. S. (2007). Studies on potash responses to field crops in light textured soils of Southern Haryana. India. e-ifc, 13, 4-7.

Aslam, M.N., M.N. Nelson, S.G. Kailis, K.L. Bayliss, J. Speijers and W.A. Cowling. 2009. Canola oil increases in polyunsaturated fatty acids and decreases in oleic acid in drought-stressed Mediterranean-type environments. Plant Breeding. 128 (4): 348-355.

Flagella, Z., Rotunno, T., Tarantino, E., Di Caterina, R. and De Caro, A. 2002. Changes in seed yield and oil fatty acid composition of high oleic sunflower (Helianthus annuus L.) hybrids in relation to the sowing date and water regime. European Journal of Agronomy 17: 221–230.

Gecgel, U., Demirci, M., Esendal, E. and Tasan, M., 2007. Fatty acid composition of the oil from developing seeds of different cultivars of safflower (Carthamus tinctorius L.). Journal of the American Oil Chemists' Society 84: 47-54.

Kauseri, R. H., U. R. Athar and M. Ashraf. 2006.

Chlorophyll fluoresce: A Potential indicator for rapid assessment of water stress tolerance in Canola. Pak. J. Bot. 38(5): 1501-1509.

Ul-Hassan, F., H. Ali, M. Akhtar Cheema and A. Manaf. 2005. Effects of environmental variation on oil content and fatty acid composition of canola cultivars. J. Res (Science), Bahauddin Zakariya University, Multan, Pakistan. 16 (2): 65-72.

Vyas, S. P., B. K. Garg, S. Kathju and A. N. Lahiri. 2001. Influence of potassium on water relations, photosynthesis nitrogen metabolism and yield of cluster bean under soil moisture deficit stress. Indian J. Plant Physiol. 6:30-37.