ANALYSIS OF THE EFFECT OF PLANT DENSITY AND USE OF SELENIUM ON OIL QUALITY AND QUANTITY IN WINTER-PLANTED CANOLA VARIETIES

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Abstract. This study was carried out in Iran to determine the effect of foliar application of Selenium and plant density on oil quality and quantity and fatty acid composition of canola cultivars. The experiment was laid out in a factorial split plot arrangement based on a complete blocked design with three replications at Karaj Seedling and Seed Breeding Institute, Karaj, Iran during 2015 and 2016. Treatments were plant density (40, 60 and 80 plants/area) and foliar application of selenium (0 and 30 g.l^{-1} sodium selenite) in main plots and varieties (Sarigol, Hyola 401, Jacomo, Jerome, and Dalgan) in sub-plots**.** The results showed that year, plant density, selenium, variety treatments, and interaction effect of density*year and cultivar*density had a significant effect on seed yield, oil yield, oil percentage, and fatty acid composition, such as palmitic, linolenic, linoleic, oleic and erusic acids ($P \leq 0.01$). The Dalgan variety had the highest seed and oil yield in 40 plants per square meter (m^2) density (4817.41 and 2134.83 kg.ha^{-1} respectively). Maximum seed oil content (43.78%) was obtained in 40 plants per square density treatment. However, the maximum rates of seed oil yield, palmitic acid, and linoleic acid were observed in Hyola-401 variety, and Jerome variety had the highest linolenic and erusic acid. The palmitic and linolenic acids in Dalgan variety at 40 plants per square treatment had the maximum rate. The findings showed that with increasing of plant density decreased grain yield, oil content and fatty acid compositions. However, application of selenium increased them especially in Dalgan variety. Also the highest seed yield, seed oil content and palmitic acid and lowest amount of linolenic and erusic acids was obtained in Dalgan variety. The maximum linoleic and erusic acid was obtained in Jermco variety. The lowest erusic acid was obtained in 40 plants per square treatment. The results also showed that foliar application of selenium increased seed yield, seed oil yield, palmitic, linolenic and erusic acid compared to non-application of it. In final the present study indicated that increased seed yield, oil content, oil yield and fatty acid quality in 40 plants/area treatment, specially Dalgan variety in Golestan province, Iran.
Keywords: *erusic acid, fatty acids, foliar application, sodium selenate, yield*

Introduction

Canola (*Brassica napus* L.) is an oilseed plant that has a wide range of adaptation to different climates, and has two autumn and spring types and is utilized in the crop rotation programs in different regions (Angadi et al., 2003). In terms of oil production canola is locate after soybean (FAO, 2017). Various canola cultivars' capability to germinate and grow at low temperatures resulted in increasing development of its cultivation in cold regions of the world, including Canada, northern Europe and the cold parts of Asia. This issue has caused several studies to be conducted on this product in

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the cold regions. Following soybean, canola is the second most important source for production of edible oil in the world (FAO, 2017).

The canola seed oil content, quality and components have always been the concern of plant breeders. Fatty acid compounds and unsaturated fatty acids levels controlled genetically controlled but also affected by environmental conditions (Bellaloui et al., 2013). Studies have shown that some environmental factors, such as the temperature and shading (Ruuska et al., 2004), for example, at high plant density per unit area, change the composition of fatty acids. They state that the oil seed produced under shade conditions has less fatty acids than those produced in full sunlight. Today, the canola yield and oil quality have rapidly increased in order to mechanize harvesting, higher yield cultivars introduction, and better agronomic practices (Shahbaz et al., 2018). However, further studies are needed to increase canola oil yield and quality.

Plant density is the most important factor to reach the maximum crops yield. Along with the use of suitable cultivars adapted to the climatic conditions of each area, as well as the maximum use of environmental resources such as light, water, and nutrients, it can allow the result to achieve higher crop yields (Chavan, 1989). However, increasing the plant density reduces the number of stems per plant due to the increase of inter-plant competition, which decreases the number of stems or lateral branches by decreasing the allocated space per plant (Vega et al., 2000). Increasing the plant density results in the single plant yield reduction by reducing the number of sub-branches and the number of pods per plant, but the appropriate increase of plant density will result in compensation of sub-branch and plant yield components' reduction by increasing the number of plants per area (Onofri et al., 1996). In high density rape seed, plant bedding and chlorophyll degradation in the plant increased, resulting in the loss of yield due to inter and intra-plant competition (Morrison et al., 1990). They argued that the reduction of light in the plant community is a major cause of the early leaves senescence, and appropriate density can delay their senescence by having an effect on the leaves emitted radiation. It was reported that with the increasse in plant density, the number of pods per square increased, but the number of seeds per pod and 1000 grain weight linearly decreased that resulted in the decrease of grain yield (Ozer, 2003). Also, Bilgili et al. (2003) and Lythgoe et al. (2001) concluded that the plant density plays a major role in rapeseed grain yield. Canola can adjust its grain yield in a wide range of density. The ability of a plant to compensate of below optimal level density depends on available resources, such as light, water, and nutrients (Angadi et al., 2004). The scores of higher plant density are prevention of the large number of branches and the number of pods in branches that leads to uniform maturity of canola (Malhi and Gill, 2004).

Due to an impact on the growth and development of plants and its presence in antioxidant systems, selenium is recognized as one of the vital elements for human and animal health. While beneficial elements are not involved directly in the metabolism of plants and completing their life cycle, they play a role in improving the vegetative and reproductive growth, especially in environmental or biological stress conditions (Hajibolan, 2012). Recent findings reveal that selenium at low concentrations can enhance oxidative stress resistance by increasing antioxidant capacity, which has a positive effect on the decrease of lipid peroxidation. This indicates the positive impact of selenium in reducing lipid peroxidation and increasing the activity of anti-oxidative enzymes (Seppanen et al., 2003; Xue et al., 2001). Low concentration of selenium has a beneficial impact on the plants' growth and stress resistance through their antioxidant capacity (Turakainen, 2000). The use of selenium leads into an increase in plant height,

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number of pods, number of seeds per pod, biological yield, harvest index and oil percentage and reduced respiration, proline and malondialdehyde (Bybordi, 2016). Seppanen et al. (2003) reported that selenium prevents chlorophyll degradation in environmental stress conditions. Other beneficial impacts of selenium are increasing metabolism of carbohydrates and the stress resistance (Zhu et al., 2004). Haji Boland et al. (2014) showed that the impact of selenium in increasing drought resistance and improving the water relations in canola was related to increasing the water absorption due to development of root, which increased the photosynthesis and forming the soluble sugars. By conducting the studies on the methods of increasing the yield under density conditions, we can provide an appropriate mechanism for improving product yields.

However, information on selenium foliar application and plant density on fatty acid composition changes and oil quality are limited in canola. Therefore, this study was conducted to examine the application of selenium on the seed oil quantity and quality in various winter-planted canola cultivars, in order to reduce the adverse effects of stress resulting from density.

Material and methods

Research location: the present study was conducted in two years of 2015 and 2016 in a 400-ha farm of Karaj Seedling and Seed Breeding Institute, Karaj, Iran (35°49’). The latitude of the location is 35°49’N and its longitude is 51°6’E and its height from sea surface is 1321 m.

Meteorological information: this region is considered among the hot and dry Mediterranean climate regions based on the climate data and amberthermic curve, due to having 150 to 180 dry days in a year. It is also considered a dry humidity regime, due to having cold and wet winters and hot and dry summers. According to the 30-year Karaj meteorological information, the average rainfall is 243 mm per year. In this region, rainfall occurs often in the late fall and early spring. The average annual maximum temperature is seen in July with 28 °C and the average annual minimum temperature is seen in January with 1 °C. The average temperature of this region in a 30-year period is 13.5 °C and the soil temperature is 14.5 °C.

Soil characteristics of the region: according to *Table 1*, soil texture of the region is loamy and clay (*Table 1*).

Table 1. *Soil characteristics in experimental location*

Characteristics	Electrical conductivity (dS/m)	pH	Percentage of neutralized materials	Humidity percentage of saturated clay	Organic carbon (%)	Nitrogen (%)	Phosphorus (Mg/kg)	Potassium (Mg/kg)	Percentage of clay	Percentage of silt	Percentage of sand
Sampling depth (0-30 cm)	1.45	7.9	8.56	36	0.91	0.09	14.7	197	28	47	25
Sampling depth (30-60 cm)	1.24	7.2	8.68	38	0.99	0.07	15.8	155	25	49	26

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According to the results of soil analysis and fertilizer recommendation, we applied fertilizer (a part of the N fertilizer and all of the P and K fertilizer required). We also applied Treflan herbicide (2.5 l/ha) laid uniformly in field. Fertilizer and herbicide were mixed with soil using disk. For the optimal usage of nitrogen, the rest of the required nitrogen fertilizer was used at the beginning of the stem generation and the emergence of the first flower buds. After conducting the experiment, the feeding operation including the control of pests, especially wax aphid, was performed using metasystoxpesticide in accordance with the planting plan and seedling emergence, which was approximately 1.5 l/ha.

Statistical design: the experiment was laid out in a factorial split plot arrangement based on completely randomized block design with three replications. Here, we would plot the plants to the maximum capacity in terms of density and would separate and single out the plants to reach an ideal amount for this experiment. In this experiment, treatments were plant density at three levels of 40, 60 and 80 m^2 and with selenium in two levels of control (lack of foliar application (water) and foliar application with selenium at amounts of 30 $g.l^{-1}$ sodium selenate were placed as a factorial in main plots, and five cultivar such as Sarigol, Hyola 401, Jacomo, Jerome, and Dalgan was placed at sub-plots. Each experimental plot included 6 rows with 30 and 4 cm row to row and plant to plant distance respectively. Middle rows were harvested to seed yield to determination. Irrigation was performed in accordance with the plant requirement using siphon. Foliar application of selenium (30 $g.l^{-1}$ sodium selenite per hectar) applied in two stages, 15 $g.l^{-1}$/ha before rosette and 15 $g.l^{-1}$/ha in the fast stem growth stage and foliar application of water as control. After treatments, a 5 grams seed sample was selected from each plot to determine the amount of the seed oil content using an NMR device. After determining the seed oil percentage, the seed yield was calculated in $kg.ha^{-1}$. Gas chromatography method was used to measure and determine the seed oil fatty acid and its composition (Yang et al., 2009). Statistical analysis was also performed using the SAS 9.1 software. In order to compare the means of the traits, Duncan statistical method was used at the level of 5%.

Results

Seed yield: according to the analysis of variance table, the effect of year, density, variety, and selenium, the interaction effect of variety * density were significant on seed yield ($P \leq 0.01$). Also, the effect of year, block and density were significant on seed oil content, while the interaction of the studied treatments had no significant effect on this trait (*Table 2*). The effect of year, block, density, variety, selenium and interaction effect of variety * density were significant on seed oil yield ($P \leq 0.01$). The results of present study showed that the year, block, density, selenium, variety treatments were significant on fatty acid composition, such as palmitic, linolenic, linoleic, oleic and erusic acids ($P \leq 0.01$). However, the interaction effect of variety * density were significant on all fatty acid composition, except linolenic and oleic acids (*Table 2*).

The results showed that the highest seed yield was obtained in Dalgan variety cultivated in 40 plants per m^2 density (4817.41 $kg.ha^{-1}$), and the lowest seed yield was obtained in Sarigol variety at 80 plant per m^2 density (1519.91 $kg.ha^{-1}$) (*Fig. 1*). Based on the results, the Jerome variety had the lowest seed yield in 40 and 60 plant per m^2 density treatment (3895 and 2541 $kg.m^{-2}$ respectively) (*Fig. 1*). Increasing the plant density decreases seed yield significantly in all varieties.

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The findings of the present study showed that the highest seed oil content was obtained at the 40 plants per square density treatment (43.78%), compared to 80 plants per square density treatment (41.71%) ($P \leq 0.05$) (*Table 3*). However, in 40 plants per square density treatment, the highest seed oil yield, palmitic, linoleic acid, linolenic, oleic and erusic acids were obtained and with increasing the plant density it reduced them significantly (*Table 3*). There are significant reductions in seed yield, seed oil yield, palmitic, linoleic acid, linolenic, oleic and erusic acids by the increase in plant densities (*Table 3*).

Table 2. *Analysis of variance for effect of plant density and application of selenium on seed yield and oil quality of canola varieties*

Source of variations	df	Seed yield (kg/ha)	Seed oil content (%)	Seed oil yield (kg/ha)	Palmitic acid (%)	Linolenic acid (%)	Linoleic acid (%)	Oleic acid (%)	Erusic acid (%)
Year	1	2033944**	53.38**	708886**	8.42**	1.02**	22.66**	15.89 ns	0.004**
Block (year)	4	196524**	21.20*	101354**	0.63**	0.49**	6.23**	23.18**	0.001 ns
Density	2	88636772**	64.22**	18379067**	29.52**	86.01**	183.25**	194.89**	0.43**
Year×density	2	31792 ns	2.53 ns	21324 ns	0.51**	0.02 ns	0.22 ns	0.47 ns	0.00 ns
Selenium	1	1340929**	2.89 ns	283387**	0.39*	0.97**	2.43 ns	2.36 ns	0.01**
Year×selenium	1	1572 ns	0.04 ns	1680 ns	0.00 ns	0.01 ns	0.00 ns	0.00 ns	0.00 ns
Density×selenium	2	167427*	0.17 ns	43175 ns	0.03 ns	0.07 ns	0.31 ns	0.23 ns	0.001 ns
Year×density×selenium	2	6707 ns	0.03 ns	1849 ns	0.01 ns	0.01 ns	0.00 ns	0.00 ns	0.00 ns
Block×year×density×selenium	20	201006	17.11	24449	0.36	0.52	3.12	10.06	0.001
Variety	4	3889155**	3.05 ns	825393**	1.27**	3.79**	8.04**	8.96 ns	0.02**
Variety×density	8	734100**	0.57 ns	156745**	0.26**	0.71**	1.41 ns	1.51 ns	0.003**
Variety×selenium	4	81848 ns	0.04 ns	17.338 ns	0.02 ns	0.04 ns	0.13 ns	0.14 ns	0.00 ns
Year×variety	4	9775 ns	0.11 ns	1667 ns	0.01 ns	0.00 ns	0.02 ns	0.03 ns	0.00 ns
Year×density×variety	8	6752 ns	0.03 ns	1600 ns	0.02 ns	0.02 ns	0.01 ns	0.01 ns	0.00 ns
Year×selenium×variety	4	2274 ns	0.00 ns	679 ns	0.00 ns	0.00 ns	0.00 ns	0.00 ns	0.00 ns
Density×selenium×variety	8	42383 ns	0.02 ns	9653 ns	0.01 ns	0.03 ns	0.05 ns	0.006 ns	0.00 ns
Year×density×selenium×variety	8	2481 ns	0.01 ns	843 ns	0.00 ns	0.00 ns	0.00 ns	0.00 ns	0.00 ns
Total error	96	52358	7.42	18583	0.07	0.11	1.68	6.63	0.00
Coefficient of variations (%)	-	7.46	6.37	10.33	5.3	5.71	6.81	3.97	5.90

*, **, and ns represent significance at the level of 5% and 1%, and non significance, respectively

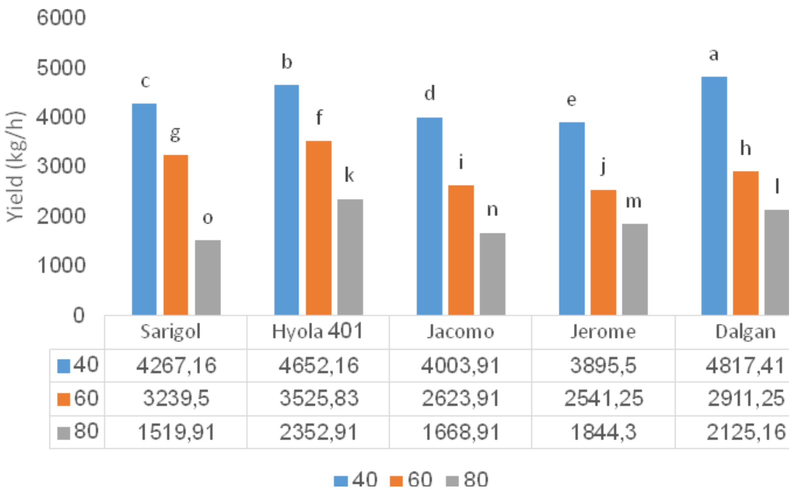

Figure 1. *Effect of different densities on seed yield of canola varieties. (Columns by uncommon letters had significant differences)*

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Table 3. *Effect of different densities on seed yield and fatty acid compounds in the canola varieties*

Density (plant per m^2)	Seed yield (kg/ha)	Seed oil content (%)	Seed oil yield (kg/ha)	Palmitic acid (%)	Linolenic acid (%)	Linoleic acid (%)	Oleic acid (%)	Erusic acid (%)
40	4327.23a	43.782 a	1896.45 a	5.85 a	7.06 a	20.74 a	65.35a	0.39 a
60	2963.35 b	42.6797 b	1267.85 b	5.21 b	5.85 b	18.96 b	63.53 b	0.31 b
80	1902.25c	41.7143 c	793.1c	4.45 c	4.66 c	17.25 c	61.75 c	0.22 c

Means by uncommon letters had significant differences

Foliar application of selenium increased seed yield significantly compared to control (3679.63 kg.ha^{-1}) (*Table 4*). Also, The results of the present study showed that application of selenium increases seed oil yield (1358.81 kg.ha^{-1}), palmitic (5.21%), linolenic (5.93%) and erusic (0.32%) acids (*Table 4*).

Table 4. *Effect of selenium application on seed yield and fatty acid compounds in the canola varieties*

Selenium	Seed yield (kg/ha)	Seed oil yield (kg/ha)	Palmitic acid (%)	Linolenic acid (%)	Erusic acid (%)
Selenium foliar application	3679.63 a	1358.81 a	5.21 a	5.93 a	0.32 a
Lack of application with foliar application	3152.26 b	1279.46 b	5.12 b	5.78 b	0.30 b

Means by uncommon letters had significant differences

The results showed that the highest amount of seed oil yield (1521 kg.ha^{-1}), palmitic acid (5.452%) and linoleic acid (19.62%) were obtained in Hyola-401 variety but the highest linolenic acid (6.17%) and erusic acid (0.33%) were obtained in Jerome variety (*Table 5*). However, the erusic acid, as a negative factor in fatty acid composition in the Dalgan variety, was lower than other varieties (0.29%). There are no significant differences between Jacomo and Jerome varieties in seed yield, seed oil yield, palmitic, linolenic, linoleic and erusic acids. However between Hyola-401 and Dalgan there are no significant differences in palmitic and linoleic acids.

Table 5. *Effect of variety treatment on seed yield and some fatty acid compounds in the canola varieties*

Variety	Seed yield (kg/ha)	Seed oil yield (kg/ha)	Palmitic acid (%)	Linolenic acid (%)	Linoleic acid (%)	Erusic acid (%)
Hyola 401	3510.31a	1521.44 a	5.42 a	5.41d	19.62 a	0.27d
Dalgan	3284.61b	1421.58b	5.29 a	5.65 c	19.30ab	0.29 c
Sarigol	3008.86c	1296.38 c	5.15 b	5.90 b	18.91bc	0.31 b
Jacomo	2765.58 d	1180.03 d	5.01 c	6.14 a	18.56 c	0.33 a
Jerome	2760.36 d	1176.25 d	4.98 c	6.17a	18.53c	0.33 a

Means by uncommon letters had significant differences

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The results showed that the Dalgan variety had the highest oil yield in 40 plants per m^2 density treatment (2134.83 kg.ha^{-1}), while Jerome variety had the lowest oil yield at the same density (1686.75 kg.ha^{-1}) (*Fig. 2*). However, in 80 plants per square density treatment the Sarigol variety had the lowest seed oil content (628.08 kg.ha^{-1}). Based on the results in all varieties, oil yield decreased significantly by the increase in plant density.

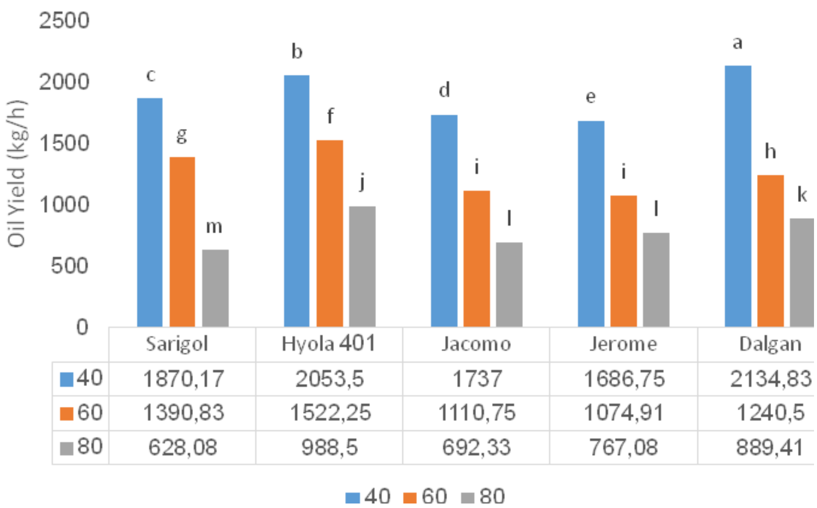

Figure 2. *The interaction effect of different densities on oil yield of canola varieties. (Columns by uncommon letters had significant differences)*

The 40 plants per square treatment had the highest fatty acid composition. The highest palmitic and linolenic acids was observed in Dalgam cultivar at 40 plants per square density treatment with amounts of 6.08 and 66.06, respectively. In addition, the lowest amount of erusic acid (0.18) was obtained in this cultivar with the same density conditions (*Table 6*). The oleic, linolenic and linoleic as three unsaturated fatty acids that oleic and erusic acids significantly decreased with increasing plants density (*Tables 3* and *6*), reaching a a maximum reduction in 80 plant per square density treatment compared with the 60 plant per square treatment. Interaction effect of plant density*variety shows that the highest palmitic acid (6.08%) and oleic acid (66.06%) were obtained in Dalgan variety in 60 plant per square density treatment (*Table 6*). The decrease of these fatty acid compounds result to oil quality reduction. The 40 plants per square density treatment had the lowest erusic acid and in this plant density treatment erusic acids percent in Dalgan, Hyola-401, Sarigol, Jacomo and Jerome varieties were 18, 19, 23, 24 and 25%, respectively (*Table 6*)

Table 6. *Interaction effect of plant density*variety on fatty acid composition in canola varieties*

Density (plant per m^2)	**Variety**	**Palmiticacid** (%)	**Oleic acid** (%)	**Erusic acid (%)**
40	Sarigol	5.79 C	65.21 b	0.23 m
	Hyola 401	6.00 b	65.85 a	0.19 n
	Jacomo	5.70 d	64.86c	0.24 l
	Jerome	5.65 e	64.79 c	0.25 k
	Dalgan	6.08 a	66.06 a	0.18 o

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60	Sarigol	5.42 g	63.96e	0.29 i
	Hyola 401	5.53 f	64.37 d	0.27 j
	Jacomo	4.99 i	63.01 g	0.33 g
	Jerome	4.88 j	62.82 g	0.34 f
	Dalgan	5.24 h	63.49 f	0.31 h
80	Sarigol	4.23 o	63.21 k	0.42 a
	Hyola 401	4.72 k	62.45 h	0.36 e
	Jacomo	4.32 n	61.42 jk	0.41 b
	Jerome	4.40 m	61.61 j	0.40 c
	Dalgan	4.56 l	62.04 i	0.38 d

Means by uncommon letters had significant differences

The palmitic acid content in 2016 was higher than 2015 due to the lower temperature at the grain filling period. In both years, the palmitic acid as a saturated fatty acid decreased linearly with increasing of plant density. The results also showed that palmitic acid decreased significantly by the increase of plant density in both years (*Fig. 3*).

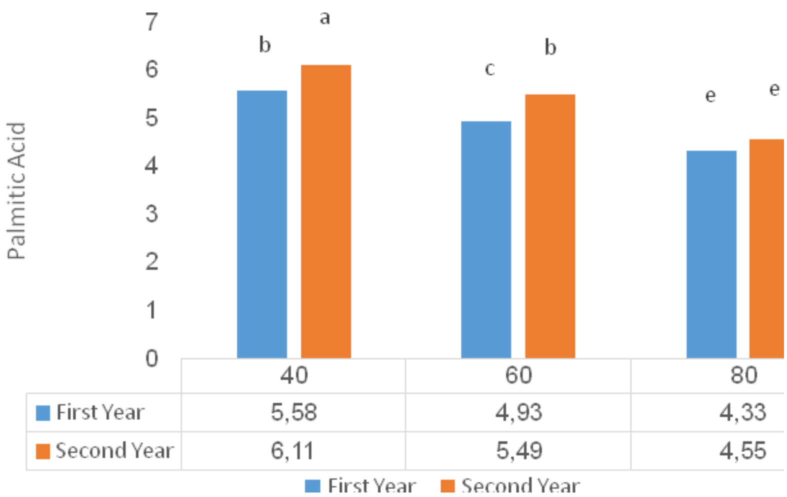

Figure 3. *The effect of different plants density on palmitic acid in canola varieties during 2015-2016. (Columns by uncommon letters had significant differences)*

Discussion

In the present study there are significant differences between varieties in the seed yield. Rezadoost and Rashidi (2003) reported that cultivar had a significant effect on the seed yield ($P \leq 0.01$). Increasing the plant density from 40 to 80 plants per square decreases the seed yield of canola genotypes from 6337 kg.ha^{-1} to 2741 kg.ha^{-1} (Nasiri et al., 2017). Looking at the yield components, including the number of pods per plant, number of seeds per pod and 1000-seed weight, it is seen that all of these traits are affected by factors such as the optimal use of light, nutrients, appropriate density, efficient photosynthesis and the adequate uptake of assimilate materials by plant, which all of them are effective in increasing the seed yield (Wales, 1991). Onofri et al. (1996) found that seed yield per hectare increased with increasing plant density, but an extreme

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increase in the plant density reduced seed yield. The seed yield was reduced in this study as density was increased from 40 to 80 plants per square meter that is in line with findings of Chavan et al. (1989); Patel et al. (1980) and Tanveer et al. (1998) in canola. Increasing the plant population per square in high density plants result in increasing of the inter-plant competition for water and nutrients, and the reduced grain number and weight per plants that laid to the grain yield reduction. Vega et al. (2000) concluded that plant density forced a strong competition for water and nutrient absorption during the grain filling period. This means that the process distributed lower nutrient between grains, therefore allocating less dry matter to physiological sinks at grain filling period. The Jerome variety had the lowest seed yield in 40 and 60 plant per m^2 density. Similarly, Naseri et al. (2012) reported that the thicker density plans (80 plants per m^2) reduced canopy sunlight absorption, assimilation, and transformed them to reproductive sinks that laid to the increasing of competition among plants and seed yield reduction. Chavan et al. (1989) reviled that higher plant densities resulted in seed yield reduction due to the increase of plant elongation and competition. However, in an appropriate density, environmental factors were optimum for higher assimilation then achieving higher seed yield.

Different results have been observed on the effect of plant density on the changes in oil content of oil-seed plants. Danesh-Shahraki et al. (2008) held that the plant density had a significant effect on oil content of canola. The seed oil content was reduced associated with increasing of plant density in canola (Onofri et al., 1996), sunflower (Vega, 2000) and soybean (Wells, 1991). It seems that the low and uniform distribution of plants in a lower plant density reduces the plant competition and better photosynthetic system performance that results in increasing of the seed oil content (Wells, 1991). Onofri et al. (1996) attributed the increasing of oil percent in lower plant density per unit area to the increasing number of pods per plant and the relative grain size reduction.

With regards to this fact that the application of selenium increased grain yield, some researchers founded that the application of selenium increases yield in rapeseed (Zahedi et al., 2009), potato (Turakainen et al., 2004; Germ et al., 2007), lettuce (Ramos et al., 2010) and buckwheat (Ozbolt et al., 2008). Kopsell et al. (2000) founded that foliar application of selenium increases chlorophyll content of *Brassicaoleracea* due to positive effects of leaves' Mg content that led to the increase of the photosynthesis and yield. Selenium delayed leaf senescence (Hawrylak-Nowak et al., 2009), increased plant growth and yield due to the increase of starch storage in chloroplasts (Xue et al., 2001). They also told that the selenium had a protective role for cell water status and adjusted it in a water deficit condition. Germ et al. (2003) holds that the selenium consumption by plants compensate the water deficit that results to increasing of grain yield. Even though selenium is not an essential element for plant growth (Djanaguiraman et al., 2005), the present study indicates that the foliar application of selenium increased the grain yield of canola at 30 $g.l^{-1}.ha^{-1}$. Zahedi et al. (2010) argued that the increase of rapeseed grain yield by foliar application of selenium is due to the increase of number of pods per plant and the number of grain per pods, which are in line with these findings. The application of selenium reduced the water deficit stress damages in potato (Germ et al., 2007) and rapeseed (Valadabadi et al., 2010) and that laid to the increase of biological yield.

The seed oil yield and fatty acid composition increased with the application of selenium. Other researchers such as Davoodi et al. (2016) founded that fatty acid

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composition such as palmitic acid oleic acid, were increased by the foliar application of selenium in canola. Since Linoleic acid is an essential fatty acid for photosynthetic activity (Hugly et al., 1989) and canola pollen development (Mc-Conn and Browse., 1996), selenium application seems to increase the linoleic acid synthesis and the improvement of photosynthetic conditions, which lead to the increase of plant grain yield. However, the increase of seed oil yield might be the result of supply assimiliation at grain filling period which linked with the increase of silique photosynthesis (Shahbaz et al., 2018). They also find that canola oil quality is depended on quantity of oleic, linoleic, and linolenic acids as fatty acid composition. The composition of canola fatty acid has 60–65% oleic acid, 18–20% linoleic acid, 10–10.5% linolenic acid, and less than 3% erusic acid (Rathke et al., 2006). However, it should be noted that the erusic acid is an important indicator for rapeseed oil quality and its edible consumption (Gesgel et al., 2007), and in this study, foliar application of selenium increases erusic acid content.

The Hyola-401 variety had the highest seed oil yield. Naseri et al. (2012) founded the Hyola-401 hybrid had the highest seed yield than Hyola 308, Zarfam and Sarigol cultivars. They argued that the seed yield difference may be due to their genetic properties. Pasbaneslam (2015) evaluated 23 spring and autumn genotypes of canola in terms of seed yield, oil, and seed oil percentage, and he reported a significant difference among the cultivars. They found that there are significant differences between the different genotypes in this state. However differences between varieties in seed yield can be found because of genetic differentiation. The variation of seed yield among the rapeseed varieties may be attributed to their genetic potential (Sana et al., 2003). There are significant differences for seed yield between 29 genotypes of *Brassicanapus* L. (Khehra and Singh, 1988). It seems that the Dalgan variety may be tolerant to environmental factors while others may be susceptible. The amount of seed yield, seed oil content, palmitic acid, linolenic acid, linoleic acid anderusic acid in Jerome variety are equal to Jacomo, and their differences were not significant (*Table 5*). Some researchers such as Das (1998), Baranyk and Zukalova (2000) and Gentent et al. (1996) reported the differences in oil yield and oil content of *brassica* species. The variation in genetic variety make up and genetic background of each variety is the main reason for different amount of seed oil content (Sana et al., 2003). Adaptation characteristics of different varieties to environmental condition are another reason for this phenomenon.

The Dalgan variety was better than other varieties in oil yield at 40 plants per m^2 density. The Sarigol variety had the lowest seed oil content compared to other varieties. The seed oil yield had a negative correlation with seed size (Onofri et al., 1996). High oil yield in 40 plants per square density treatments could be due to the high seed yield (Nasiri et al., 2017). It was reported that the thin density leads to the increase in pod per plant and the reduction of seed size and the increase of seed oil content in thin density (Onofri et al., 1996). Two main factors that affected the canola oil content are genetic and environmental factors (Ozoni and Davaji, 2007). However the higher seed oil yield in Dalgan variety is due to the smaller seed size and the higher number of seed per plant compare to other varieties. In the present study, the seed oil yield reduced at high plant population treatments was due to the reduction of seed yield. The changes of seed yield result correlate to the same direct change of oil yield (Ali and Zhou, 2018). Ozer (2003) reviled that the lower seed size is associated with higher seed oil yield that is in line with these findings. Based on the results, the increase in plant density results in the increase of plant vegetative growth of seedlings, which reduced photo assimilation of

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translocation to reproductive grain sinks then seed oil percentage. Also, increasing of vegetative growth coincide the grain filling period to high temperatures of July and August, which negatively affects the plant metabolism and oil synthesis.

The palmitic and linolenic acids in Dalgam variety were higher than others mainly in 40 plants per square density. The oleic, linolenic and linoleic as well decreased in higher plant densities. The decrease of these fatty acid compounds is the result of oil quality reduction. Nasiri et al. (2017) holds that the highest erusic acid was founded in 80 plants per square that was in line with present findings. Also Fathy et al. (2009) founded that highest palmitic acid and linoleic acid increased by plant density increase, which was in line with present results too. Shahbaz et al. (2018) holds that the content of rapeseed erusic acid was significantly reduced at high plant density compared with to the low plant density. Our study in 2015-2016 indicated that Palmitic acid influenced by plant density and year treatments. The palmitic acid decreased in higher plant density compared to lower densities. However, seed filling period is a crucial stage in oilseed growth, and during grain filling period plant density effects on oil quality, stability, and content. Decreasing the oil content and oil yield in the higher plant density is the main reason for reduction of fatty acid compounds, such as the saturated and unsaturated fatty acids. The higher plant densities result in increasing of vegetative growth and late pod formation in the field condition. The pod shattering due to the nonuniformed pods maturity at higher plant densities leads to seed damage, resulting in low oil quality. Shahabaz et al. (2018) concludes that changes in conversion of carbohydrates into lipids as photosynthetic function negatively affect biosynthesis and accumulation of fatty acids that is founded in higher canola plant density. The unsaturated fatty acids, oleic acid for example, were strongly influenced by environmental changes. The linoleic acid is an important and essential fatty acid for the photosynthetic activity of the plant (Hugly et al., 1989) and the development of canola pollen (Mc-Conn and Browse, 1996). However, because the synthesis of fatty acids is a light-dependent process (Suresha et al., 2013), the increase in plant density reduced their biosynthesis due to the increase of shading in the canopy. The canola grain filling period is one of the most sensitive stages that changes in temperature and sunlight in this period, and it directly affects the fatty acid composition, accumulation of assimilates, and their modification of the source-sink ratio (Gauthier, 2017). Based on Ruuska et al. (2004) seeds produced in shade conditions have a lower fatty acids compared to the seeds of plants fully exposed to the sunlight. Therefore, in this study, the increase of shading in higher plant density treatments led to a decrease in seed oil content and composition of saturated and unsaturated fatty acids in canola.

Conclusion

This study was laid out in order to study the effect of foliar application of selenium on seed yield, quality and quantity of seed oil of canola varieties in three 40, 60 and 80 plant/area treatments. Based on the results, plant density and foliar application of selenium was significant on seed yield, oil production, and fatty acid compositions of canola varieties. The maximum seed yield in canola was founded in foliar application of selenium and low plant density. The amount of two beneficial fatty acids in canola oil including linoleic acid (Omega 6) and oleic acid (Omega 9) was reduced by increasing of plant density treatments. In addition, the application of selenium element reduced harmful fatty acids, such as erusic acid, while it increased the beneficial fatty acids such

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as oleic acid and linoleic acid. Our results showed that the Dalgan had a highest seed yield compared to other varieties. However, these findings suggest that, the Dalgan variety with 40 plant/area along with foliar application of selenium is better treatment to achieving the highest canola seed yield and oil quality in the Golestan province, Iran.

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