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Effect of selenium foliar application on oil yield, fatty acid composition and glucosinolate content of rapeseed cultivars under late-season thermal stress☆

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Abstract – To determine the possible protective and enhancer role of selenium foliar application on oil yield, fatty acid composition and glucosinolate content of rapeseed cultivars under late-season thermal stress, a factorial split-plot experiment based on randomized complete block design with three replications was carried out in Karaj, Iran during the two growing seasons 2014–2015 and 2015–2016. Three sowing dates (Oct. 7 as normal planting date), (Oct. 17 as semi-late planting date), (Oct. 27 as late planting date) and two selenium foliar application (non-application as control and sodium selenate as foliar application) were factorially randomized to main plots, and rapeseed cultivars were allocated to sub-plots. Plant materials were six cultivars including three hybrids and three Iranian open pollinated varieties. Late-season thermal stress caused by late planting date reduced oil yield, oil content, oleic acid, linoleic acid, palmitic acid and increased linolenic acid, erucic acid and glucosinolate content of investigated cultivars. The results of this study demonstrated that the highest amount of oil yield, oil content, oleic acid, linoleic acid, palmitic acid and the lowest amount of erucic acid and glucosinolate content were observed in L72 cultivar in both control and selenium application treatments. This study provided new important findings about the supportive and enhancer role of selenium in the form of sodium selenate on quantity and quality of oil in rapeseed plant.

Keywords: canola / linoleic acid / oil quality / sodium selenate / sowing date

Résumé – Effet de l'application foliaire de sélénium sur le rendement en huile, la composition en acides gras et les teneurs en glucosinolates de cultivars de colza en situation de stress thermique de fin de saison. Afin d'étudier le possible effet protecteur et fortifiant de l'application foliaire de sélénium sur le rendement en huile, la composition en acides gras et les teneurs en glucosinolates de cultivars de colza en situation de stress thermique de fin de saison, un plan d'expériences factoriel en parcelles divisées selon un plan en blocs aléatoires complets avec 3 répétitions a été réalisé à Karaj, en Iran, pendant les deux saisons de culture 2014–2015 et 2015–2016. Trois dates de semis (le 7 octobre, comme date de plantation normale, le 17 octobre comme date de plantation semi-tardive et le 27 octobre comme date de plantation tardive) et deux modalités d'application foliaire de sélénium (non application en tant que témoin et sélénate de sélénium pour l'application foliaire) ont été aléatoirement attribuées aux principales parcelles selon le plan factoriel. Les cultivars de colza ont été répartis sur les sous-parcelles. Parmi les six cultivars, trois étaient des hybrides et trois des variétés à pollinisation libre. Le stress thermique de fin de saison dû à la date de plantation tardive a entraîné une diminution du rendement en huile, de la teneur en huile, des teneurs en acides oléique, linoléique, et palmitique et une augmentation des teneurs en acides linolénique, érucique et en glucosinolates dans les cultivars

☆ Contribution to the Topical Issue "Rapeseed / Colza".
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analysés. Le rendement et les teneurs les plus élevés en huile, acide oléique, linoléique, palmitique et les teneurs les plus faibles en acide érucique et en glucosinolates étaient obtenus pour le cultivar L72, aussi bien en cas d'application foliaire de sélénium qu'en son absence. Cette étude apporte de nouveaux résultats importants à propos de l'effet stimulant et fortifiant du sélénium sous forme de sélénate de sodium sur la quantité et la qualité de l'huile de colza.

Mots clés : colza / acide linoléique / qualité de l'huile / sélénate de sodium / date de semis

1 Introduction

Rapeseed (*Brassica napus* L.) is one of the most important oilseeds in the world that is considered as the third provider of edible oil after oil palm and soybean. With the lowest content of saturated fatty acids, rapeseed is one of the most important sources of vegetable oils for human diet (Nelson and Grombacher, 1992), industrial and pharmaceutical consumptions (Carvalho *et al.*, 2006).

Rapeseed is a long-day plant that grows well if it is sown on an appropriate sowing date (Shirani-Rad *et al.*, 2015a). Therefore, following proper agronomic practices, including setting a suitable sowing date, will help increase yield and produce high-quality oil (Shirani-Rad *et al.*, 2015b). Planting date is one of the main factors in rapeseed production affecting crop yield and other agronomic traits. Most previous studies have revealed that late planting date results in low yields (Hocking and Stapper, 2001; Oz, 2002; Ozer, 2003; Shah and Rahman, 2009; Uzun and Furat, 2009; Singh *et al.*, 2017).

Plants are exposed to various types of biotic and abiotic stresses during their growth period, which reduce their yield production (Kumar, 2013). Rapeseed oil production is negatively influenced by late-season thermal stress and low precipitation and positively affected by above-average precipitation and below-average lower temperatures (Kutcher *et al.*, 2010). Maximum daily temperatures greater than 27 °C, which usually occurs in rapeseed growing areas, can reduce flower number, the number of pods per plant and consequently seed yield losses due to heat stress (Morrison and Stewart, 2002).

Selenium (Se) as a naturally occurring chemical element, which was long known as a toxic substance before its usefulness, was identified by Schwarz and Foltz (1957). Only in the last decades, its physiological importance as a micronutrient fundamental to animal and human health has been assessed (Mora *et al.*, 2015). Selenium is known to reduce abiotic stresses, which have been extensively studied in animals and less in humans and plants (Feng *et al.*, 2013).

The first report of positive effect of selenium application in the form of selenite on growth and dry-matter yield of Indian mustard (*Brassica juncea* L.) was presented by M. Singh *et al.* (1980). Lack of selenium concentration in the soil causes its deficiency in the human diet. Recently, sodium selenate has been used as a fertilizer for foliar application in order to increase selenium content in the edible portion of crops (Broadley *et al.*, 2010; Pezzarossa *et al.*, 2012) and simultaneously to deal with the damage caused by various environmental stresses (Saidi *et al.*, 2014).

Application of selenium as a foliar fertilizer has been reported for soybean (Yang *et al.*, 2003; Djanaguiraman *et al.*, 2005), green tea (Hu *et al.*, 2003), lettuce (Xue *et al.*, 2001), ryegrass (Hartikainen *et al.*, 2000), chicory (Germ *et al.*, 2007), wheat (Stephen *et al.*, 1989; Ducsay and Lozek, 2006; Yao *et al.*, 2013; Nawaz *et al.*, 2015), barley (Gissel Nielsen, 1981; Ylaranta, 1983), rice (Hu *et al.*, 2002; Fang *et al.*, 2008), potato (Poggi *et al.*, 2000) and corn (Sajedi *et al.*, 2011). The effect of selenium application *via* solution culture was reported to increase growth and seed production of *Brassica* plants (Lyons *et al.*, 2009).

The protective role of selenium in delayed planting of rapeseed under salt stress was observed in the study of (Hashem *et al.*, 2013), in which Se increased plant growth, seed yield, photosynthetic pigments content and improved the quality of rapeseed oil. Selenium application can improve plant growth (Pilon-Smits *et al.*, 2009), increase tolerance against biotic and abiotic stresses (Hartikainen *et al.*, 2000, Hartikainen, 2005) and improve other physiologic parameters (Xue *et al.*, 2001; Djanaguiraman *et al.*, 2005; Turakainen *et al.*, 2006).

The quality and quantity of oil in oilseed crops are associated with fatty acid composition, mainly with percentage of unsaturated linoleic and oleic acids, and other saturated fatty acids. Some stresses including temperature and sowing date of rapeseed may affect fatty acid composition of the crop (Izquierdo *et al.*, 2006).

This study aimed to determine the possible protective and enhancer role of selenium foliar application on oil yield, fatty acid composition and glucosinolate content of rapeseed cultivars under late-season thermal stress.

2 Materials and methods

2.1 Site description and soil type

This study was carried out at an experimental field of Seed and Plant Improvement Institute, Karaj, Iran (N35°49' E51°6', elevation = 1321 m) during the two growing seasons 2014–2015 and 2015–2016. According to IRIMO data (IRIMO, 2016), this location has a semi-arid climate (243 mm mean annual rainfall over the past 30 years, mainly in late fall and early spring). Meteorological data of the experimental location in two growing seasons are shown in Table 1.

The soil texture in the experimental field was clay-loam, low in organic matter and alkaline in reaction. Basic soil chemical properties of experimental field are presented in Table 2.

2.2 Experimental design

This study was performed in a factorial split-plot experiment based on randomized complete block design with three replications. Three sowing dates (Oct. 7 as normal

Table 1. Meteorological data of experimental location in two growing seasons (2014–2016).

Month	October		November		December		January		February	
Year	2014	2015	2014	2015	2014	2015	2015	2016	2015	2016
Rainfall (mm)	5	22.2	31.4	57	22.8	27.9	2.9	14.7	24.7	11.2
Mean temp. (°C)	15.1	17.8	7.6	8.6	5.9	2.8	5.2	5.5	6.1	7.8
Month	**March**		**April**		**May**		**June**		**July**	
Year	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Rainfall (mm)	30.1	24.6	14.2	51.6	9.3	12.6	0.2	0	3	0
Mean temp. (°C)	9.3	11.3	16.7	14.8	22	21.3	28.1	25.6	28.9	27.6

Table 2. Soil charactristics of experimental field.

Soil texture	Soil depth (cm)	EC (ds/m)	pH	Organic carbon (%)	Phosphorus (mg/kg)	Potassium (mg/kg)	Nitrogen (%)
Clay-loam	0–30	1.45	7.9	0.91	14.7	197	0.09
	30–60	1.24	7.2	0.99	15.8	155	0.07

Table 3. Description of rapeseed genotypes used in the experiment.

No.	Cultivar name	Type	Origin
1	Opera	Open pollinated	Sweden
2	L72	Open pollinated	Iran
3	KR1	Open pollinated	Iran
4	GKH3705	Hybrid	Hungary
5	GKH0224	Hybrid	Hungary
6	Neptune	Hybrid	France

planting date), (Oct. 17 as semi-late planting date), (Oct. 27 as late planting date) and two selenium foliar application (non-application as control and sodium selenate as foliar application) were factorially randomized to main plots, and rapeseed cultivars were allocated to sub-plots. Plant materials were six cultivars including three hybrids and three Iranian open pollinated varieties, which were described in Table 3.

2.3 Experimental procedure

Each experimental plot consisted of six 6 m lines with 30 cm space between the lines and 4 cm between plants. Hence, the required area for each plot was 10.8 m^2. Two lateral lines were considered as margins. Phosphorus, nitrogen, and potassium were applied according to the recommendations of soil analysis before and after sowing at a rate of 70, 50, and 100 kg/ha in the form of ammonium phosphate, urea, and potassium sulfate, respectively. Irrigations were done based on the water needs of plants. To apply the Se treatment, 30 g/L/ha sodium selenate was sprayed as foliar application and pure water for non-application were used as control before the rosette stage (early December) as described by Seppänen *et al.* (2010). Urea fertilization was applied equally at stem elongation and heading stages at the rate of 50 kg/ha. Plants were thinned by hand at the 6-leaf stage. To minimize seed shattering, each experimental plot was harvested in different dates before the seed is fully mature.

2.4 Measurement of oil content, oil yield and fatty acid composition

Measurement of oil content were performed by 5 g seed sample which selected from each plot using NMR (Nuclear Magnetic Resonance) German Broker Brand minispec mq20 Model based on the International Standard (ISO-5511:1992, 1998). Then, oil yield was calculated by multiplying oil content in seed yield. Fatty acid composition of oils was analyzed using gas chromatography (GC) as described by Aksouh *et al.* (2001). The glucosinolate content of seed samples was determined as described by Makkar *et al.* (2007).

2.5 Statistical analysis

Outlier detection and testing the normality of the data were done before variance analysis. Then, homogeneity of variance assumption was performed using Bartlett's test. Differences among treatments were analyzed by ANOVA and then compared using the least significant difference test (LSD) at 0.05 level of probability. Interactions were interpreted using slicing procedure by SAS 9.1 (SAS, 2008) statistical software. Excel software used for graphs.

3 Results and discussion

The main effects of year, planting date, selenium application and cultivar on all investigated traits were significant (Tab. 4). The interaction effect of cultivar × planting date was significant on all traits except for oleic and erucic acids (Tab. 4). The interaction effect of planting date × selenium × cultivar was significant on oil yield, oleic

Table 4. Analysis of variance and comparison of main effects for oil yield, oil content and fatty acid composition of rapeseed cultivars under late-season thermal stress and selenium foliar application.

S.O.V	df		Oil yield (kg/ha)	Oleic acid (%)	Linolenic acid (%)	Linoleic acid (%)	Palmitic acid (%)	Erucic acid (%)	Glucosinolate (μmole/g)
Year (Y)	1		**	**	**	**	**	**	**
		2013–2014	1610 b	62.00 b	5.48 a	19.02 a	4.77 b	0.29 a	12.90 a
		2014–2015	1933 a	64.52 a	5.89 a	17.50 b	5.18 a	0.32 a	12.44 a
		LSD 5%	250.25	0.06	1.08	0.42	0.11	0.07	2.68
Planting date (P)	2		**	**	**	**	**	**	**
		Oct. 7	2352 a	64.67 a	4.55 c	19.94 a	5.60 a	0.18 c	9.40 c
		Oct. 17	1771 b	63.35 b	5.68 b	18.23 b	5.10 b	0.30 b	12.70 b
		Oct. 27	1192 c	61.76 c	6.82 a	16.61 c	4.22 c	0.44 a	15.91 a
		LSD 5%	103.19	0.43	0.12	0.40	2.22	0.01	0.32
Selenium (Se)	1		**	**	**	*	**	**	**
		Control	1697 b	63.09 b	5.83 a	18.06 b	4.89 b	0.32 a	13.08 a
		Se application	1845 a	63.43 a	5.54 b	18.46 a	5.06 a	0.29 b	12.26 b
		LSD 5%	84.25	0.32	0.10	0.33	0.15	0.01	0.26
Cultivar (C)	5		**	**	**	**	**	**	**
		Opera	1839 a	63.48 a	5.55 b	18.47 a	5.10 a	0.29 b	12.31 b
		L72	1923 a	63.67 a	5.37 c	18.67 a	5.14 a	0.27 c	11.85 c
		KR1	1667 b	63.02 b	5.89 a	17.97 b	4.87 b	0.33 a	13.27 a
		GKH3705	1670 b	63.00 b	5.89 a	17.98 b	4.85 b	0.33 a	13.22 a
		GKH0224	1624 b	62.84 b	5.98 a	17.85 b	4.77 b	0.34 a	13.45 a
		Neptune	1905 a	63.56 a	5.42 c	18.63 a	5.12 a	0.28 bc	11.93 c
		LSD 5%	97.53	0.37	0.11	0.29	0.18	0.01	0.34
P × Y	2		ns	ns	**	*	**	ns	**
Y × Se	1		ns	ns	ns	ns	ns	ns	ns
Se × P	2		ns	ns	ns	ns	ns	ns	ns
Se × P × Y	2		ns	ns	ns	ns	ns	ns	ns
C × Y	5		ns	ns	ns	ns	ns	ns	ns
C × P	10		**	**	ns	**	**	ns	**
C × Se	5		ns	ns	ns	ns	ns	ns	ns
C × P × Y	10		ns	ns	ns	ns	ns	ns	ns
C × Se × Y	5		ns	ns	ns	ns	ns	ns	ns
C × Se × P	10		*	ns	*	*	*	*	*
C × Se × P × Y	10		ns	ns	ns	ns	ns	ns	ns
CV (%)			11.80	0.96	1.28	4.35	3.43	8.03	10.07

*: Significant at 5% level of probability; **: Significant at 1% level of probability; S.O.V.: Source of variation; df: Degree of freedom; CV: Coefficient of variation; Y: Year; R: Replication; P: Planting date; Se: Selenium; C: Cultivar.
a–c: Means followed by similar letters in each column are not significant at 0.05 probability level.

acid, linolenic acid, linoleic acid, palmitic acid, erucic acid and glucosinolate content (Tab. 4).

3.1 Oil content and yield oil

Response of cultivars to year, planting date and selenium application in terms of oil yield and oil content was statistically significant (Tab. 4). The interaction effect of planting date × selenium × cultivar was significant on oil yield but non-significant for oil content (Tab. 4).

The highest oil content were observed in 2015–2016 growing year (42.31%), normal planting date (Oct. 7) (43.43%) and selenium application treatment (42.30%) (Figs. 1–3). L72 cultivar with the average of 42.49% had the highest oil content among cultivars. In addition, there were no significant differences between Opera and Neptune with L72 cultivars (Fig. 4).

Higher amounts of oil content, the highest oil yield was obtained in the second year of the experiment can be attributed to more rainfall and a lower mean temperature than the first year, especially at seed filling period in critical months April and May (Tab. 1). Fayyaz-Ul-Hassan *et al.* (2005) concluded that lower late-season temperatures are suitable for good quality of oil in crops. Results of present study were in accordance with Pritchard *et al.* (2000) and Omidi *et al.* (2010) studies who found that oil content of cultivars are associated with cooler temperature and higher spring rainfall. This shows that the normal planting is superior to delayed planting in terms of selenium application That is because the longer vegetative period and the optimal use of selenium spray application.

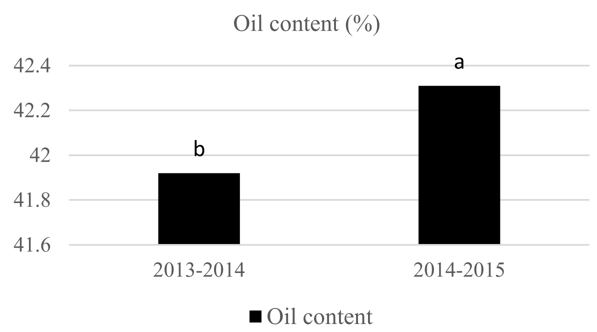

Fig. 1. Mean comparison of main effect of year on oil content.

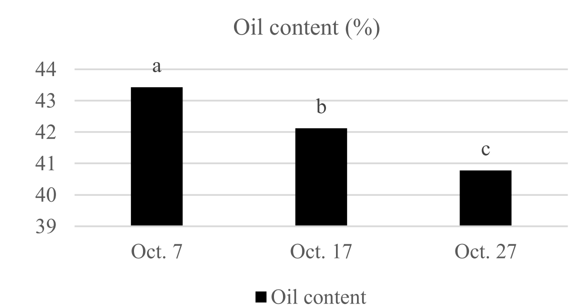

Fig. 2. Mean comparison of main effect of planting date on oil content.

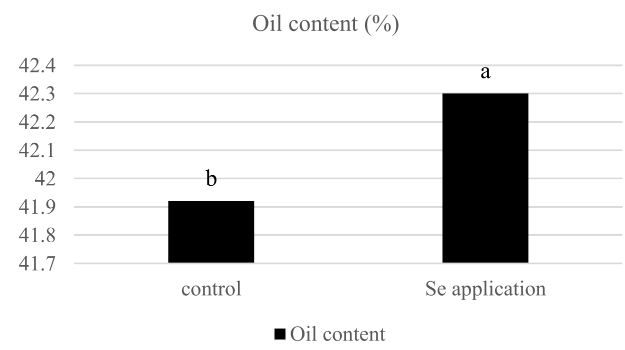

Fig. 3. Mean comparison of main effect of selenium on oil content.

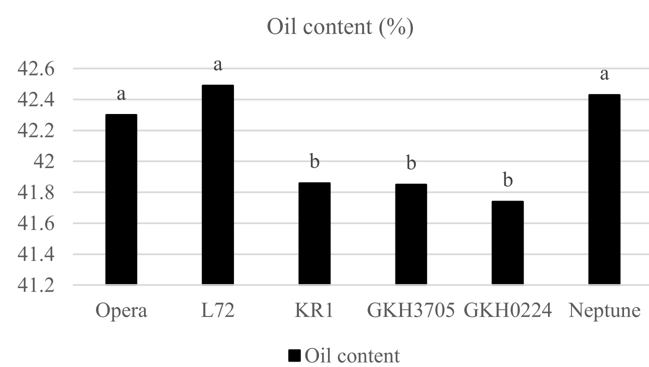

Fig. 4. Mean comparison of main effect of cultivar on oil content.

Sinaki *et al.* (2007) reported that seed and oil yield of canola cultivars were increased with increasing the moisture content after pollination phase. Water stress in different stages of canola especially at end of the season reduced seed oil yield (Soleymani *et al.*, 2011). The average oil content was higher in normal planting date (Oct. 7) compare to semi-late (Oct. 17) and late (Oct. 27) planting dates under controlled conditions (Fig. 2). It seems that late planting dates cause shorter growth period for rapeseed. Therefore, the less growth period, the more reduce in oil content. However, delay in planting, due to plant growth retardation, exposure to thermal stress during the seed filling stage at the end of the season (Gilbertson *et al.*, 2007), increased respiration and decreased photosynthesis efficiency (Seppänen *et al.*, 2003), resulting in a decrease in the seed oil content, compared to the normal planting date. In addition, the average oil content was higher in selenium foliar application than control (Fig. 3). Therefore, application of selenium increased the oil content. Similar to oil content, highest oil yield was obtained in the second year of the experiment (1933 kg/ha) and normal planting date (2352 kg/ha). Selenium application treatment increase oil yield from 1697 to 1845 kg/ha in all planting dates of the experiment (Tab. 4). Lyons *et al.* (2009) reported that Se treatment showed a 43% increase in seed yield of Brassica plants. L72 cultivar with the average of 2630 kg/ha in normal planting date (Oct. 7) and selenium application had the highest amount of oil yield, while in semi-late planting date (Oct. 17) and delayed planting date (Oct. 27) the highest amount of oil yield was related to Opera cultivar (Tab. 4). Generally, in rapeseed, oil content is mainly determined by genetic factors rather than environmental factors (Robertson and Holland, 2004). The results showed that oil content and oil yield were decreased in late planting dates but selenium treatment, as a supporting role, was able to reduce the adverse effects of end-season thermal stress in rapeseed cultivars.

3.2 Oleic acid

A significant difference was observed in the response of cultivars to year, planting date and selenium application in terms of oleic acid (Tab. 4). The highest oleic acid was observed in L72 cultivar with the average of 65.33% in normal planting date (Oct. 7) and selenium application treatment but statistically non-significant with other cultivars (Tab. 4).

In rapeseed, oil quality is determined mainly by the amounts of oleic and linoleic fatty acids. Cooler temperatures at seed filling stage cause increase in oleic content of seeds (Pritchard *et al.*, 2000; Fayyaz-Ul-Hassan *et al.*, 2005). Similar to oil content and oil yield, higher amounts of oleic acid in the second year of the experiment can be attributed to lower mean temperature than the first year at seed filling period in critical months April and May (Tab. 1). Tohidi-Moghadam *et al.* (2011) reported that the amount of unsaturated fatty acids is reduced by drought stress in the development stage of seeds due to lower sink capacity. Safavi-Fard *et al.* (2018) reported that drought stress due to irrigation interruption in flowering and pod formation stages reduced oleic content of investigated canola cultivars.

Selenium treatment reduce late-season thermal stress due to delayed planting date on oleic acid compared to the control treatment (Tab. 4). Selenium foliar application on canola plants in Hashem *et al.* (2013) study showed 107.7% increase in oleic acid content. In addition, in their study, selenium application reduced unfavorable impact of salt stress on canola plants.

3.3 Linolenic acid

A significant difference was observed in the response of cultivars to year, planting date and selenium application in terms of linolenic acid (Tab. 4). The interaction effect of planting date × selenium × cultivar revealed that delay in planting date and selenium application increased linolenic acid (Tab. 4). The highest linolenic acid was related to GKH0224 cultivar with the average of 7.36% in the late planting date (Oct. 27) and control treatment (Tab. 4).

According to the Safavi-Fard *et al.* (2018) study, drought stress and late planting date increased linolenic acid content of investigated canola cultivars, which was in agreement with the findings of present study. Aslam *et al.* (2009) reported that drought stress enhanced 1.7 to 2% in multiple unsaturated fatty acid contents such as linolenic and linoleic acids and 3.8% reduce in oleic acid content. In addition, Hashem *et al.* (2013) reported that selenium application increase linolenic acid content of canola cultivars under salt stress, which was similar to present study.

3.4 Linoleic acid

Response of cultivars to year, planting date and selenium application was significant in terms of linoleic acid (Tab. 4). In normal planting date (Oct. 7) and selenium application, the highest amount of linoleic acid was related to L72 cultivar with the average of 20.63%. Delay in planting date reduced the linoleic acid content of cultivars, while selenium application increased it (Tab. 4). Moreover, response of cultivars to selenium application in normal planting date was not statistically significant, while in delayed planting date, selenium application had a significant effect on cultivars. Therefore, the application of selenium treatment in delayed cultivation has more significant impact rather than its application in normal planting date. Similar result was reported by Hashem *et al.* (2013) for canola cultivars under salt stress. Result of present study was in accordance with the findings of Enjalbert *et al.* (2013) and Safavi-Fard *et al.* (2018) who found that drought stress reduced linoleic fatty acid content in rapeseed. Tohidi-Moghadam *et al.* (2011) study revealed that application of super absorbent polymer on canola genotypes under drought stress condition increased linoleic acid content for all genotypes from 18.91 to 19.69%.

3.5 Palmitic acid

Response of cultivars to year, planting date and selenium application were significant in terms of palmitic acid (Tab. 4). L72 cultivar with the average of 5.79% in normal planting date (Oct. 7) and selenium application had the highest amount of palmitic acid, while the highest amount of palmitic acid in semi-late planting date (Oct. 17) and delayed planting date (Oct. 27) was related to Opera cultivar which was not statistically different with L72 cultivar (Tab. 4).

Delay in planting date reduced the palmitic acid content of cultivars, while selenium application increased it (Tab. 4). In addition, response of cultivars to selenium application in normal planting date (Oct. 7) and semi-late planting date (Oct. 17) was not statistically significant, while in delayed planting date (Oct. 27), selenium application had a significant effect on cultivars. Therefore, the application of selenium treatment in delayed cultivation has more significant impact rather than its application in normal planting date.

Palmitic and stearic acids are two main saturated fatty acids in rapeseed. Shoja *et al.* (2018) reported that boron, zinc and sulfur treatment affected fatty acid composition of canola cultivars compared to the control. The least amount of saturated stearic and palmitic acids were observed with boron treatment. Bybordi and Mamedov (2010) found that foliar application of zinc and iron reduced saturated fatty acids and enhanced unsaturated fatty acids of canola. Result of present study was in consistence with the findings of Safavi-Fard *et al.* (2018) who found that drought stress reduced palmitic fatty acid content in canola, while Mekki *et al.* (1999) results in sunflower were opposite.

3.6 Erucic acid

Response of cultivars to planting date and selenium application was significant in terms of erucic acid (Tab. 4). L72 cultivar with the average of 0.12% in normal planting date (Oct. 7) and selenium application had the least amount of erucic acid (Tab. 4). Delay in planting date increased the erucic acid content of cultivars, while selenium application decreased it (Tab. 4). GKH0224 cultivar with the average of 0.49% in delayed planting date (Oct. 27) and control treatment of selenium application had the highest erucic acid content (Tab. 4).

Erucic acid content of cultivars in all planting dates and was at standard level (=< 0.5%). This result was in consistent with the findings of Safavi-Fard *et al.* (2018) study in late-season draught stress of canola cultivars. Fayyaz-Ul-Hassan *et al.* (2005) reported that erucic acid content of canola cultivars varied by different environments and varieties. In Shoja *et al.* (2018) study, boron + zinc treatment could significantly reduce erucic acid content of canola cultivars compared with the control. Results of present study was in accordance with the findings of Hashem *et al.* (2013) study who observed maximum reduce in erucic acid content of canola cultivars by using foliar application of selenium as compared with control treatment under salt stress.

3.7 Glucosinolate content

There was a significant difference in the reaction of cultivars to planting date and selenium application (Tab. 4). L72 cultivar with the average of 7.94 μmole/g in normal planting date (Oct. 7) and selenium application had the least amount of glucosinolate content (Tab. 4), while the least amount of glucosinolate in semi-late planting date (Oct. 17) and delayed planting date (Oct. 27) was related to Opera cultivar in both control and selenium application (Tab. 4). In addition, GKH0224 cultivar in late planting date (Oct. 27) in both control and selenium application with the average of 17.03 and 16.55 μmole/g had the highest glucosinolate content. Therefore, in normal and late planting dates, the glucosinolate content of all cultivars was at standard level which should be less than 30 μmole/g of dry weight of oil cake. Similar results were reported in Safavi-Fard *et al.* (2018) study. Champolivier and Merrien (1996) study revealed that glucosinolate accumulations in canola was affected by availability of water/moisture especially at seed filling stage. Fayyaz-Ul-Hassan *et al.* (2005) found that, although the impact of different locations on glucosinolate content of canola cultivars was non-significant but locally bred cultivars were better than those of foreign were. Tohidi-Moghadam *et al.* (2011) study showed that application of super absorbent polymer on canola genotypes under drought stress condition decreased about 7% of glucosinolate accumulations for all genotypes.

Quality of oil in oil seed rape and nutritional value of rapeseed oil cake depends on lower glucosinolate content, which is controlled by environmental and genetic factors (Salisbury *et al.*, 1988). Fayyaz-Ul-Hassan *et al.* (2005) concluded that variety, soil moisture content and temperature are three main factors impact on the level of oil and canola fatty acid composition. Proper planting date and selection of suitable variety in any region can control those three main factors. Results of present study showed that selenium foliar application reduce glucosinolate accumulation of cultivars especially in late-season thermal stress.

4 Conclusion

Thermal stress, especially at the end of the season due to late planting date, is one of the important limiting factors in the growth and development of rapeseed. It can be concluded that late planting date influenced oil content, oil yield and fatty acid composition and glucosinolate content of rapeseed cultivars. Late-season thermal stress caused by late planting date reduced oil yield, oil content, oleic acid, linoleic acid, palmitic acid and increased linolenic acid, erucic acid and glucosinolate content of investigated cultivars. This study provided new important findings about the supportive and enhancer role of selenium in the form of sodium selenate on quantity and quality of oil in rapeseed plant. Selenium foliar application promote oil yield, oil content, oleic acid, linoleic acid, palmitic acid and decreased linolenic acid, erucic acid and glucosinolate content of investigated cultivars, in all planting date. In addition, selenium application was able to reduce the adverse effects of end-season thermal stress in rapeseed cultivars. The results of this study demonstrated that the highest amount of oil yield, oil content, oleic acid, linoleic acid, palmitic acid and the lowest amount of erucic acid and glucosinolate content were observed in L72 cultivar in both control and selenium application treatments. Present study intensifies the evidence for the effective role of selenium in crops.

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