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Effect of selenium and zinc foliar application to increase the quantitative and qualitative yields of rapeseed at different sowing dates

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SUMMARY: The sowing date is an important factor for expanding the cultivated area of rapeseed and affects seed yield, oil content, and fatty acid compounds. Micronutrient elements play an important role in improving the vegetative and reproductive growth of the plant, especially under conditions of biological and environmental stresses. A two-year experiment (2014-2016) was performed to study the response of rapeseed genotypes to foliar application of micronutrients on different sowing dates. The treatments were arranged as a factorial-split plot in a randomized complete block design with three replicates. Three sowing dates of 7 (well-timed sowing date), 17, and 27 (delayed sowing dates) October and two levels of foliar application with pure water (control), selenium (1.5%), zinc (1.5%), and selenium+zinc (1.5%) were factorial in the main plots and five genotypes of SW102, Ahmadi, GKH2624, GK-Gabriella, and Okapi were randomized in the subplots (a total of 30 treatments). Seed yield, oil yield and content, oleic acid, and linoleic acid were reduced when rapeseeds were cultivated on 17 and 27 October, while the contents in palmitic, linolenic, and erucic acids, and glucosinolate increased ($p < 0.01$). a selenium+zinc treatment improved seed yield, oil content and yield ($p < 0.01$). The oil quality increased due to increased contents of oleic and linoleic acids under the selenium+zinc treatment ($p < 0.01$). The GK-Gabriella and GKH2624 genotypes are recommended to be sown on well-timed (7 October) and delayed sowing dates (17 and 27 October) and treated with selenium+zinc due to the higher oil yield, linoleic and oleic acids.

KEYWORDS: *Delayed sowing; Fatty acid composition; Foliar application*

RESUMEN: ***Efecto de la aplicación foliar de selenio y zinc para aumentar los rendimientos cuantitativos y cualitativos de colza en diferentes fechas de siembra.*** La fecha de siembra es un factor importante para expandir el área cultivada de colza que afecta el rendimiento de la semilla, el contenido de aceite y la composición en ácidos grasos. Los micronutrientes juegan un papel importante en la mejora del crecimiento vegetativo y reproductivo de la planta, especialmente en condiciones de estrés biológico y ambiental. Se realizó un experimento de dos años (2014-2016) para estudiar la respuesta de los genotipos de colza a la aplicación foliar de micronutrientes en diferentes fechas de siembra. Los tratamientos se organizaron como una parcela dividida factorial en un diseño de bloques completos al azar con tres repeticiones. Tres fechas de siembra del 7 (fecha de siembra en el momento oportuno), 17 y 27 (fechas de siembra retrasadas) de octubre y dos niveles de aplicación foliar con agua pura (control), selenio (1,5%), zinc (1,5%) y selenio + zinc (1.5%) fueron factoriales en las parcelas principales y cinco genotipos de SW102, Ahmadi, GKH2624, GK-Gabriella y Okapi fueron aleatorizados en las subparcelas (un total de 30 tratamientos). El rendimiento de semilla, el contenido y rendimiento de aceite, los ácidos grasos oleico y linoleico se redujeron cuando se cultivaron semillas de colza los días 17 y 27 de octubre, mientras que los contenidos de los ácidos grasos palmítico, linolénico y erúcico y glucosinolato aumentaron ($p <0,01$). El tratamiento con selenio + zinc mejoró el rendimiento de semillas, el contenido de aceite y el rendimiento ($p <0,01$). La calidad del aceite aumentó debido al mayor contenido de ácidos oleico y linoleico bajo tratamiento con selenio + zinc ($p <0.01$). Se recomiendan los genotipos GK-Gabriella y GKH2624 sembrados en fechas oportunas (7 de octubre) y tardía (17 y 27 de octubre) y tratados con selenio + zinc, respectivamente, debido al mayor rendimiento de aceite y contenido de los ácidos linoleico y oleico.

PALABRAS CLAVE: *Aplicación foliar; Composición en ácidos grasos; Siembra retrasada*

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1. INTRODUCTION

Rapeseed with the scientific name of *Brassica napus* L. is considered to be one of the most important oilseed plants in the world and it is the third oilseed crop after oil palm and soybean.

According to the latest Food and Agriculture Organization (FAO) report, total rapeseed production in the world and Iran were 72.2 and 0.128 million tons, respectively. Due to its suitable agricultural properties, this oilseed crop can be used as an alternative to cereal-based crop rotations, especially in arid and semi-arid climates (Hamzei and Soltani, 2012). Rapeseed is mainly considered by farmers due to its high oil content (40-45%), and one of the healthiest edible oils due to its low content in saturated fatty acids (7%), high content in monounsaturated fatty acids (60%) and sufficient content in polyunsaturated fatty acids (12%) (Starner *et al.,* 1999).

In order to produce high-quality oil as well as acceptable oil yield in different environmental conditions, it is necessary to manage agronomic practices such as identifying high-yielding genotypes, setting of well-timed sowing dates, and nutritional capacity. Selecting the appropriate genotype in each region can lead to achieving optimal quantitative and qualitative yields. The genotype is considered as the most important determinant factor in fatty acid composition (Knowles, 1988). However, the interaction of genotype with environmental conditions affects the quality of rapeseed fatty acid compounds (Gunasekera *et al.,* 2006). On the other hand, in rapeseed cultivable areas, harvesting crops grown in spring or summer may lead to a delay in rapeseed cultivation, increasing frost risk, and crop losses. Under these circumstances, farmers are less inclined to expand rapeseed cultivation. In fact, the sowing date is an important factor for expanding the cultivated area of rapeseed and affects seed yield, oil content, and fatty acid compounds (Koutroubas and Papadoska, 2005). Accordingly, the evaluation of rapeseed genotypes' response to different sowing dates as well as a selection of high-yielding genotypes under these conditions can have significant positive effects on the expanding area under the cultivation of this crop (Moradi Aghdam *et al.,* 2019). If suitable genotypes for delayed sowing are identified and introduced, it is also possible to reduce the severity of early-season cold damage. In a study by Nazeri *et al.* (2018), the quantitative and qualitative yields of different rapeseed cultivars were evaluated on conventional (7 October) and delayed (27 October) sowing dates in Iran and it was reported that a 20-day delay in sowing reduced rapeseed seed yield by 60%. In another study, Moradi Aghdam *et al.* (2019) investigated the quantitative and qualitative traits of five rapeseed genotypes on two sowing dates of 7 October and 1 November (delayed and optimum sowing dates, respectively) in Iran and indicated that SW102 and HW1 genotypes produced the highest seed yield (3877 and 3801 $kg \cdot ha^{-1}$) and had a high-quality fatty acid composition, making them suitable for delayed sowing.

Supplying micronutrient elements could improve plant growth and development under different environmental conditions. While micronutrients are not directly involved in plant metabolism and life cycle completion, they play an important role in improving the vegetative and reproductive growth of the plant, especially under conditions of biological and environmental stress. Zinc is a micronutrient that plays an important role in many biological processes in plants and is essential for plant growth and reproduction as well as animal and human health, although it may pollute soil, water, and nutrient chains in excessive amounts (Lebourg *et al.,* 1998). From an agricultural point of view, increasing zinc content in the seeds is a desired qualitative factor and the quantitative and qualitative yields of crops may be reduced under zinc deficiency conditions (Noulas *et al.,* 2018). This element is a factor in reducing the adverse effects of stress on a plant system, and plant growth and metabolism will be affected by any factor affecting its efficiency (Noulas *et al.,* 2018). In a study, Shahsavari *et al.* (2014) concluded that zinc application as a micronutrient element significantly increased oil yield and content in rapeseed. Selenium as another micronutrient element at low concentrations can increase resistance to oxidative stress through increasing plant antioxidant properties and reducing lipid peroxidation (Seppanen *et al.,* 2003). Selenium application increases carbohydrate metabolism (Zhu *et al.,* 2004) and prevents the plant's chlorophyll degradation under environmental stress (Seppanen *et al.,* 2003). Furthermore, glutathione as an important component in chlorophyll which is affected by selenium and this process probably increases photosynthesis and yield through production mechanisms (Valladares *et al.,* 2008). The study results of Bybordi (2016) showed that selenium application increased plant height, pod number, seed number, biological yield, harvest index, and rapeseed oil content while respiration rate, proline, and malondialdehyde contents were decreased.

Regarding the importance of rapeseed as an important oilseed crop, the present study was conducted and aimed to improve the quantitative and qualitative yield of rapeseed genotypes sown on conventional and delayed sowing dates by applying selenium and zinc elements.

2. MATERIALS AND METHODS

2.1. Experimental description and treatments

A two-year experiment (2014-2015 and 2015-2016) was performed at the Research Field of Seed and Plant Improvement Institute (SPII), Karaj, Iran, to study the response of rapeseed genotypes to foliar application of zinc and selenium at different sowing dates. The experiment site (Karaj) is located at an altitude of 1321 meters above

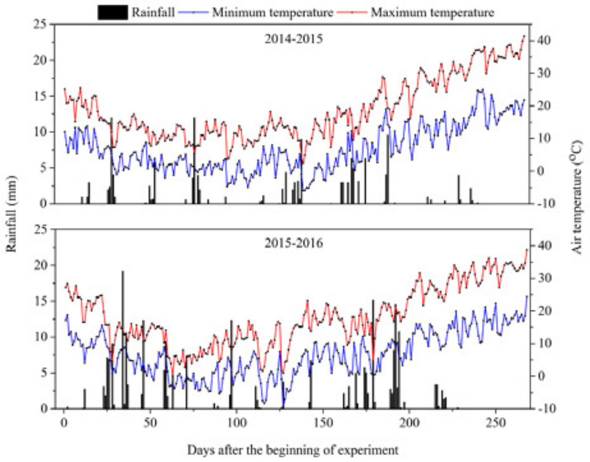

Figure 1. Daily minimum and maximum air temperatures (˚C), and rainfall (mm) recorded over the growing season in 2014-2015 and 2015-2016.

sea level with 35˚ 59´ N latitude and 50˚ 75´ E longitude. The daily climatic data of the experiment location during the rapeseed growth period are presented in Figure 1.

The experiment was conducted as a factorial-split plot in a randomized complete block design (RCBD) with three replicates. In the present study, three sowing dates of 7 (well-timed sowing), 17, and 27 October (delayed sowing dates) and two levels of foliar application with pure water (control), selenium (1.5%), zinc (1.5%), and selenium+zinc (1.5%) were factorial in the main plots and five genotypes of SW102 (early-maturity line), GKH2624 and Okapi (mid-maturity cultivar), and Ahmadi and GK-Gabriella (late-maturity cultivar) were randomized in the subplots (a total of 30 treatments). Sodium selenate (as selenium source) and chelated zinc (as zinc source) were applied in two stages of (i) before rosette (ii) and stem elongation for each sowing date and genotype, respectively.

2.2. Field practices

In this study, experimental plots consisted of six 6 m lines with 30 cm spacing between the lines, with two lateral lines considered as margins. The inter-plant spacing in each line was also 5 cm. It should be noted that the distance between the blocks and main plots in each block were 7 and 2.4 m, respectively.

In order to determine physical and chemical properties of the soil at the experiment site, soil samples were randomly taken at 0-30 and 30-60 cm depths. The experiment field soil was clay loam (Table 1). Fertilization was performed according to the results of soil analysis and rapeseed fertilizer recommendations. Accordingly, 50 kg·ha^{-1} nitrogen and 70 kg·ha^{-1} P_2O_5 from two sources of urea and ammonium phosphate and 10 kg·ha^{-1} K_2O (as pre-plant) and 46 kg·ha^{-1} nitrogen (equivalent to 100 kg·ha^{-1} urea) were used at the beginning of the stem elongation stage. The weeds were controlled by applying 2.5 liters per hectare of trifluralin before sowing as well as hand weeding during the rapeseed growth period. Finally, the seed of rapeseed genotypes was sown on the mentioned sowing dates. Irrigation was carried out throughout the growing period based on 80 mm evaporation from a Class A evaporation pan.

2.3. Qualitative and quantitative traits

Rapeseed seed yield was determined by hand-harvesting 3.6 m^2 in the center of each plot and weighed using a precise scale. It should be noted that the final harvest for each plot over two years was performed when 50% of the seeds in the main siliques and primary branches turned brown. In order to measure and determine the oil content in the rapeseed, three grams of seeds were selected from each experimental plot and the oil content was measured using a Nuclear Magnetic Resonance (NMR) German Broker Brand minispec mq20 model according to the international standard ISON.5511. For this purpose, the calibration of the device was performed with a reference sample and the product calibration with pre-prepared standard samples, and then three grams of rapeseed seeds were transferred to the device-specific cell. The cell containing the specimen was placed at a specific location and the amount of oil was monitored in less than 1 minute. After determining the oil content in the rapeseed seed, oil yield was obtained by multiplying the seed yield by oil content.

In the present study, rapeseed seed oil samples were extracted according to the method proposed by Azadmard-Damirchi *et al.* (2005) and Fathi-Achachlouei and

Table 1. Physicochemical properties of soil collected from the study site.

Year	Depth (cm)	EC (ds·m^{-1})	pH	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (mg·kg^{-1})	Available potassium (mg·kg^{-1})	Soil texture
2014-2015	0-30	1.45	7.9	0.91	0.08	14.7	197	clay loam
	30-60	1.24	7.2	0.99	0.07	15.8	155	
2015-2016	0-30	1.51	8.0	0.89	0.09	14.5	200	clay loam
	30-60	1.25	7.1	0.98	0.07	16.1	152	

Azadmard-Damirchi (2009). In summary, rapeseed seed samples (approximately 10 g) with 30 ml hexane/isopropanol (3:2, v/v) were kept at room temperature for one hour in metal tubes containing four metal balloons to facilitate homogeneity. In order to extract oil from 100 g of rapeseed seed, 10 tubes were used, each tube containing 10 g of rapeseed seed. After one hour of shaking the samples, the extract was filtered through filter paper with a Buchner funnel under vacuum. The remained defatted cake was washed twice with the same solution to extract the entire potential oil content. Then, 35 ml of sodium sulfate was added to the solvent containing the oil and thoroughly mixed. Subsequently, the organic solvent layers containing the oil were separated and evaporated at 35 °C under reduced pressure. Finally, the extracted oil was stored at -20 °C for subsequent analyses.

Fatty acid methyl esters were prepared from oil samples according to the method proposed by Savage *et al.* (1997). Briefly, 2 ml of 0.01 M NaOH solution were added to a tube containing the oil sample (about 10 mg) dissolved in 0.5 M hexane and then placed in a water bath at 60 °C for 10 minutes. Thereafter, a boron trifluoride solution in methanol (20% of boron trifluoride in methanol) was added, and the samples were kept in a 60 °C water bath for 10 minutes. The sample was cooled under running water, and 2 ml of sodium chloride 20% and 1 ml of hexane were added. After complete mixing, the hexane layer containing fatty acid methyl esters was separated by centrifugation.

Fatty acid methyl esters were analyzed using gas chromatography (GC) based on the method proposed by Azadmard-Damirchi and Dutta (2006). The GC instrument was equipped with a flame ionization detector and a Split/Splitless injector. The injector and detector temperatures were 230 and 250 °C, respectively. The oven conditions were such that from 158 to 220 °C, the temperature rose to 2 °C per minute and was maintained at each temperature for five minutes. Helium was used as carrier gas and nitrogen was used as an auxiliary gas at a flow rate of 30 ml per minute. Fatty acid methyl esters were identified by comparing their shelf-life with standard fatty acid methyl esters, and peak areas were reported as the percentage of total fatty acids. In this study, palmitic, stearic, oleic, erucic, linoleic and linolenic fatty acids were measured.

Rapeseed seed oil glucosinolate content was measured using a Varian Spectrophotometer Cary 100 equipped with a 50-m-long CP-Sil 88 capillary, 0.25 mm inner diameter, and 0.2 μm static phase thickness (Harinder *et al.,* 2007).

2.4. Data analysis

A combined analysis of variance was performed using SAS software (version 9.2). The mean comparison was performed by the least significant difference (LSD) at 5% probability level, and interactions among treatments were determined with by-processing.

3. RESULTS AND DISSCUSION

The results indicated that the simple effect of year was significant for all studied traits except for linolenic acid and glucosinolate (Table 2). The mean comparison results

Table 2. Analysis of variance (mean squares) on quantitative and qualitative traits as affected by sowing date, foliar application, and genotype.

S.O.V	df	Seed yield	Oil yield	Oil content	Palmitic acid	Linoleic acid	Linolenic acid	Oleic acid	Erucic acid	Glucosinolate content
Y	1	**	**	**	*	*	ns	**	*	ns
SD	2	**	**	**	**	**	**	**	**	**
Y*SD	2	ns	*	ns	ns	**	**	**	**	**
FA	3	**	**	**	**	**	**	**	**	**
Y×FA	3	ns	ns	ns	ns	ns	ns	ns	ns	ns
SD×FA	6	ns	ns	**	**	**	**	**	**	**
Y×SD×FA	6	ns	ns	ns	ns	ns	ns	ns	ns	ns
G	4	**	**	**	**	**	**	**	**	**
Y×C	4	ns	ns	ns	ns	ns	ns	ns	ns	ns
SD×G	8	**	**	**	**	**	**	**	**	**
Y×SD×G	8	ns	ns	ns	ns	ns	ns	ns	ns	ns
FA×G	12	ns	ns	ns	ns	ns	ns	ns	ns	ns
Y×FA×G	12	ns	ns	ns	ns	ns	ns	ns	ns	ns
SD×FA×G	24	ns	ns	ns	ns	ns	ns	ns	ns	ns
Y×SD×FA×G	24	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)		11.02	10.94	7.54	5.69	3.12	3.74	0.97	8.93	4.76

ns: not significant, * and ** Significant at the 5% and 1% levels of probability, respectively.
Y: Year, SD: Sowing date, FA: Foliar application, G: Genotype

Table 3. Mean comparison (± standard deviation) of main effect of year on qualitative and quantitative traits of rapeseed.

Year	Seed yield	Oil yield	Palmitic acid	Oleic acid	Linoleic acid	Linolenic acid	Erucic acid
	Kg·ha⁻¹		%				
2014-2015	3056±1222b	1216±590b	38.9±2.76b	4.68±0.70b	16.6±2.53a	57.3±4.17b	0.31±0.12b
2015-2016	3656±1326a	1416±616a	39.3±2.74a	5.06±0.68a	15.5±1.73b	59.9±3.91a	0.33±0.10a

Means followed by similar letters in columns are not significantly different at 5% probability level by the LSD test. All treatments were performed in three replicates.

showed that seed yield, oil yield, oil content, palmitic acid, oleic acid, and erucic acid were higher in the first year (2015-2016) than the second year (2014-2015); while the linoleic acid in the first year was higher than the second year (Table 3). The difference between studied traits in the two experimental years can be attributed to differences in the weather. (Figure 1). As shown in Figure 1, total rainfall during the rapeseed growing period was 140.7 mm in the first year of the experiment; while in the second year of the experiment 238 mm of rainfall were recorded. On the one hand, in the last months of the rapeseed growing period (April, May, and June), which is important for the quantitative and qualitative rapeseed yields, the amount of rainfall in the first year was 67% lower than the second year (Figure 1). In addition, the mean temperatures in April, May, and June in the first year were 1.75 °C lower than in the second year (Figure 1).

The results of the combined analysis of variance showed that the oil and palmitic acid contents were significantly affected by the simple effects of sowing date, foliar application, and genotype as well as two-way interactions between sowing date × foliar application, and sowing date × genotype (Table 2). The seed yield was affected by the simple effects of sowing date, foliar application, genotype, and interaction of sowing date × genotype. The oil yield was affected by the simple effects of sowing date, foliar application, and genotype as well as two-way interactions between year × sowing date, and sowing date × genotype at a 1% probability level. As shown in Table 2, the simple effects of sowing date, foliar application, and genotype as well as interactions of sowing date × year, sowing date × foliar application, and sowing date × genotype were significant for linoleic, linolenic, oleic, erucic fatty acids, and glucosinolate contents.

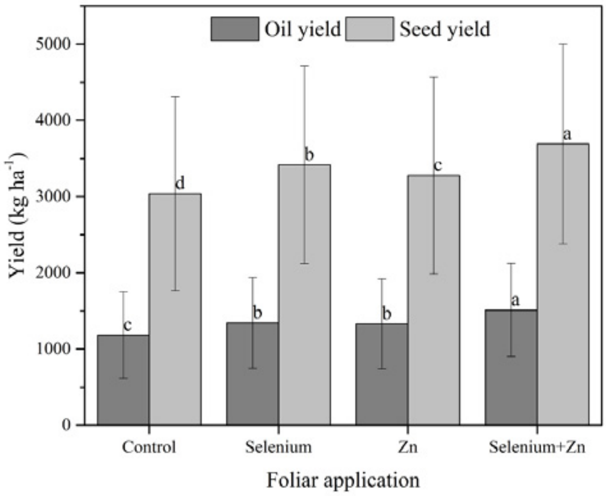

Figure 2. Seed and oil yields of rapeseed as affected by main effect of foliar application. Means followed by similar letters in bars are not significantly different at 5% probability level by the LSD test. The vertical bars are standard deviation. The LSD values for seed and oil yields are 129.4 and 54.75 kg·ha⁻¹, respectively. All treatments were performed in three replicates

3.1. Seed yield

The results of mean comparison showed that the foliar application of selenium + zinc produced the highest seed yield with an average of 3692 kg·ha⁻¹ and had 17.7, 7.6, and 11.2% higher seed yield compared to the control, selenium, and zinc treatments, respectively (Figure 2).

The foliar application of selenium, zinc, and selenium + zinc increased the seed yield of rapeseed on three sowing dates, indicating their desired effect on increasing the photosynthesis rate of rapeseed and seed yield (Shoja *et al.,* 2018). Sieprawska *et al.* (2015) reported that the selenium element is important due to activating the antioxidant system in plant cells against environmental stresses such as drought, ultraviolet rays, and high/low temperatures. The formation of reactive oxygen species (ROS) is intensified when zinc deficiency has occurred; while the application of zinc provides protection against cold stress in plants (Cakmak, 2006). It is worth noting that the protective range of micronutrients such as selenium and zinc varies depending on the stress and genotype. Fang *et al.* (2008) in a study investigated the effect of foliar application of selenium, zinc, and iron and reported that rice seed yield increased significantly compared to the none-foliar application of micronutrients.

The interaction between sowing date and genotype showed that the rapeseed seed yield (on average across genotypes) was reduced by 45.7 and 52.5% on the sowing dates of 17 and 27 October (delayed sowing dates) compared to 7 October (well-timed sowing date), respec-

Table 4. Mean comparison (± standard deviation) of interaction effect of sowing date and foliar application on qualitative and quantitative traits of rapeseed.

Sowing date	Foliar application	Oil content (%)	Palmitic acid (%)	Oleic acid (%)	Linoleic acid (%)	Linolenic acid (%)	Erucic acid (%)	Glucosinolate (µmol·g^{-1})
7 October	Control	41.06±0.46d	4.30±0.36a	61.08±1.15d	18.21±1.38b	4.36±0.39ab	0.190±0.04a	9.13±1.16ab
	Selenium	41.57±0.46c	3.87±0.33b	61.89±1.19c	18.60±1.45ab	4.10±0.35c	0.156±0.03b	8.29±0.96c
	zinc	42.36±0.48b	4.49±0.37a	63.01±1.18b	18.80±1.42ab	4.50±0.41a	0.196±0.04a	9.52±1.21a
	Selenium+zinc	42.89±0.47a	4.03±0.34b	63.84±1.23a	19.21±1.23a	4.23±0.36bc	0.161±0.04b	8.56±1.00bc
17 October	Control	38.57±0.51d	5.63±0.41a	58.35±1.66c	15.17±0.58c	6.51±0.48ab	0.429±0.04ab	15.22±1.02b
	Selenium	39.00±0.55c	5.13±0.36d	59.22±1.69c	15.49±0.65b	6.24±0.46c	0.399±0.05c	14.49±1.18c
	zinc	39.78±0.52b	5.87±0.43a	60.19±1.71b	15.66±0.60b	6.72±0.50a	0.443±0.04a	15.86±1.06a
	Selenium+zinc	40.23±0.57a	5.35±0.38c	61.09±1.75a	16.00±0.67a	6.44±0.48bc	0.411±0.05bc	15.11±1.23b
27 October	Control	34.10±0.45d	4.91±0.36b	50.98±1.45c	13.02±0.50d	5.68±0.42c	0.375±0.03b	13.11±0.88c
	Selenium	34.49±0.49c	4.48±0.32c	51.74±1.48c	13.30±0.56c	5.44±0.40d	0.348±0.04c	12.49±1.02d
	zinc	37.35±0.49b	5.45±0.40a	55.89±1.59b	14.67±0.56b	6.30±0.47a	0.416±0.03a	14.41±0.97a
	Selenium+zinc	37.77±0.53a	4.97±0.35b	56.72±1.62a	14.99±0.63a	6.04±0.45b	0.386±0.04b	13.72±1.12b

Means followed by similar letters for each treatment in columns are not significantly different at 5% probability level by the LSD test. All treatments were performed in three replicates.

tively (Table 5). GK-Gabriella and Okapi on 7 October with the averages of 5355 and 5273 kg·ha^{-1}, GKH2624 and GK-Gabriella on 17 October with the averages of 3068 and 2936 kg·ha^{-1}, and GKH2624, GK-Gabriella, and Okapi on 27 October with the averages of 2682, 2567, and 2504 kg·ha^{-1} were known as the superior genotypes, respectively (Table 5).

As previously mentioned, delayed sowing (on average across genotype and foliar application treatments) reduced rapeseed seed yield. Delayed sowing led to a more rapid development of the crop, a reduction in the number of days from emergence to flowering and maturity, and the duration of flowering and seed filling, which has a negative impact on final performance and reduces seed yield (Faraji *et al.,* 2009). The higher seed yield due to optimum sowing date can be attributed to better plant growth conditions which help the plant grow faster and reach the rosette stage before the winter frost. On the other hand, timely sowing reduces drought and heat stresses at the end of the season and increases seed yield (Turner 2004; Gunasekera *et al.,* 2006). Obviously, seed yield losses are greater when the delay in sowing is longer. Moradi Aghdam *et al.* (2019) reported that delayed sowing of rapeseed cultivars on 1 November compared to the well-timed sowing date on 7 October reduced seed yield by 38.4%. Faraji *et al.* (2009), in a study evaluating different sowing dates including 9 November (optimum sowing date), 6 December, 5 January, 4 February, and 6 March and concluded that the sowing of rapeseed genotypes after optimum sowing date reduced rapeseed seed yield by 18, 19.6, 31.3, and 77.5%, respectively.

3.2. Oil content

As shown in Table 4, the oil content in rapeseed (averaged across foliar application treatments) was reduced by delayed sowing dates (17 and 27 October) compared to well-timed sowing date (7 October). The average across foliar application treatments, with rapeseed plants sown on 7 October had the highest oil content with an average of 41.97%; while the oil contents in rapeseed plants sown on 17 and 27 October were 39.39 and 35.92%, respectively (Table 4). The slicing interaction of sowing date × foliar application showed that selenium + zinc treatment on three sowing dates 7, 17, and 27 October produced the highest oil content with averages of 42.89, 40.23, and 37.77%, respectively.

The oil contents in the studied genotypes were reduced when rapeseed plants sown on 17 and 27 October were compared to 7 October. The highest oil content (42.4%) on 7 October was observed in the GK-Gabriella genotype and the lowest oil content (35.45%) on 27 October was observed in SW102 genotype (Table 5). The average seed oil content of rapeseed across genotypes on 7 October (41.94%) was higher than those of 17 and 27 October (39.34 and 35.92%, respectively) (Table 5).

Obviously, quality and quantity yields are determined by genetic and environmental factors as well as management practices (Ashrafi and Razmjoo, 2010; Eyni-Nargeseh *et al.,* 2020). In general, genetic factors are important and effective parameters for crop oil content and environmental factors have little effect on this trait (Robertson and Holland, 2004).

In the present study, the sowing dates and foliar application of micronutrients as different environmental and management factors and genotypes as a genetic factor were investigated and a significant difference was observed between the levels of each treatment in terms of oil content. In this regard, the results of Eyni-Nargeseh *et al.* (2020) showed a statistically significant difference among 17 rapeseed genotypes in terms of oil content. Nazeri *et al.* (2018) evaluated the response of rapeseed genotypes to a delay in sowing date and reported that the oil content in genotypes was significantly different and the delayed sowing of rapeseed reduced the oil contents in rapeseed genotypes. The application of zinc can increase oil content and yield due to an increase in auxin biosynthesis, chlorophyll content, nitrogen, and phosphorus uptake as well as a reduction in sodium concentration in plant tissues (Moinuddin and Imas, 2008). The results of Shoja *et al.* (2018) showed that the seed oil content in rapeseed was increased under the foliar application of zinc compared to the control treatment (non-foliar application). The combined application of micronutrients can lead to more useful results. Eskandari Zanjani *et al.* (2012) concluded that the combined use of selenium and zeolite resulted in increased oil content and yield in rapeseed.

3.3. Oil yield

The selenium+zinc treatment had the highest seed oil yield with an average of 1512 kg·ha^{-1} and produced 21.8, 12, and 11.2% more seed oil compared to the control, zinc, and selenium treatments, respectively (Figure 2). Increased seed oil yield under the foliar application of micronutrients can be the result of further assimilation during the seed filling period, which is associated with an increased photosynthesis of siliques (Shahbaz *et al.,* 2018). Zaman Fashami *et al.* (2018) investigated the response of different rapeseed cultivars to a foliar application of selenium and reported that the oil yield of rapeseed cultivars under selenium foliar application conditions was 5.8% greater than the control treatment (no foliar application). Shahsavari (2019) studied the effects of zeolite and zinc on the quantitative and qualitative yields of rapeseed and showed that although the foliar application of zinc increased the seed oil yield of rapeseed, the combined use of zeolite and zinc produced even greater seed oil yield.

With respect to the average across sowing dates, the highest seed oil yield was related to 7 October with the averages of 1942.75 and 2257.43 kg·ha^{-1} in 2014-2015 and 2015-2016 growing seasons, respectively, and the sowing

Table 5. Mean comparison (± standard deviation) of interaction effect of planting date and genotype on qualitative and quantitative traits of rapeseed.

Sowing date	Genotype	Seed yield (kg·ha^{-1})	Oil content (%)	Oil yield (kg·ha^{-1})	Palmitic acid	Oleic acid	Linoleic acid	Linolenic acid	Erucic acid	Glucosinolate Content (µmolg^{-1})
					%					
7 October	Ahmadi	4897±722b	41.8±0.80b	2051±323b	3.92±0.30b	18.5±1.38ab	4.39±0.27b	62.3±1.60ab	0.189±0.03b	9.1±0.85b
	SW102	4831±586b	41.7±0.74b	2018±262c	3.85±0.26b	18.4±1.46ab	4.48±0.37b	62.1±1.38b	0.196±0.03b	9.4±0.79b
	Okapi	5273±523a	42.3±0.80a	2223±243a	4.29±0.38a	19.0±1.53a	4.02±0.24c	62.6±1.53ab	0.144±0.02c	8.0±0.77c
	GKH2624	4620±541b	41.5±0.77c	1922±248c	4.43±0.42a	18.2±1.49b	4.68±0.32a	62.1±1.78b	0.219±0.03a	9.9±0.92a
	GK-Gabriella	5355±594a	42.4±0.79a	2275±278a	4.36±0.38a	19.1±1.41a	3.92±0.22c	62.9±1.55a	0.130±0.02c	7.8±0.95c
17 October	Ahmadi	2386±458b	38.9±0.75c	932±188b	5.4±0.43ab	15.2±0.54b	6.7±0.47a	59.2±1.99a	0.458±0.02a	15.9±0.92a
	SW102	2280±465b	38.8±0.80c	889±195b	5.4±0.39ab	15.0±0.49b	6.8±0.43a	59.1±2.05a	0.476±0.02a	16.1±1.08a
	Okapi	2864±568b	39.5±0.79b	1135±235a	5.6±0.51a	15.7±0.62a	6.3±0.37b	59.8±1.95a	0.405±0.03b	14.8±0.90b
	GKH2624	3068±493a	39.8±0.71a	1224±209a	5.3±0.44b	16.0±0.63a	6.1±0.37b	60.1±1.92a	0.380±0.04c	14.2±0.90c
	GK-Gabriella	2936±490a	39.7±0.72ab	1168±204a	5.6±0.59a	15.8±0.64a	6.2±0.43b	60.0±1.92a	0.393±0.04bc	14.6±1.10bc
27 October	Ahmadi	2086±428b	35.55±1.69c	745±174b	4.9±0.46ab	13.6±0.93b	6.1±0.53a	53.4±2.96a	0.415±0.02a	14.1±1.01a
	SW102	1994±432b	35.45±1.71c	711±177b	4.9±0.43ab	13.5±0.90b	6.2±0.50a	53.3±3.00a	0.424±0.03a	14.2±1.14a
	Okapi	2504±530a	36.07±1.73b	907±216a	5.0±0.52a	14.1±1.00a	5.7±0.44b	53.9±2.96a	0.367±0.03b	13.1±0.98b
	GKH2624	2682±472a	36.34±1.71a	979±203a	4.8±0.46b	14.3±1.01a	5.5±0.44b	54.2±2.95a	0.344±0.04c	12.6±0.97c
	GK-Gabriella	2567±467a	36.22±1.71ab	933±196a	5.0±0.58a	14.2±1.01a	5.6±0.48b	54.1±2.95a	0.356±0.04bc	12.9±1.12bc

Means followed by similar letters for each treatment in columns are not significantly different at 5% probability level by the LSD test. All treatments were performed in three replicates.

dates of 17 and 27 October showed a significant yield reduction compared to 7 October in terms of oil yield (Table 6). The results of the slicing interaction between sowing date and genotype showed that the seed oil yield varied from 711 kg·ha^{-1} for the SW102 genotype on 27 October to 2275 kg ha^{-1} for the GK-Gabriella genotype on 7 October. When averaged by genotypes, the sowing of rapeseed plants on 17 and 27 October compared to 7 October resulted in 49 and 52% reductions in seed oil yield (Table 5). The difference in the oil yield by genotype is due to the unique characteristics of each genotype which give different yields (Naseri *et al.,* 2012; Eyni-Nargeseh *et al.,* 2020). Oil yield differences between genotypes have been reported for rapeseed by Safavi Fard *et al.* (2018). The reduction in seed oil yield under delayed sowing dates is probably due to higher temperatures during the seed filling period, which can reduce seed size and consequently oil yield (Nazeri *et al.,* 2018). Of course, the seed oil yield is directly affected by seed yield and oil content; the reasons for which were earlier discussed. The reduction in rapeseed oil yield due to delayed sowing dates has been reported by Adamsen and Coffelt (2005) and Moradi Aghdam *et al.* (2019).

3.4. Palmitic acid

After foliar application treatments, the average palmitic acid contents were 4.17, 5.49, and 4.95% on 7, 17, and 27 October, respectively (Table 4). The results showed that the foliar application of zinc resulted in the highest palmitic acid contents on three sowing dates of 7, 17, and 27 October with averages of 4.49, 5.87, and 5.45%, respectively (Table 4); whereas the foliar application of selenium produced the lowest palmitic acid contents with averages of 3.87, 5.13, and 4.48% under such conditions.

Across genotypes, the average palmitic acid contents were 3.97, 5.46, and 4.92% on 7, 17, and 27 October, respectively (Table 5). The results showed that the highest palmitic acid content on 7 October belonged to the GKH2624 genotype (4.43%) followed by GK-Gabriella (4.36%) and Okapi (4.29%) genotypes (Table 5). On the sowing date of 17 October, the GK-Gabriella and Okapi genotypes had the highest palmitic acid content with an average of 5.6%. The highest content in palmitic acid on 27 October belonged to the GK-Gabriella and Okapi genotypes with an average of 5%.

The contents in saturated and unsaturated fatty acids depend on different factors such as genotype, management, and environmental conditions and these compounds may be increased or reduced under different conditions (Eyni-Nargeseh *et al.,* 2020; Safavi Fard *et al.,* 2018). The results of Eyni-Nargeseh *et al.* (2020) showed that the palmitic acid content in 17 rapeseed genotypes was significantly different due to genetic differences among genotypes. As one of the management practices, sowing date can have different effects on fatty acid composition (Maradi Aghdam *et al.,* 2019; Nazeri *et al.,* 2018). Long periods of high temperatures during the seed filling stage can produce seeds with low oil content and quality (Omidi *et al.,* 2010). In one study, Turhan *et al.* (2011) investigated the effect of sowing dates (10, 20, and 30 October, and 10 November) on rapeseed fatty acid compositions and reported that delayed sowing dates reduced palmitic acid content. Also, the composition of rapeseed fatty acids is significantly affected by fertilizer management such as micronutrients (Shoja *et al.,* 2018). The study results of Bybordi and Mamedov (2010) showed that the application of micronutrients (zinc and iron) increased the content in saturated fatty acids. Zaman Fashami *et al.* (2018) analysed the effect of foliar application of selenium on the quantitative and qualitative yields of different rapeseed cultivars and concluded that palmitic acid content showed an increasing trend under foliar application treatments.

3.5. Linoleic acid

As shown in Table 4, linoleic acid varied from 19.21% on 7 October when treated with selenium + zinc to 13.02% on 27 October in the control treatment. After foliar application treatments, the linoleic acid content was 18.70% on the sowing date of 7 October and reduced by 16.7 and 25.2% on 17 and 27 October, respectively (Table 4). Shoja *et al.* (2018) investigated the effect of the foliar application of micronutrients on the quantitative and qualitative properties of rapeseed seed oil and showed that the lowest linoleic acid content was related to a non-foliar application treatment (41.41 mg·g^{-1}); while the highest linoleic acid content was detected in the foliar application of zinc + boron (55.55 mg·g^{-1}).

The highest content in linoleic acid among the studied sowing dates in both years of the experiment was detected on 7 October (Table 6). When compared to 17 and 27 October, the linoleic acid content was 20 and 28.1% higher on 7 October in the 2014-2015 growing season, and 13 and 21.8% higher in the 2015-2016 growing season, respectively. The results showed that the linoleic acid content of the studied genotypes was reduced with delay in sowing so that the amounts of this trait on 17 and 27 October were 16.6 and 25.2% less than 7 October (Table 5).

Linoleic acid content ranged from 19.1% for the GK-Gabriella genotype on 7 October to 13.5% for the SW102 genotype on 27 October (Table 5). On the sowing dates of 17 and 27 October, the highest linoleic acid content belonged to the GKH2624 genotype with the averages of 16 and 14.3%, respectively. In separate studies, Eyni-Nargeseh *et al.* (2020) and Nazeri *et al.* (2018) stated that different genotypes showed statistically significant differences in terms of linoleic acid content. The results of Turhan *et al.* (2011) showed that delay in sowing significantly reduced the linoleic acid content. Moradi Aghdam

TABLE 6. Mean comparison (± standard deviation) of interaction effect of year and sowing date on qualitative and quantitative traits of rapeseed.

Year	Sowing date	Oil yield Kg·ha^{-1}	Linoleic acid	Linolenic acid	Oleic acid	Erucic acid	Glucosinolate content µmol·g^{-1}
			(%)				
2014-2015	7 October	1942.75±254a	19.86±1.10a	4.16±0.39c	61.52±1.36a	0.158±0.04c	9.36±1.04c
	17 October	948.82±184b	15.89±0.67b	6.22±0.45a	58.17±1.24b	0.413±0.05a	15.23±1.35a
	27 October	758.73±171c	14.28±1.02c	5.64±0.50b	52.44±2.54c	0.375±0.05c	13.48±1.33b
2015-2016	7 October	2257.43±257a	17.54±0.62a	4.43±0.37c	63.39±1.18a	0.193±0.04c	8.43±1.12c
	17 October	1190.70±237b	15.26±0.55b	6.73±0.43a	61.25±1.22b	0.428±0.03a	15.11±1.07a
	27 October	952.22±219c	13.71±0.93c	6.09±0.49b	55.22±2.64c	0.388±0.03b	13.38±1.11b

Means followed by similar letters for each treatment in columns are not significantly different at 5% probability level by the LSD test. All treatments were performed in three replicates.

et al. (2019) evaluated the response of different rapeseed cultivars to delayed sowing and concluded that linoleic acid content was reduced by 15.2% due to delayed sowing date (1 November) compared to the well-timed sowing date (7 October).

3.6. Linolenic acid

After the foliar application treatments, the average linolenic acid contents were 4.3, 6.8, and 5.87% on 7, 17, and 27 October, respectively (Table 4). It should be noted that the foliar application of zinc on the three sowing dates (7, 17, and 27 October) produced the highest linolenic acid contents (4.5, 6.72, and 6.30%, respectively) (Table 4). Zaman Fashami *et al.* (2018) concluded that the foliar application of selenium significantly increased the linolenic acid contents in different rapeseed cultivars. Shoja *et al.* (2018) reported that the amount of linolenic acid in rapeseed was significantly increased when zinc, boron, and sulphur were applied compared to the non-foliar application treatment.

The results showed that in the 2014-2015 and 2015-2016 growing seasons, the sowing date of 17 October showed the highest linolenic acid contents with the averages of 6.22 and 6.73%, respectively (Table 6). The average linolenic acid contents across genotypes were 4.3, 6.42, and 5.82% on 7, 17, and 27 October, respectively (Table 5). The difference between genotypes in terms of linolenic acid content has been reported by Safavi Fard *et al.* (2018) and Eyni-Nargeseh *et al.* (2020). Omidi *et al.* (2010) studied rapeseed fatty acid compounds as affected by environmental, genotype, and agronomic parameters and found that the linolenic acid content of the studied genotypes showed an increasing trend due to delayed sowing. The results of Moradi Aghdam *et al.* (2019) showed a 28.8% increase in linolenic acid content as a result of delayed sowing dates. Nazeri *et al.* (2018) also investigated the response of rapeseed genotypes to two sowing dates including 7 October (well-timed sowing date) and 17 October (delayed sowing date) and showed that linolenic acid content increased by 30.7% with delayed sowing date.

3.7. Oleic acid

The oleic acid content varied from 63.84% on 7 October and treated with selenium + zinc treatment to 50.98% on 27 October for the non-foliar application treatment (control) (Table 4). the average oleic acid content across foliar application treatments on 7 October was 62.45% and was reduced by 4.4 and 13.8% on 17 and 27 October, respectively (Table 4). In a study, Hashem *et al.* (2013) showed the protective role of selenium foliar application on rapeseed and reported that oleic acid content increased when selenium was applied compared to non-foliar application. The study results of Shoja *et al.* (2018) showed that the foliar application of micronutrients including boron, zinc, and sulphur resulted in increased oleic acid content. Their results also showed that the combined application of these micronutrients had more beneficial effects.

The results illustrated that the rapeseed plants sown on 7 October had the highest amount of oleic acid with the averages of 61.52 and 63.39% in the 2014-2015 and 2015-2016 growing seasons, respectively (Table 6). Averaged by genotypes, the highest oleic acid content was detected on 7 October with an average of 62.4%, and was reduced by 4.4 and 13.8% on 17 and 27 October, respectively (Table 5). The difference in the studied genotypes in terms of oleic acid content is related to genetic differences. Farahani *et al.* (2019) and Eyni-Nargeseh *et al.* (2020) reported differences among genotypes in terms of oleic acid content in separate studies. When compared to 17 and 27 October, higher oleic acid content on 7 October could be attributed to cooler temperatures at the seed filling stage (Fayyaz-UI-Hassan *et al.,* 2005). Nazeri *et al.* (2018) investigated the response of different rapeseed cultivars to well-timed (7 October) and delayed (27 October) sowing dates and found that oleic acid content on 7 October was 2.1% more than 27 October. Moradi Aghdam *et al.* (2019) showed in another study that the oleic acid content of different rapeseed genotypes was significantly reduced with a delay in sowing.

3.8. Erucic acid

Average erucic acid contents across foliar application treatments were 0.175, 0.418, and 0.381% on 7, 17, and 27 October, respectively (Table 4). Erucic acid is one of the most important fatty acids for rapeseed oil and its edible use, which is needed in small quantities (Gecgel *et al.,* 2007), and its content should not exceed 2% (Moradi Aghdam *et al.,* 2019). The results revealed that the foliar application of selenium provided the minimum erucic acid contents on 7, 17, and 27 October with averages of 0.156, 0.399, and 0.348%, respectively (Table 4). Shahsavari *et al.* (2014) investigated the effect of the foliar application of zinc and zeolite on the qualitative yield and composition of the fatty acids in rapeseed and found that the erucic acid content was significantly affected by foliar application and increased when zinc and zeolite were applied compared to a non-foliar application treatment. Shoja *et al.* (2018) investigated the response of rapeseed fatty acid compounds to foliar application of micronutrients (sulfur, boron, and zinc) and concluded that it led to a decrease in erucic acid content compared the non-foliar application treatment.

The results showed that the highest erucic acid content was obtained on 17 October with averages of 0.413 and 0.428% in 2014-2015 and 2015-2016 growing seasons, respectively (Table 6). Averaged by genotypes, rapeseed plants sown on 7 October had the minimum erucic acid content with an average of 0.175%, while erucic acid contents were 0.422 and 0.383% on sowing dates of 17 and 27 October, respectively (Table 5). Plant growth and development as well as oil quality and quantity in rapeseed are affected if maximum daily temperatures are greater than 27 ˚C (Morrison and Stewart, 2002). When rapeseed is sown late in the fall, long periods of high temperatures during the seed filling stage can produce seeds with low oil content and quality (Omidi *et al.,* 2010; Nazeri *et al.,* 2018). The study results of Samadzadeh Ghale Joughi *et al.* (2018) showed that the delayed sowing of rapeseed increased erucic acid contents in all studied genotypes. The difference in erucic acid content was due to genetic differences between genotypes, and in agreement with the current study results, Moradi Aghdam *et al.* (2019) reported that studied cultivars were significantly different in terms of erucic acid content.

3.9. Glucosinolate

After foliar application treatments, the average glucosinolate content was 8.87 μmol·g^{-1} on 7 October; while the glucosinolate content for rapeseed plants sown on 17 and 27 October were 15.17 and 13.43 μmol g^{-1}, respectively (Table 4). It should be noted that for all treatments the glucosinolate content did not exceed the standard level for edible consumption (30 μmol·g^{-1}). Increasing glucosinolate content resulted in a reduction in the quality and nutritional value of rapeseed oil (Sulisbury *et al.,* 1987), which is affected by hereditary and environmental factors (Fieldsend *et al.,* 1991). The results of Shahsavari *et al.* (2014) in evaluating the quantitative and qualitative responses of rapeseed to foliar application of zeolite and zinc showed that glucosinolate content was significantly reduced when zeolite and zinc were applied compared to non-foliar application.

The highest glucosinolate content was observed on 17 October with averages of 15.23 and 15.11 μmol·g^{-1} in the 2014-2015 and 2015-2016 growing seasons, respectively (Table 6). Averaged across genotypes, glucosinolate content was 8.84 μmol g^{-1} on 7 October, and increased by 71 and 51.4% on 17 and 27 October, respectively (Table 5). Glucosinolate content is dependent on environmental and genetic factors (Fieldsend *et al.,* 1991) and its content might vary between genotypes (Farahani *et al.,* 2019). The difference in glucosinolate content due to genetic differences between cultivars has been reported by Li *et al.* (2019) and Safavi Fard *et al.* (2018). A delay in sowing date also has a significant effect on glucosinolate content in rapeseed as an environmental factor. In this regard, Samadzadeh Ghale Joughi *et al.* (2018) investigated the effect of sowing date on the qualitative yield of different rapeseed cultivars and found that a 10-day delay in sowing resulted in a 69% increase in the seed glucosinolate content in rapeseed. Increased glucosinolate content in rapeseed cultivars with delayed sowing dates has also been reported by Moradi Aghdam *et al.* (2019).

4. CONCLUSIONS

Our study illustrated that rapeseed genotypes sown on delayed sowing dates produced lower seed yield in comparison to the well-timed sowing date mainly due to a reduction in the number of days from emergence to flowering and maturity, and the duration of flowering and seed filling. Owing to the importance of oleic and linoleic fatty acids in improving the oil quality regarding edible uses, the delay in sowing date of rapeseed caused a reduction in oil quality by dropping these traits as well as increasing erucic acid and glucosinolate contents. The combined application of selenium + zinc had a more positive effect on oil qualitative and quantitative yield when rapeseeds were planted on well-timed and delayed sowing dates. The improvement in the oil quality of rapeseed genotypes was due to enhanced oleic and linoleic acid contents. As a general result, The GK-Gabriella and GKH2624 genotypes sown on well-timed (7 October) and delayed sowing dates (17 and 27 October) and treated with selenium+zinc are recommended due to higher oil yield, and linoleic and oleic acid contents.

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