Evaluation of the oil quality properties of Rapeseed genotypes contributed to drought stress at the flowering stage in semi-arid conditions

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Abstract

Climate change and water scarcity are among the significant limited factors to constrain the production and development of oilseed crops, especially rapeseed (*Brassica napus* L.), in arid and semi-arid areas. The effects of drought stress and late-sowing on the grain yield and oil quality of rapeseed were studied by conducting a factorial split-plot experiment as a randomized complete block design with three replications for two years (2015-2017) in Karaj, Iran. Irrigation and sowing date treatments were considered in the main plots as factorial, and cultivars were placed in subplots. Two sowing dates were considered; the regular date (October 7th) and the late-sowing date (November 6th). Irrigation was also carried out at two levels of normal irrigation and irrigation interruption from the flowering stage onwards. Experimental cultivars included ES Hydromel, ES Alonso, ES Darko, ES Lauren, and Ahmadi. The highest grain yield (4505.6 kg ha^{-1}) was obtained on the regular date, and the normal irrigation. ES Hydromel had the best quality of oil and grain meal due to the highest percentage of palmitic acid (4.44%) under late cultivation and drought stress and the lowest glucosinolates content (23.19 µmol g^{-1} DW) under late cultivation. Therefore, the ES Hydromel hybrid cultivar was more successful in optimal use of water resources in the face of water scarcity and late-planting in arid and semi-arid regions.

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Introduction

Rapeseed (*Brassica napus* L.) production is an important strategy to reduce dependency on imported edible oil from other countries to Iran. Due to its high oil quality, rapeseed is a highly sought-after crop among oilseed crops. In Iran, in 2018, the harvested area and production rate of rapeseed were 76805 ha and 139946 tons, respectively.[1] During the past decade, the area under cultivation of rapeseed has been increasing, but the crop yield does not mirror the same trend.

One of the most important factors constraining the growth and the production of rapeseed in Iran is drought.

Cultivation fields are mostly located in semi-arid areas. Crop yield could be changed by different factors such as genotype, severity, duration of stress, climatic conditions, soil microbial activity and developmental stages under drought stress.[2-4] The yield is reduced chiefly at the flowering stage when the plant faces irrigation interruption or limitation. Flowering and silique formation are the most drought-sensitive stages.[5] The yield of rapeseed could be improved by adhering to the principles of cultivation and breeding. In addition, to introduce great yielding varieties, the maximum genetic capacity of cultivars can also be utilized in different climatic conditions. This is partially achieved by applying management methods such as sowing at the right time to improve the quantitative and qualitative yield of rapeseed. Late-sowing of rapeseed due to the shortened vegetative growth period leads to reduced biomass production. Late-sowing decreases the yield and yield components due to high temperatures in the reproduction stage. However, timely sowing increases the rapeseed growth and reduces its vulnerability to early season cold, and highly increases the grain yield.[6] Different species of rapeseed react significantly to the climatic conditions.[7]

Thirty-year meteorological statistics (Karaj Synoptic Meteorological Office) in Karaj and other similar areas show that the precipitation is relatively high during March and April, meeting the water needs of rapeseed at the early flowering stages. Because of the precipitation shortage at the end of spring, farmers do not have enough water for early irrigation of spring crops and late irrigation of rapeseed during flowering and seed filling stages. These specifications lead to genetic and environmental effects.[8-11] The fundamental aim of this experiment is to select a suitable cultivar that can simultaneously tolerate early-season delayed planting and water deficiency at the end of the growing season, with the lowest rate of yield loss. Saving water, especially in the late-season irrigation (flowering stage), which coincides with the early irrigation of spring cultivations, is crucial, as farmers mostly do not have enough water to devote to both cultivations. Furthermore, for the sustainable development of cultivation of this product, along with the increased production per surface area, it was necessary to consider the critical factor of cultivation's time limitation.

Materials and Methods

New rapeseed hybrid varieties including, ES Hydromel, ES Alonso, ES Darko, and ES Lauren that originated in France, and an open pollination cultivar, Ahmadi, of Iranian origin, were studied in this research. We selected such cultivars in order to study and compare them for cultivation at cold temperature and in semi-arid areas under late cultivation and two stressed and non-stressed environments. Adopting a species with high-stress tolerance suitable for relatively late to late cultivation can add up to more than 60,000ha to the area under cultivation of rapeseed in Iran.

The experiment was conducted in two cropping years, 2015-2016 and 2016-2017, and was performed at the Seed and Plant Improvement Institute in Karaj, Iran. The city is located at the latitude of 35°59´N, longitude of 50°55´ and an altitude of 1313m with a mean 30-year precipitation of 244 mm. Based on meteorological and climatic statistics, the city of Karaj is a hot and dry area with a semi-arid Mediterranean climate. The city has 150-180 and sometimes up to 200 dry days during the year. Table 1 shows the climatology information of the experimental zone (Alborz province Meteorology Office, 2015-17).[12] The soil was sampled before fertilization from a depth of 0-30 cm. Table 2 includes the results of the field soil test. To evaluate the response of late-sown rapeseed cultivars under drought stress in cold temperature and semi-arid conditions, a factorial split-plot experiment was conducted as a randomized complete block design, with three replications in two cropping years (2015-16 and 2016-17) at Seed and Plant Improvement Institute in Karaj, Iran. Sowing date and irrigation treatments were considered in the main plots as factorial and cultivars were placed in subplots. Two sowing dates were the regular date (October 7th) and the late-sowing date (November 6th). Irrigation was also carried out at two levels of normal irrigation and irrigation interruption from the flowering stage onwards. Experimental cultivars included ES Hydromel, ES Alonso, ES Darko, ES Lauren, and Ahmadi.

According to soil parameters (Table 2), during both cropping years, fertilization was carried out by using nitrogen (urea 300kg ha^{-1}; at three-leaf, stem emergence, and complete flowering stages), phosphorus (150kg ha^{-1} ammonium phosphate at sowing time) and potassium (150kg ha^{-1} potassium sulphate at sowing time). To control the weeds, trifluralin (Treflan EC 48%) herbicide was used at the rate of 2.5 L ha^{-1}. The application procedure was the distribution of the herbicide evenly across the field. A light disk was used to mix manure and herbicide with soil. Oxydemeton methyl (Metasystox EC 25%, 1.5 L ha^{-1}) and Thiometon (Ekatin® EC %25, 1L ha^{-1}) insecticides were also used to control pests, specifically aphids. Furrow irrigation was performed by using siphon pipes based on an 80 mm evaporation from the surface of the Class A evaporation pan. The frequency of irrigations was eight and five times in normal and cut-off irrigation treatments, respectively, with 5120 and 3200 m^3 ha^{-1} water used in these treatments, respectively.

6×6m experimental plots were used with a 30 cm distance between rows and plant spacing of 5 cm on the rows. In each plot, a couple of lateral rows were considered as marginal rows, and four middle rows with an area of 6 m^2 each were used to measure grain and oil yield and percentage as well as grain oil quality indices, such as unsaturated fatty acids (oleic acid, linolenic acid, erucic acid, and linoleic acid) and saturated fatty acid (palmitic acid).

Table 1. Temperature and precipitation levels during two years of experiment in Karaj region.

Parameter	Year	October	November	December	January	February	March	April	May	June	July
Month Mean Temperature (°C)	2015-16	17.8	8.6	2.8	5.2	6.1	9.3	16.7	22	28.1	28.9
	2016-17	16.6	8.1	4.7	5.5	7.8	11.3	14.8	21.3	25.6	27.6
Month Precipitation (mm)	2015-16	22.2	57	27.9	2.9	24.7	30.1	14.2	9.3	0.2	3
	2016-17	2.4	0.9	41.1	14.7	11.2	24.6	51.6	12.6	0	0

Source: Alborz province Meteorology Office (2015-2017).

Table 2. Chemical and physical characteristics of field soil.

Characteristic	Soil depth cm	Soil texture -	OC %	pH -	EC ds m-1	N %	P ppm	K mg kg^{-1}
2015–2016	0.0 – 30	Silt loam	0.93	7.8	1.53	0.07	13.3	202
2016–2017	0.0 – 30	Silt loam	0.95	7.5	1.41	0.07	14.5	194

OC: Organic Carbon; EC: Electrical Conductivity.

Planting was carried out mechanically. In order to measure grain yield during physiological processing in the second half of June, according to the treatments at sowing dates (harvest time for the October 7th sowing date and for the November 6th late-sowing date were around June 20th and around July 1st, respectively), the seedlings were rooted from the desired level and placed in two separate batches for four days in the open air and inside each corresponding plot to reduce the moisture content of the plants to 12%. The grains were then separated, placed in a cloth bag, and weighed with a precise digital scale, and the grain yield per hectare was determined in kilograms per hectare. To determine the oil percentage of the bags containing the grains of each experimental plot, 150g of grains were transferred to the laboratory, and the percentage of seed oil was measured using Nuclear Magnetic Resonance (NMR-ISO 5511, 1992). Finally, the oil yield was obtained by multiplying the grain yield by the percentage of oil and in kg ha^{-1}. The High-Performance Liquid Chromatography was applied to measure the glucosinolate content and fatty acids in grain oil.[13]

After considering uniformity assumptions of experimental errors by Bartlett test, combined ANOVA analysis was made by taking advantage of Duncan's multiple range tests in SAS v.9 statistical software at 5% level of probability.

Results and Discussion

Grain yield

The results in the ANOVA Table indicate that the main effects of year, sowing date, and irrigation were significant on grain yield ($p<0.01$; Table 3). The main effect of the year refers to the influence of climatic factors and soil characteristics, and its statistical significance indicates the difference between climatic and soil conditions during the studied growing seasons (Table 1 and 2). In other words, more favorable climatic and soil conditions in the first year caused more grain production in most cultivars during the 2015-2016 cropping season, so that the average grain yield in the first year (3293kg ha-1) was about 14% higher than the second year (2881kg ha-1). Grain yield was significantly affected also by the interactions of sowing date × irrigation ($p<0.05$) and cultivar × year ($p<0.01$; Table 3). The interaction effects of sowing date × irrigation on grain yield showed that late-planting and drought stress reduced the yield of rapeseed by 60% so that the highest grain yield was 4505.6kg ha^{-1} on the normal sowing date (October 7th), and the common irrigation and minimum grain yield of 1814.6kg ha^{-1} were obtained at the delayed sowing date (November 6th) and under drought stress (Table 4). It is

Table 3. Analysis of variance (mean squares) for oil parameters of the studied cultivars (2015-2017).

Sources of variation	df	Mean of squares							
		Grain yield	Oil yield	Palmitic acid	Oleic acid	Linoleic acid	Linolenic acid	Erucic acid	Glucosinolate
Year	1	5089024.53**	734454**	0.101**	12**	8.1ns	6.27*	0.011*	61.47**
Block (Year)	4	39085.23	3487	0.002	0.01	3.15	0.41	0.0009	0.22
Sowing date (SD)	1	81055778.13**	16885501**	14.12**	47**	188.43**	87.47**	1.182**	1932.57**
SD ×Year	1	64867.50 ns	27846ns	0.002*	0.8**	2.96**	2.5**	0.0001ns	3.24**
Irrigation (IR)	1	32903024.13**	6620421**	4.971**	16**	43.52**	22.46**	0.241**	522.93**
IR ×Year	1	70180.03ns	4813ns	0.004*	0.4**	0.07ns	0.1ns	0.001ns	0.03ns
SD × IR	1	636272.03*	231089**	0.285**	0.02ns	0.52ns	3.07**	0.008*	1.55*
SD × IR ×Year	1	481333.33ns	79258ns	0.008**	1.6**	0.08ns	0.22ns	0.0003ns	0.05ns
Error SD	12	107379.61	20075	0.001	0.02	0.22	0.17	0.001	0.24
Cultivar (CV)	4	739213.07ns	138407ns	0.026**	0.2**	0.32ns	0.24ns	0.003ns	4.42**
CV × Year	4	2388786.47**	462713**	0.08**	0.3**	0.95ns	0.37ns	0.005**	11.95**
SD × CV	4	132706.20ns	27101ns	0.011**	0.09ns	0.12ns	0.17ns	0.001ns	2.46**
SD × CV × year	4	396788.06ns	91164ns	0.03**	0.1ns	0.4ns	0.07ns	0.0012ns	3.9**
IR × CV	4	13825.24ns	3237ns	0.001ns	0.05ns	0.03ns	0.03ns	0.00012ns	0.18ns
IR × CV × year	4	43388.05ns	10140ns	0.001ns	0.03ns	0.02ns	0.01ns	0.00004ns	0.13ns
SD × IR × CV	4	6170.60ns	1258ns	0.002*	0.04ns	0.05ns	0.02ns	0.00021ns	0.16ns
SD × IR × CV ×Year	4	13279.31ns	3304ns	0.002*	0.02ns	0.05ns	0.02ns	0.00007ns	0.04ns
Error	64	349514.60	64218.67	0.001	0.04	0.6	0.21	0.00123	0.24
Coefficient of variation %	19.15	19.63	0.525	0.33	5.09	7.05	10.7	2.54	

*, ** denote significance at $P < 0.05$ and $P < 0.01$ probability level, respectively; ns, non-significant.

Table 4. Effect of sowing date × irrigation interaction on grain yield, oil yield, linolenic acid, and erucic acid of all studied genotypes.

Sowing date	Irrigation	Grain yield (kg ha^{-1})	Oil yield (kg ha^{-1})	Linolenic acid (%)	Erucic acid (%)
Oct. 7	Control	4505.6a	1944.9a	5.34d	0.19d
	Drought stress	3312.7b	1387.4b	5.89c	0.26c
Nov. 6	Control	2716.2c	1106.9c	6.73b	0.37b
	Drought stress	1814.6d	724.9d	7.92a	0.48a

Any two means sharing a common letter do not differ significantly from each other at 5% probability level.

noteworthy that the effect of delayed planting on grain yield is higher than that of drought stress on this trait. Indeed, grain yield is higher under common irrigation and normal sowing date (October 7^{th}) than under common irrigation and delayed sowing date (November 6^{th}; Table 4). The sowing date determines the crop quality and quantity affecting the duration of the vegetative and reproductive growth periods and establishing a reasonable balance between the two periods.[14] Similar results have been reported on reduced rapeseed grain yield under delayed planting conditions.[4-15] Irrigation interruption from the flowering stage, and grain filling onwards reduces the grain yield by 35% and 18%, respectively.[16] A highly significant interaction of cultivar × year revealed that the cultivars responded differently to climatic conditions in the two experimental years, and a higher yield in rapeseed cultivars resulted from the availability of climatic conditions for the growth of the cultivars in the first experimental year (Table 5). This is due to the level and distribution of rainfalls, that were more favorable in the first year (2015-2016) than in the second year (2016-2017; Table 1). The first year was also cooler than the second year. Among the studied cultivars, therefore, the highest average grain yields were observed in the Ahmadi cultivar (3855.6kg ha^{-1}) and the ES Hydromel cultivar (3383.3kg ha^{-1}) in the first and the second years, respectively, and the lowest average grain yield (2544.6kg ha^{-1}) was obtained in ES Darko cultivar in the second year (Table 5). ES Hydromel cultivar was probably more tolerant to temperature and humidity changes than the other cultivars in the second experimental year, so that it could maintain grain yield at an optimal level, with a slightly significant difference in the average grain yield of this cultivar relative to that of Ahmadi cultivar in favorable conditions of the first year. A decrease in the grain yield of promising rapeseed lines under drought stress and delayed planting was also reported.[16]

Oil yield

Oil yield was significantly affected by the main effect of year, sowing date, and irrigation ($p<0.01$; Table 3). In addition, there were highly significant interactions of sowing date × irrigation and cultivar × year ($p<0.01$; Table 3). Delayed planting and drought stress at the end of the planting season reduced the yield of rapeseed oil. The highest oil yield in the normal sowing date (October 7^{th}) combined with common irrigation and the lowest oil yield in the delayed sowing date (November 6^{th}) with irrigation interruption from the flowering stage onwards were 1944.9 and 724.9kg ha^{-1}, respectively (Table 4). It seems that the delayed planting reduces the grain yield and, ultimately, the yield of rapeseed oil by shortening the growth period and reducing time to fill the grains. On one hand, temperature is one of the influential environmental factors in increasing the yield of rapeseed oil, which increases the yield of grain oil significantly. This drop-in yield by temperature is more prominent in delayed planting.[17] On the other hand, rapeseed exposure to high temperature from the flowering stage onwards, induces a shortage of water, reduces the number of flowers as well as effective pollination, and reduces the number of seeds and seed oil yield. A 3.2% decrease in rapeseed oil yield under drought stress conditions is also reported.[18] Oil is one of the most valuable products of rapeseed processing, and its contents and compounds are under the influence of environmental factors.[5] The interaction of cultivar × year reveals that the cultivars responded distinctly to different humidity and temperature conditions in the two years of the experiment (Table 1). The highest oil yield averages were measured in Ahmadi cultivar (1610.4kg ha^{-1}) and ES Hydromel cultivar (1437.3kg ha^{-1}) in the first and the second years, respectively, and ES Darko cultivar contained the lowermost (1066.9kg ha^{-1}) mean oil yield in the second year (Table 5). ES Hydromel cultivar was apparently able to withstand changes in weather conditions of the second year and, in other words, could maintain oil yield at a high level. Drought stress in grain development stages of rapeseed affects the sink size, shortens the grain filling period, and reduces the source capacity, thereby decreasing grain weight and, consequently, both grain yield and oil yield, making the plant impossible to recover and return to the normal conditions.[19]

Palmitic acid

The palmitic acid trait was influenced significantly by the main effects of year, sowing date, irrigation, and cultivar ($p<0.01$). Most of interactions were also significant ($p<0.01$ and $p<0.05$) on this trait (Table 3). The comparison of mean significant interactions of year × sowing date × irrigation × cultivar ($p<0.05$) revealed that the highest average percentage of PA (5.58%) was measured in ES Hydromel cultivar under normal sowing date (October 7^{th}) and common irrigation in the second experimental year. The lowest percentages were observed in delayed planting (November 6^{th}) and drought stress in ES Alonso cultivar (4.24%) and Ahmadi cultivar (4.25%) in the first and the second experimental years, respectively (Figure 1). It should be noted that the percentage of palmitic acid reduction under drought stress and delayed planting was higher in the second year due to unfavourable experimental conditions than that of more favourable climatic conditions in the first year (Table 1). Delayed planting and late-season drought stress significantly reduced the percentage of palmitic acid as a saturated fatty acid. It seems that delayed planting resulted in the shortened growth period, delayed flowering, the coincidence of flowering with higher temperatures, decreased budding and formed grains, and finally diminished synthesis of palmitic acid as an important fatty acid. Additionally, drought stress probably

Table 5. Mean comparisons of interaction effect of year and cultivar on grain yield, oil yield, erucic acid, and oleic acid.

Year	Cultivar	Grain yield (kg ha^{-1})	Oil yield (kg ha^{-1})	Erucic acid (%)	Oleic acid (%)
2015-2016	ES Hydromel	3200.9bc	1328.9bc	0.30de	62.54ed
	ES Alonso	3046.1bcde	1259.3bcde	0.34ab	62.24f
	ES Darko	3432.8ab	1433.3ab	0.31bcde	62.49e
	ES Lauren	2930.7 bcde	1214.3bcde	0.32bcd	62.44e
	Ahmadi	3855.6a	1610.4a	0.29e	62.67d
2016-2017	ES Hydromel	3383.3ab	1437.3ab	0.31cde	63.3a
	ES Alonso	3100.8bcd	1309.8bcd	0.33abcd	63.08bc
	ES Darko	2544.6e	1066.9e	0.34abc	63.06bc
	ES Lauren	2785.3cde	1168.9cde	0.33bcd	63.17ab
	Ahmadi	2592.9de	1081.0de	0.36a	62.92c

Any two means sharing a common letter do not differ significantly from each other at 5% probability level.

reduced fertilization, budding, flowering, and the percentage of palmitic acid in the studied cultivars. Among the cultivars, the highest palmitic acid average percentage (4.44%) belonged to ES Hydromel cultivar with delayed sowing date and late-season drought stress in unfavourable conditions of the second year (Figure 1). ES Hydromel cultivar could probably tolerate the stress of delayed planting and drought stress conditions. Under drought stress conditions, saturated fatty acids, such as palmitic acid, and thus the unsaturated fatty acids synthesized from saturated fatty acids are significantly reduced.[20] The effect of the sowing date on palmitic acid was significant, and it reduced the amount of palmitic acid.[21] Some studies have estimated a palmitic acid content of 4-8% in their study on palmitic acid and important stearic fatty acids and attributed variations of palmitic acid in the grain oil of rapeseed cultivars to genetic differences.[22] Environmental conditions had a significant effect on the quality of rapeseed oil.[23]

Oleic acid

According to the results of ANOVA (Table 3), the main effects of year, sowing date, irrigation, and cultivar were significant on oleic acid content ($p<0.01$). The percentage of oleic acid was significantly affected by the interaction of year × cultivar ($p<0.01$), as well as the interactions of year × sowing date × irrigation ($p<0.01$; Table 3). In both experimental years, the highest percentages of oleic acid (63.72% and 63.83%) were obtained under the normal sowing date and common irrigation, whereas delayed planting and drought stress resulted in the lowest level (61.44%) in the first year (Figure 2). Therefore, delayed planting and late-season drought stress caused significant reductions in oleic acid percentages in rapeseed cultivars in both years. Delayed planting might have reduced the oleic acid content by shortening the growth period, and drought stress reduced the percentage of this important fatty acid in rapeseed, probably due to early ripening of the plant. The temperature and humidity conditions were likely more available for oleic acid synthesis in the second year. Since, oleic acid (omega-9) plays a vital role in determining the quality of rapeseed oil,[5-24] oleic acid percentage reduction led to a decrease in seed oil quality. Plant phenology explains the difference between production potential and adaptability. Under stressful conditions, genotypes ripen earlier to escape the stress.[25] Previous studies have reported that the percentage of oleic acid decreased significantly under drought stress due to the shortening of the growth period.[26]

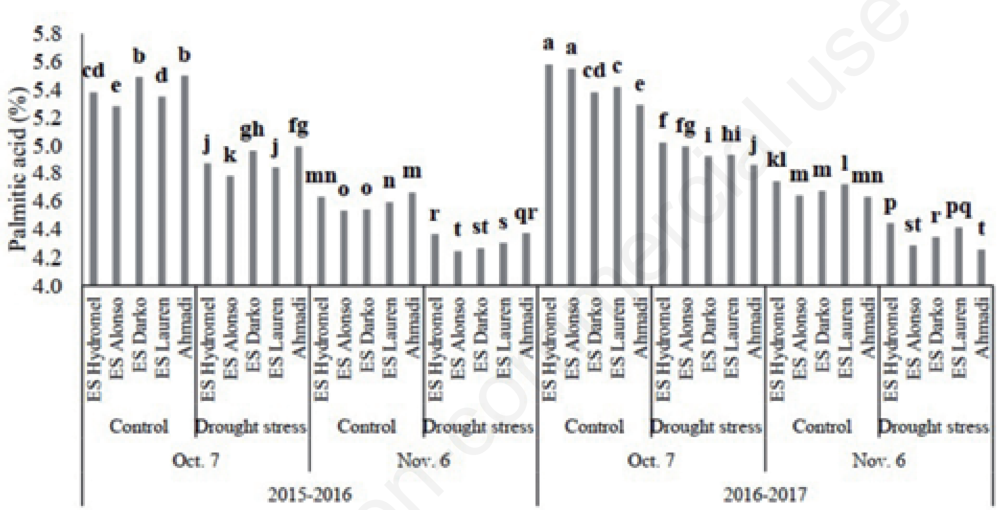

Figure 1. Effect of year × sowing date × irrigation × cultivar interaction on palmitic acid content of all studied genotypes (means with the same letters are not significantly different at p<0.05).

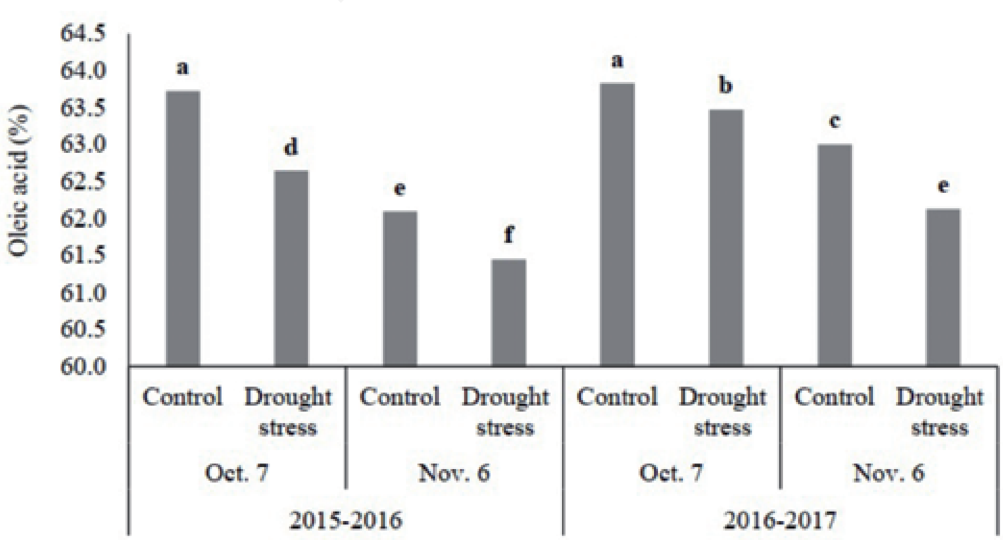

Figure 2. Effect of year × sowing date × irrigation interaction on oleic acid content of all studied genotypes (means with the same letters are not significantly different at p<0.01).

Linoleic acid

Only the main effect of sowing date and irrigation, as well as the interaction of year × sowing date, were significant ($p<0.01$) on the linoleic acid trait (Table 3). Based on the comparison of means (Table 6), delayed planting decreased the linoleic acid percentage in both years. The highest average linoleic acid content (16.90%) was recorded on the normal sowing date (October 7th) in the first year, and the lowest percentage average (13.88%) was obtained on the delayed sowing date (November 6th) in the second year of the experiment (Table 6). Likely, the weather conditions of the second year, decreased rain, and the improper distribution of rainfall were the causes of the diminished percentage of linoleic acid in the second year (Table 1). Additionally, delayed planting reduced linoleic acid percentage in the plant due to the shortened growth period of rapeseed. Linoleic acid is one of the most essential factors in identifying the quality of rapeseed oil. Since omega-6 oil is not synthesized by the human body, it is important to introduce it with diet.[20] Low temperatures (delayed planting) oxidize rapeseed fatty acids and produce stable oxidized oleic acid, while oxidized linoleic acid is not stable and is converted to other products.[27] Similar results have been reported with a reduction in the percentage of linoleic acid in delayed cultivation[28] and under drought stress.[5]

Linolenic acids

The results of combined ANOVA showed that linolenic acid trait was affected significantly by the main effects of the year ($p<0.05$), sowing date, and irrigation ($p<0.01$), as well as interactions of year × sowing date and sowing date × irrigation ($p<0.01$; Table 3). The comparison of the mean year × sowing date interaction indicated that delayed planting increased the percentage of linolenic acid in both experimental years. Delayed (November 6th) and normal (October 7th) sowing dates resulted in the highest (7.70%) and the lowest (5.53%) average percentages of linolenic acid in the second and the first years of the experiment, respectively (Table 6). The unfavourable weather conditions of the second year (Table 1) probably led to the high percentage of linolenic acid. Previous studies have also shown an increase in the percentage of linolenic acid under delayed planting and have found that a 20-day delay in sowing date led to a significant increase in this fatty acid in comparison to the sowing date commonly used in rapeseed genotypes.[29] The comparison of the mean effects of sowing date × irrigation showed increases in linolenic acid and its content under late-sowing and drought stress. The highest percentage of linolenic acid was observed in the late-sowing date (November 6th) and irrigation interruption from the flowering stage onwards. However, the lowest percentage of linolenic acid was obtained on the regular sowing date (October 7th) and normal irrigation with an average of 7.92% and 5.34%, respectively (Table 4).

Rapeseed contains high levels of linolenic acid,[30] which is also very important in the pharmaceutical industry.[31] Some studies have shown that severe drought stress caused a 3.8% decrease in oleic acid and a 1.7% increase in linolenic acid in rapeseed oil.[18]

Erucic acid

The percentage of erucic acid was affected significantly by the main effects of year ($p < 0.05$), sowing date, and irrigation ($p<0.01$; Table 3), as well as by the interactions of sowing date × irrigation ($p<0.05$) and year × cultivar ($p<0.01$; Table 3). Table 4 shows that delayed planting and drought stress increased the percentage of erucic acid. Accordingly, the highest percentage of erucic acid was observed with an average of 0.48% in delayed planting (November 6th) and drought stress (irrigation interruption from the flowering stage onwards) and the lowest with an average of 0.19% on normal sowing date (October 7th) and common irrigation (Table 4). Amount of erucic acid (less than 2%) is an important indicator to estimate the quality of rapeseed oil.[5] Previous studies have reported that the delay in planting and drought stress in the silique formation stage resulted in a 48.74% and 25.50% increase in erucic acid of rapeseed oil, respectively.[26] The highest (0.36%) and the lowest (0.29%) average percentages of erucic acid were respectively measured in Ahmadi cultivar in the second and the first years (Table 5). In addition, the ES Hydromel cultivar contained the most negligible percentage of erucic acid in the second experimental year when the distribution and amount of rainfall were unfavourable compared to those of the first year (Table 1). Since a high percentage of erucic acid in rapeseed grain oil reduces the quality of this oil, ES Hydromel cultivar, with a low percentage of erucic acid, contained a higher oil quality than the other examined cultivars. Treatments with 60% and 100% irrigation resulted in the highest and the lowest levels of erucic acid, respectively.[32] Other reports mentioned that the effect of genotype on fatty acids of oilseeds was more significant than environmental stresses.[33-36]

Grain glucosinolate content

The main effects of year, sowing date, irrigation, and cultivar were highly significant on glucosinolate ($p<0.01$; Table 3). Also, the interactions of year × sowing date × cultivar had a significant effect on this trait ($p<0.01$; Table 3). Among the tested cultivars, the Ahmadi cultivar contained the highest average level of glucosinolate (25.28 μmol g^{-1} DW) in the delayed planting treatment (November 6th) in the second year. Still, the lowest average of glucosinolate content (23.19μmol g^{-1} DW) belonged to ES Hydromel cultivar in similar conditions (Figure 3). Apparently, ES Hydromel cultivar with a lower glucosinolate content had a higher meal quality in delayed planting and unfavourable conditions of the second year (Table 1). However, the glucosinolate content in all cultivars was standard (less than 30μmol g^{-1} DW). In addition to genetic characteristics, environmental factors, including climatic conditions, nutrient availability, and cultivation methods influence the glucosinolate content.[34] Increasing glucosinolate reduces the quality and nutritional value of winter rapeseed meals.[29] Previous studies also reported an increase in rapeseed glucosinolate content from 13.8 to 20.3μmol g^{-1} dry weight under delayed planting conditions. Furthermore, during late autumn sowing, due to the harsh environmental conditions such as temperature changes and

Table 6. Effect of year × sowing date interaction on linoleic acid and linolenic acid of all studied genotypes.

Year	Sowing date	Linoleic acid (%)	Linolenic acid (%)
2015-2016	Oct. 7	16.90a	5.53c
	Nov. 6	14.08c	6.95b
2016-2017	Oct. 7	16.07b	5.70c
	Nov. 6	13.88c	7.70a

Any two means sharing a common letter do not differ significantly from each other at 5% probability level.

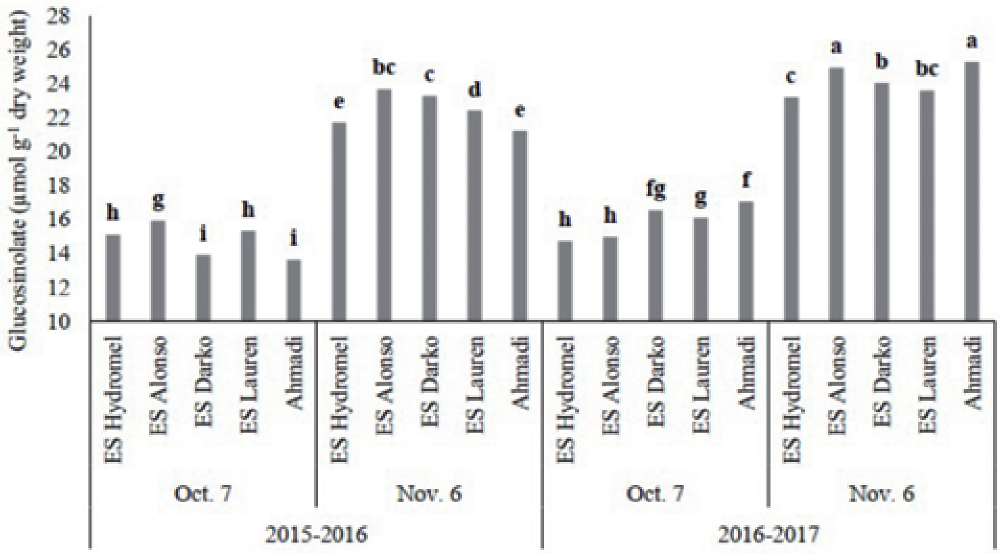

Figure 3. Effect of year × sowing date × cultivar interaction on glucosinolate content of all studied genotypes (means with the same letters are not significantly different at $p<0.01$).

drought stress, accumulation of glucosinolate enhances in rapeseed.[35] Although glucosinolate has a significant effect on plant defense mechanisms against pests, it is not an approved option for livestock feed and seed production.[21]

Conclusions

Late-season drought stress and delayed sowing decreased the quantity and quality of rapeseed oil due to the reduction of palmitic acid, oleic acid, linoleic acid, grain and seed oil yield. In contrast erucic acid and glucosinolate content increased.

According to the results, the quality of studied cultivars was more affected by environmental conditions than by their genotype, and the effect of sowing date was much higher than drought stress due to irrigation interruption from flowering stage onwards. The percentages of erucic acid and glucosinolate content of all cultivars were observed at an international standard level. According to the primary goal of this study, ES Hydromel hybrid cultivar can be introduced as a superior cultivar in arid and semi-arid regions due to having the uppermost palmitic acid under late-sowing and drought stress and the highest grain and oilseed yield in the second year of the study. On the other hand, ES Hydromel obtained the lowermost glucosinolate content under delayed cultivation, and the lowest erucic acid in the second year of the research led to higher oil and meal quality.

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