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Research article

Influence of drought stress and application of ammonium sulfate on quality of rapeseed oil

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Abstract

Nowadays, drought stress is one of the most highlighted consequences of global warming, resulting in various environmental and economic drawbacks in the planting systems of important oil seed crops, particularly rapeseed. In the present study, an experiment was performed to assess the influence of drought stress and the application of ammonium sulfate on the quality of rapeseed oil during 2015–2016 and 2016–2017. This study was designed using a factorial split-plot based on complete randomized blocks with three replicates. Irrigation factors consisted of two levels (normal and irrigation interruption at the pod formation stage and at the elongation stage) and ammonium sulfate was included at two levels (0 kg/ha and 150 kg/ha), as a factorial set in the main plots (in factorial status in main plots) and cultivars (in subplots). The results showed the highest amount of grain oil (45.5%) was obtained in the second year of the experiment and under normal irrigation. The amount of oil increased by 2.5% using ammonium sulfate compared with the normal condition. The highest amounts of palmitic acid (5.2%) and oleic acid (65.5%) were obtained using the BAL128 line under normal irrigation, while the least palmitic acid (4.3%) and oleic acid (63.8%) were obtained using the Nima cultivar under irrigation interruption. The BAL128 line had the highest percentage of grain oil. Under normal irrigation, the use of ammonium sulfate decreased the amount of glucosinolate to 22.9%. The overall results of this study suggested that the BAL128 line was superior to the other genotypes in terms of the yield and quality of fatty acids; therefore this line might be applicable for farming or as a parent or both to increase the yield and quality in future breeding systems.

Introduction

Drought is the most important limiting factor in plant growth and agricultural production worldwide, especially in arid and semi-arid regions (Sun et al., 2013). Among the oilseeds, rapeseed is one of the most important species of oily seeds in the world due to the high quality of its oil and meal; however, drought stress is one of the important factors that can limit the development and successful cultivation of rapeseed (Rashidi et al., 2012).

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Different varieties of rapeseed have 37–47% seed oil and grain yield. According to Jabbari et al., (2017), a high seed oil percentage is an important factor in the profitability of rapeseed production. The seed oil content is affected by drought stress (Aslam et al., 2009; Tohidi Moghaddam et al., 2011) and temperature (Aslam et al., 2009) during the grain-filling period. Reduced seed oil content and oil yield of rapeseed varieties have been reported under drought stress conditions during the flowering stage, which could be due to the oxidation of some unsaturated fatty acids and reduced ability to convert carbohydrates into oils under stress conditions (Jabbari et al., 2017).

The fatty acid composition determines the quality characteristics of each type of oil and the quality of seed oil is one of the most important traits for the breeding purposes regarding the *Brassica* genus (Enjalbert et al., 2013). The rapeseed oil fatty acids include saturated fatty acids and unsaturated fatty acids and rapeseed cultivars have significant differences in their fatty acid composition (Kadivar et al., 2010). The quality of rapeseed oil is mainly determined by the amount of oleic, linoleic and erucic fatty acids and is greatly influenced by environmental conditions and variety (Jabbari et al., 2017). In one experiment, the reaction to drought stress was investigated of the oil fatty acid profile of different species in the *Brassica* genus and it was found that linoleic acid levels decreased significantly under stress conditions (Enjalbert et al., 2013). It has also been reported that drought stress at the flowering stage of canola reduced the amount of unsaturated fatty acids of seed oil, such as linoleic acid, linolenic acid and gadoleic acid, by 16%, 7% and 4%, respectively, compared to non-stress conditions (Tohidi Moghaddam et al., 2011).

Currently, sulfur deficiency is increasing rapidly in soils around the world due to continuous cultivation and use of high purity fertilizers and sulfur dioxide reduction in the atmosphere (Habibi et al., 2016). Unfortunately, most oilseed producers lose 10–40% of their production potential and suffer yield loss due to their lack of awareness of the importance of sulfur in the production of oily seeds (Habibi et al., 2016). Sulfur plays a significant role in the synthesis of proteins and enzymes and in the chemical composition of the seeds and the percentage of seed oil (Abdul and Fayyazul, 2006). In studying the effect of different sources of sulfur on the yield and quality of rapeseed, the effect of different sources on growth parameters, oil content and grain protein content, and the amount of high and low consumption elements in grain are significant, but among the different sources, ammonium sulfate is the most influential (Kandil and Gad. 2012). Sulfur consumption increases the amount of oleic acid in canola, which is due to the availability of sulfur at the time of seed filling (Jan et al., 2002).

Tested genotypes can have different responses to drought stress; nevertheless, applying ammonium sulfate can reduce the negative effects of drought stress. Therefore, this research investigated whether the examined genotypes might have better seed quality and oil yield under drought stress conditions?

Based on the issues raised above, the purpose of this project was to evaluate the effect of irrigation interruption and the application of ammonium sulfate on the composition of oil fatty acids and the evaluation of the reaction by rapeseed genotypes in terms of oil quality to drought stress and ammonium sulfate fertilizer.

Materials and Methods

This experiment was conducted at the Seed and Plant Improvement Institute of Karaj, Iran in the 2016 and 2017 growing seasons. The experimental designs were randomized complete blocks with a factorial split-plot arrangement and three replications. The treatments were: 1) irrigation (IR), normal (complete; IR1), and irrigation interruption from the pod formation stage (IR2); 2) ammonium sulfate (SUA) at 0 kg/ha (SUA1) and 150 kg/ha (SUA2) from the elongation stage. These treatments were applied on the BAL111, BAL119, BAL121, BAL128 and Nima cultivars (Table 1).

Table 1 Growth type and origin of studied rapeseed genotypes

Name	Origin	Growth type	Hybrids	Cultivar	Line
BALL111	Iran	Winter	-	-	*
BALL119	Iran	Winter	-	-	*
BALL121	Iran	Winter	-	-	*
BALL128	Iran	Winter	-	-	*
Nima	Iran	Winter	-	*	-

Land preparation before conducting the test involved irrigation, plowing and discing. Seeds were planted on 1 October each year. Each experimental subplot consisted of six rows (6 m in length) and spacing between rows of 30 cm. The seeds were planted 5 cm apart in the row (66.6 plants/m). Two lateral lines were considered as margins and four intermediate lines were used to determine the various traits. Weeds were controlled using Galant Super and Lontrel (1 L/ha) from the 4-leaf stage to the 8-leaf stage. Climate data (temperature and precipitation for the whole year) are presented in Table 2. Fertilizer was applied according to soil testing analyses (urea at 200 kg/ha, triple super phosphate at 90 kg/ha and potassium sulfate at 70 kg/ha at planting time). The results of the physical and chemical analysis of the soil of the test site are given in Table 3.

The irrigation treatment was carried out with continuous sampling from depths of 0 cm to 60 cm of soil (using a time-domain reflectometer device), when 50% of the water used was drained on the soil. A small pump was used to irrigate with connection to the hose and the water meter (to measure the volume of water consumed). Irrigation for the interruption condition treatment did not receive water during the stress period (from the pod formation stage). The volumes of water applied for the normal irrigation and irrigation interruption treatments in the first year of the experiment were 4,350 m^3/ha and 3,100 m^3/ha and in the second year of the experiment were averages of 4,600 m^3/ha and 3,220 m^3/ha. The difference in irrigation between the first and second years was due to higher rainfall in the first year (225 mm) than in the second year (190 mm).

At the end of the growing season and at the time of physiological maturity, the grain yield was calculated after separating the seeds from their pods. Measurement of the seed oil content was performed using a nuclear magnetic resonance spectrometer (mq20; Bruker; Germany). Determination of the fatty acid composition, (palmitic acid, oleic acid, linoleic acid, linolenic acid and erucic acid) used the gas chromatography of the methyl esters (Metcalf et al., 1966; Lee et al., 1988). The amount of glucosinolate was measured using a high performance liquid chromatography apparatus (Thies, 1974).

Table 2 Climate data experimental from Karaj 2016–2017

Month	October		November		December		January		February	
Year	2015	2016	2015	2016	2015	2016	2016	2017	2016	2017
Rainfall (mm)	22.2	2.4	57	0.9	27.9	41.1	14.7	15	11.2	27
Average temperature (°C)	17.8	16.6	8.6	8.1	2.8	4.7	5.5	3.7	7.8	2.5
Month	March		April		May		June			
Year	2016	2017	2016	2017	2016	2017	2016	2017		
Rainfall (mm)	24.6	38.4	51.6	46.7	12.6	22	-	-		
Average temperature (°C)	11.3	9.3	14.8	15.1	21.3	21.9	25.6	26.1		

Table 3 Result of chemical and physical analysis of experimental soil

Year	Depth (cm)	Electrical conductivity (ds/m)	pH	Organic Matter (%)	Nitrogen (kg/ha)	Phosphorus P_2O_5 (kg/ha)	Potassium K_2SO_4 (kg/ha)	Soil Texture
2015–2016	0–30	1.39	7.8	0.89	0.09	14.4	170	Clay Loam
2016–2017	0–30	1.34	7.9	0.85	0.08	14.2	164	Clay Loam

Statistical analyses

Bartlett's test was performed to evaluate homoscedasticity at a significance level of 0.05. Where homoscedasticity was identified in all of traits, a combined analysis of variance (ANOVA) was conducted at a significance level of 0.05 on both sides and at a significance level of 0.01. A least significant difference test was carried out to compare the means within the ANOVA at a significance level of 0.05. Data were analyzed using the SAS 9.1 software package.

Results and Discussion

Grain yield

Between the two years of the experiment, there was a significant difference ($p < 0.01$) in the grain yield (Table 4). The highest grain yield (3,552 kg/ha) was obtained during the first year (Table 5). The increased the grain yield components in the first year due to the favorable rainfall was significantly higher than in the second year. The interaction effect of irrigation on ammonium sulfate was significant at the 5% probability level (Table 4). The comparison of the averages showed that the highest grain yield (4,859 kg/ha) was produced from complete irrigation and the application of ammonium sulfate. However, with irrigation interruption from the pod formation stage, the grain yield decreased significantly ($p < 0.05$; Fig. 1A).

The simple effect of genotype on seed yield was highly significant ($p < 0.01$; Table 4). Among the genotypes, the BAL128 and BAL121 lines had the highest (3,904 kg/ha) and lowest (2,953 kg/ha) grain yields, respectively. Among the genotypes examined, only the BAL121 line had a lower grain yield than the control cultivar, while the remaining lines all had higher yields than the control cultivar (Table 5).

Previous experiments had already demonstrated that decreasing the number of branches during the seed filling stage for canola under drought stress can be one of the key factors in reducing grain yield (Nielsen, 1997). Golipoor et al. (2004) reported that the transfer of nutrients into the seeds decreased while the plant was under drought stress during the growth stage of pods and this reduction resulted in a decreased yield.

Table 4 Analysis of variance of some quality traits of rapeseed genotypes in irrigation and sulfate-ammonium treatments

Source	DF	F-value							
ANOVA model		Grain yield	Oil content	Palmitic acid	Oleic acid	Linoleic acid	Linolenic acid	Erucic acid	Glucosinolate
Y	1	130.51**	4.22ns	60.98**	1441.21**	2.57ns	15.45*	11.84*	286.94**
Rep(Y)	4	0.11	3.30	2.57	0.19	5.25	1.95	0.76	0.89
IR	1	754.78**	369.42**	19916.4**	2349.07**	848.00**	514.76**	751.15**	7891.87**
Y*IR	1	0.61ns	15.43**	2.24ns	40.40**	13.32**	14.74**	0.09ns	13.27**
SUA	1	306.36**	85.23**	7016.15**	829.03**	195.84**	132.16**	153.99**	2135.05**
Y*SUA	1	0.65ns	4.28ns	2.25**	23.10**	0.31ns	0.60**	0.70ns	0.10ns
IR*SUA	1	5.91*	3.68ns	402.52*	0.82ns	2.36ns	18.01ns	5.15*	6.30*
Y*IR*SUA	1	4.47ns	1.54ns	11.28**	81.56**	0.37ns	1.28ns	0.21ns	0.23ns
Rep(Y*IR*SUA)	12	0.31	1.93	1.10	0.47	0.37	0.82	1.27	1.02
Genotype	4	8.90**	5.24**	163.32**	12.68**	2.10ns	2.85*	7.15**	67.94**
Y* Genotype	4	0.05ns	0.19	0.27ns	0.14ns	0.02ns	0.10ns	0.03ns	0.13ns
IR* Genotype	4	1.42ns	1.72ns	63.12**	4.15**	0.82ns	1.02ns	2.27ns	26.16**
Y*IR* Genotype	4	0.09ns	0.09ns	0.09ns	0.42ns	0.04ns	0.13ns	0.02ns	0.26ns
SUA* Genotype	4	0.16ns	0.06ns	2.01ns	0.89ns	0.03ns	0.04ns	0.04ns	0.34ns
Y* SUA* Genotype	4	0.01ns	0.03ns	1.35ns	1.01ns	0.06ns	0.16ns	0.09ns	0.95ns
IR* SUA* Genotype	4	0.04ns	0.13ns	3.38*	1.06ns	0.08ns	0.12ns	0.18ns	0.16ns
Y*IR* SUA* Genotype	4	0.02ns	0.09ns	3.10*	0.28ns	0.09	0.09ns	0.05ns	0.66ns
Coefficient of variation (%)		19.15	1.07	0.53	0.33	5.09	7.05	10.77	2.54

ns = non-significant; Y = year; IR = irrigation; SUA = ammonium sulfate

* $p < 0.05$ and ** $p < 0.01$

Table 5 Comparison of mean yield and fatty acids of rapeseed genotypes in years of experiment

	Grain yield (kg/ha)	Oil content (%)	Palmitic acid (%)	Oleic acid (%)	Linoleic acid (%)	Linolenic acid (%)	Erucic acid (%)	Glucosinolate (mg/g dw)
Year								
2015–2016	3552.17±554[a]	43.82±1.16[a]	4.75±0.41[b]	64.39±0.89[b]	15.96±1.68[a]	6.12±0.91[b]	0.29±0.11[b]	17.69±4.3[b]
2016–2017	3108.00±561[b]	44.14±1.60[a]	4.81±0.40[a]	65.05±0.71[a]	15.43±1.56[a]	6.57±1.16[a]	0.31±0.11[a]	19.05±4.5[a]
Irrigation Type								
IR_1	4216.60±500[a]	45.13±0.91[a]	5.12±0.27[a]	65.36±0.53[a]	16.99±1.05[a]	5.51±0.50[b]	0.21±0.05[b]	14.55±2.16[b]
IR_2	2443.57±357[b]	42.83±0.70[b]	4.44±0.17[b]	64.07±0.63[b]	14.41±0.99[b]	7.18±0.80[a]	0.40±0.06[a]	22.19±2.43[a]
Ammonium Sulfate								
SUA_1	2765.28±491[b]	43.43±1.22[b]	4.58±0.30[b]	64.33±0.81[b]	15.08±1.45[b]	6.77±1.12[a]	0.35±0.11[a]	20.36±4.09[a]
SUA_2	3894.88±614[a]	44.54±1.38[a]	4.98±0.40[a]	65.10±0.75[a]	16.32±1.59[a]	5.92±0.82[b]	0.26±0.09[b]	16.39±3.89[b]
Genotype								
BAL111	3523.8±689[b]	44.05±1.53[ab]	4.80±0.46[b]	64.71±0.97[b]	15.75±1.76[ab]	6.36±1.18[ab]	0.304±0.12[b]	18.32±5.07[c]
BAL119	3228.4±522[bc]	43.97±1.34[b]	4.80±0.37[b]	64.78±0.78[b]	15.74±1.54[ab]	6.28±0.97[b]	0.298±0.99[bc]	18.17±4.02[c]
BAL121	2953.0±516[c]	43.89±1.31[bc]	4.76±0.38[c]	64.68±0.82[b]	15.61±1.55[ab]	6.36±1.0[ab]	0.311±0.10[ab]	18.60±4.12[b]
BAL128	3904.0±671[a]	44.30±1.44[a]	4.87±0.42[a]	64.92±0.82[a]	16.02±1.63[a]	6.15±1.02[b]	0.281±0.10[c]	17.29±4.38[d]
Nima	3041.2±557[c]	43.70±1.34[c]	4.69±0.38[d]	64.49±0.89[c]	15.38±1.66[b]	6.57±1.11[a]	0.329±0.11[a]	19.47±4.35[a]

DW = dry weight.

Mean values with the same lowercase superscript in each column are not significantly (p0.05 <) different.

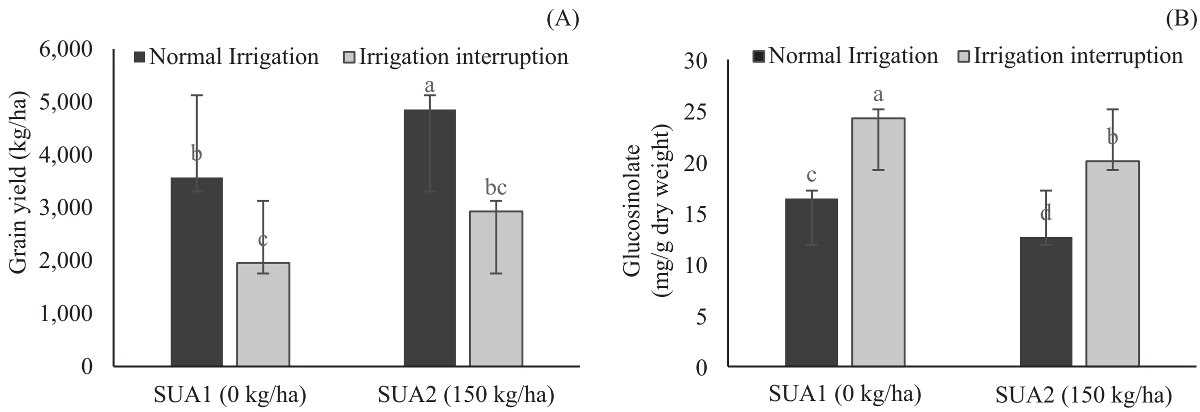

Fig. 1 Interaction effect of irrigation × ammonium sulfate on rapeseed: (A) grain yield; (B) glucosinolate content, where different lowercase letters above bars indicate significant different ($p < 0.05$).

Oil content

There was no significant difference in the oil content between the two years of the experiment (Table 4); however, the interaction effect of year on irrigation was significant ($p < 0.01$; Table 4). The highest amount of seed oil (45.53%) was obtained under normal irrigation in the second year of the experiment. The oil content decreased in both the first and second years of the experiment for the irrigation interruption from the pod formation stage (Table 8). The effect of ammonium sulfate treatment on the seed oil content was also significant ($p < 0.01$; Table 4). Application of 150 kg/ha increased the overall yield by approximately 2.5% compared to non-application. The simple effect of genotype on the seed oil content was significant at the 1% level (Table 4) and the comparison of means showed that the BAL128 line had the highest percentage of seed oil (44.29%). The Nima variety (the control) had the lowest amount of seed oil (43.69%; Table 5). Apart from the interaction of year on irrigation discussed above, the remaining interaction effects on this trait were not significant (Table 4).

In one study, drought stress from the flowering and pod formation stages did not have a significant effect on the seed oil content of two rapeseed cultivars Zarfam and Okapi (Soleymani et al., 2011). In contrast, other researchers have reported that drought stress in the flowering stage reduced the percentage of seed oil and oil yield of canola cultivars. This could have been due to the oxidation of some unsaturated fatty acids and the reduction of the ability to convert carbohydrates into oils under stress conditions (Nielsen, 1997; Daneshmand et al., 2008).

Fatty acids composition

The quality characteristics of each type of oil depend on the fatty acids composition. One of the important correctional goals in rapeseed, in addition to the quantity of oil, is increased oil quality

(Azizi et al., 1999). However, the quality of seed oil is one of the most important traits for rapeseed breeding purposes in semi-arid environments (Enjalbert et al., 2013).

The current study investigated five fatty acids (palmitic acid, oleic acid, linoleic acid, linolenic acid and erucic acid). The results of the variance analysis (Table 4) showed a significant effect of year on the percentage of all investigated fatty acids (except linoleic acid). Means comparison indicated a higher percentage of fatty acids in the second year of the experiment (Table 5). The interaction of year and irrigation on the amounts of oleic acid, linoleic acid and linolenic acid was significant at the 1% probability level (Table 4). Means comparison demonstrated that irrigation interruption from the pod formation stage in the first year, decreased the linoleic acid content by 20% and in the second year by 15.8% (Fig. 2C). However, linolenic acid increased with irrigation interruption, so that in the first and second years, there were increases of 25.7% and 35% in this fatty acid, respectively (Fig. 2B).

Jabbari et al. (2017) reported that the unsaturated fatty acid composition of rapeseed oil was mostly affected by drought stress and cultivar type due to irrigation interruption from the elongation, flowering and pod formation stages, resulting in significant increases in oleic acid and a significant reduction in the amount of linoleic and linolenic acids.

Enjalbert et al. (2013) investigated the reaction of the fatty acid composition of seed oil of different species of brassica to drought stress and reported that the amount of linolenic acid decreased under stress conditions because of the shortened plant growth period under stress conditions (Tohidi et al., 2011) reported that drought stress in the canola flowering stage reduced the amount of unsaturated fatty acids in the seed oil, such as linoleic acid and linolenic acid, by 16% and 7%, respectively, compared to non-stress conditions, while there was an increase of 1.7–2% in unsaturated fatty acids, such as linoleic acid and linolenic acid with a 3.8% reduction in oleic acid in rapeseed oil due to drought stress under Mediterranean climatic conditions (Aslam et al., 2009).

Reductions in the seed oil content and oil yield of rapeseed varieties were reported under drought stress conditions during the flowering stage and this could have been due to the oxidation of some unsaturated fatty acids and the reduced ability to convert carbohydrates to oils under stress conditions (Singh and Sinha. 2005; Tohidi et al., 2011).

The effect of ammonium sulfate treatment on the amount of all five fatty acids was significant at the 1% probability level (Table 4). Furthermore, the interactions of the year × ammonium sulfate (except for linoleic acid) on other fatty acids was significant (Table 4). The mean comparison showed that the application of ammonium sulfate in the first and second years of the experiment resulted in decreases in linolenic acid of 12.1% and 13.6%, respectively, and decreases in erucic acid of 26.2% and 22.1%, respectively (Figs. 3A and 3B).

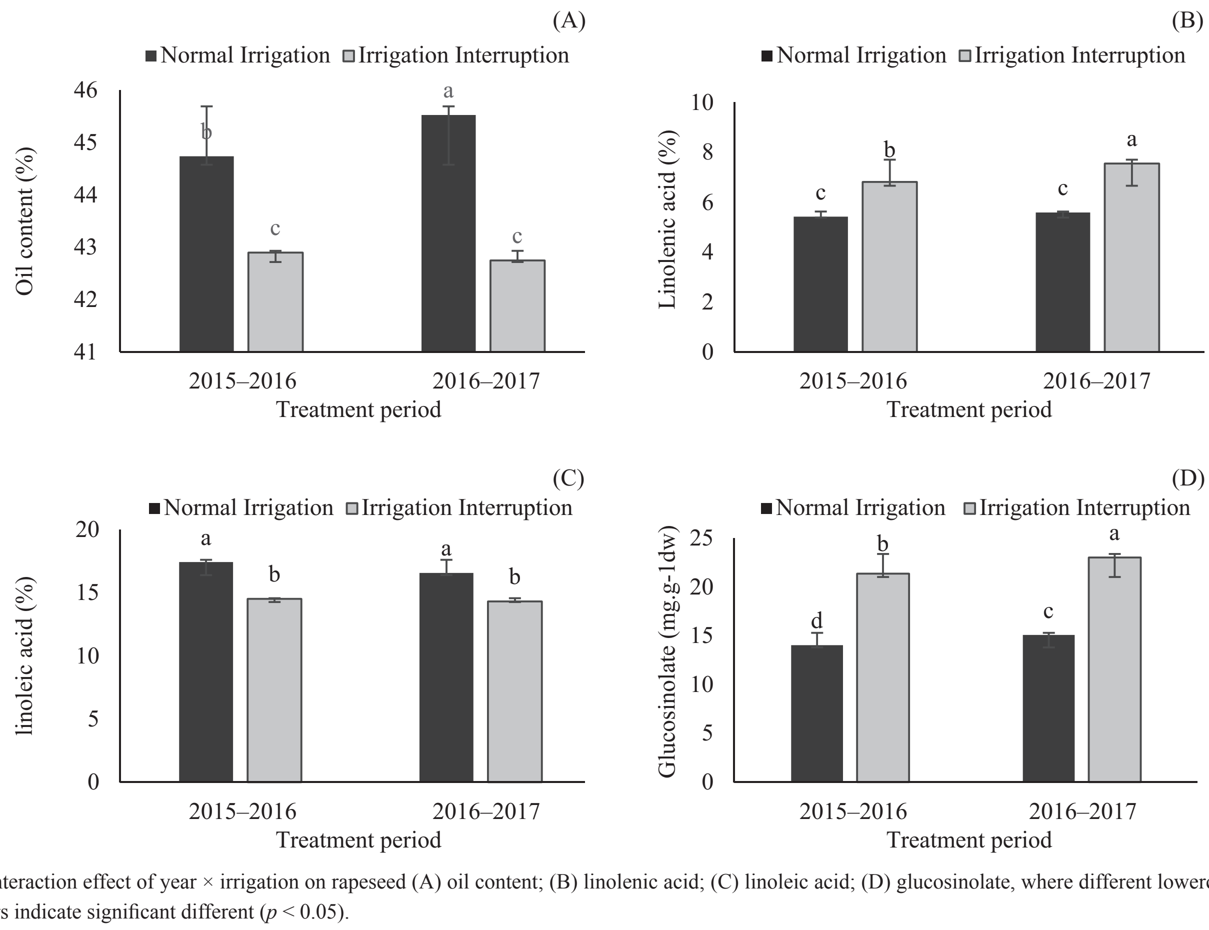

Fig. 2 Interaction effect of year × irrigation on rapeseed (A) oil content; (B) linolenic acid; (C) linoleic acid; (D) glucosinolate, where different lowercase letters above bars indicate significant different ($p < 0.05$).

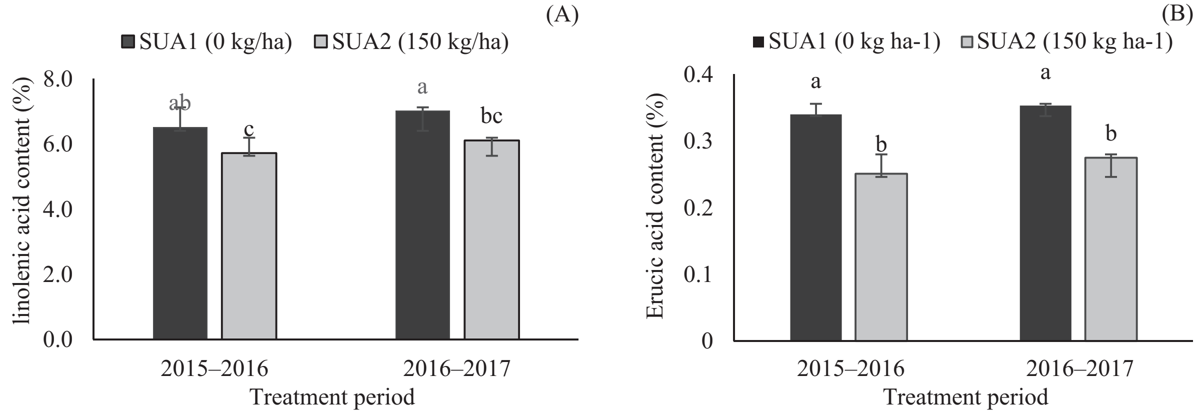

Fig. 3 Interaction effect of year × ammonium sulfate (SUA) on rapeseed content of (A) linolenic acid; (B) erucic acid, where different lowercase letters above bars indicate significant different ($p < 0.05$).

According to the variance analysis results, the interaction of year × irrigation × ammonium sulfate was significant on palmitic acid and oleic acid at the 1% probability level (Table 4). In both years of the experiment, the highest amounts of palmitic acid and oleic acid under normal irrigation and the application of ammonium sulfate (150 kg/ha) and the lowest amounts of palmitic acid and oleic acid were observed in the treatment involving irrigation interruption and non-application of ammonium sulfate (Figs. 4A and 4B).

The effects of genotype on palmitic acid ($p < 0.01$), oleic acid ($p < 0.01$), erucic acid ($p < 0.01$) and linolenic acid ($p < 0.05$) were significant but the genotypes tested did not different significantly in terms of the linoleic acid fatty acid contents (Table 4). Among the genotypes, the BAL128 line had the highest percentages of palmitic acid (4.87%) and oleic acid (64.92%) and the lowest percentages of linolenic acid (6.15%) and erucic acid (0.281%). The Nima cultivar had the highest percentages of linolenic acid (6.57%) and erosic acid (0.329%) and the lowest percentages of palmitic acid (4.69%) and oleic acid (64.49%; Table 5).

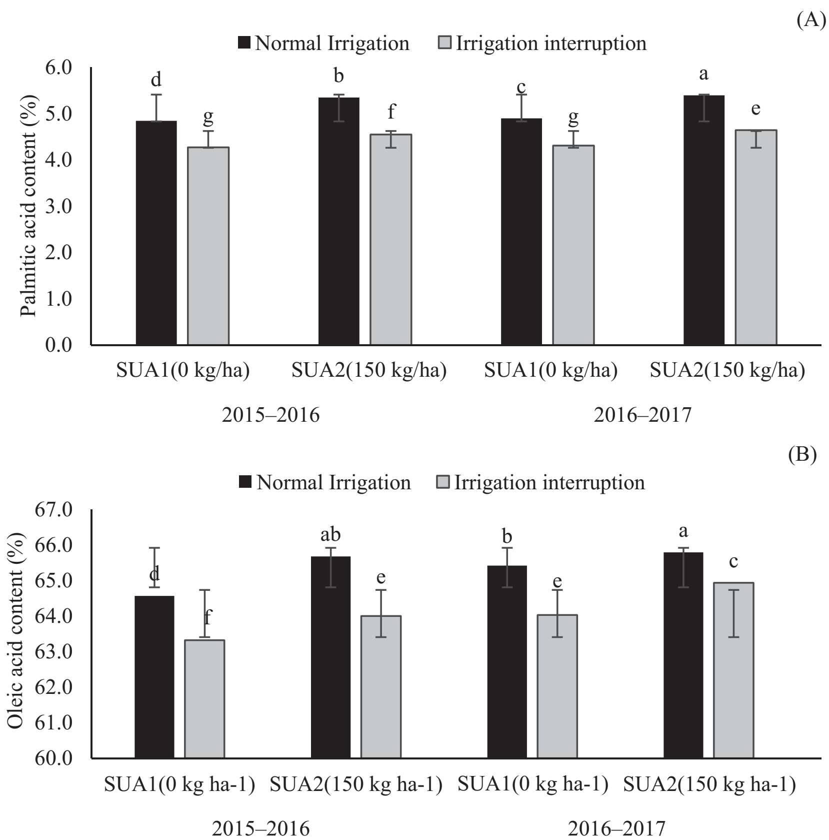

Fig. 4 Interaction effect of year × irrigation × ammonium sulfate (SUA) on rapeseed content of: (A) palmitic acid; (B) oleic acid, where different lowercase letters above bars indicate significant different ($p < 0.05$).

The interaction effect of irrigation × genotypes was not significant on the linoleic acid, linolenic acid and erucic acid fatty acids, whereas there was a significant ($p < 0.01$) effect on the percentages of palmitic acid and oleic acid (Table 4). Mean comparison showed that highest amounts of palmitic acid (5.2%) and oleic acid (65.6%) were obtained from the BAL128 line under normal irrigation, and the least amounts of palmitic acid (4.4%) and oleic acid (63.8%) were obtained from the Nima cultivar under irrigation interruption (Figs. 5A–C).

Glucosinolate content

The interaction effect of year × irrigation on glucosinolate was significant at the 1% probability level (Table 4). Means comparison showed that the highest amount of glucosinolate (23.02 mg/g dry weight, dw) was obtained during the second year of the experiment and irrigation interruption condition, also the lowest level of glucosinolate (14.02 mg/g dw) was obtained during the first year of the experiment and normal irrigation conditions. During both years of the experiment, normal irrigation led to a significant ($p < 0.05$) increase in glucosinolate levels (Fig. 2D). Increasing glucosinolate reduces the quality and nutritional value of rapeseed meal (sulisbury et al., 1987) and is influenced by inherited and environmental factors (Fieldsend et al., 1991.

The interaction effect of irrigation × ammonium sulfate on the glucosinolate level was significant at the 1% probability level (Table 4). Mean comparisons showed that the highest levels of glucosinolate (24.28 mg/g dw) were obtained under irrigation interruption and the non-application of ammonium sulfate and its lowest level (12.67 mg/g dw) was under normal irrigation and ammonium sulfate application. Under normal irrigation conditions, the application of 150 kg of ammonium sulfate at the elongation stage reduced the amount of glucosinolate by 22.88%. However, the same amount of ammonium sulfate under irrigation interruption reduced glucosinolate by 17.25% (Fig. 1B). The interaction effect of irrigation × genotype on the glucosinolate content was significant at the 1% probability level (Table 4). Mean comparisons showed that the Nima and BAL111 lines had the highest glucosinolate in terms of irrigation interruption with 23.28 mg/g dw and 22.92 mg/g dw, respectively. With normal irrigation, the BAL128 and BAL111 lines had the lowest glucosinolate levels of 13.66 mg/g dw and 13.67 mg/g dw, respectively. The BAL111 line had the highest (67.3%) and the BAL119 line had the lowest (45.3%) variations under irrigation interruption compared to normal irrigation (Fig. 5C).

Researchers have reported high genetic variation among rapeseed varieties in terms of the amount of glucosinolate in the seed (Burton et al., 2004). In a study that investigated agronomic traits and the seed yield of canola autumn cultivars, significant differences were presorted in the grain yield, fatty acid composition and glucosinolate content (Mostafavi Rad et al., 2011).

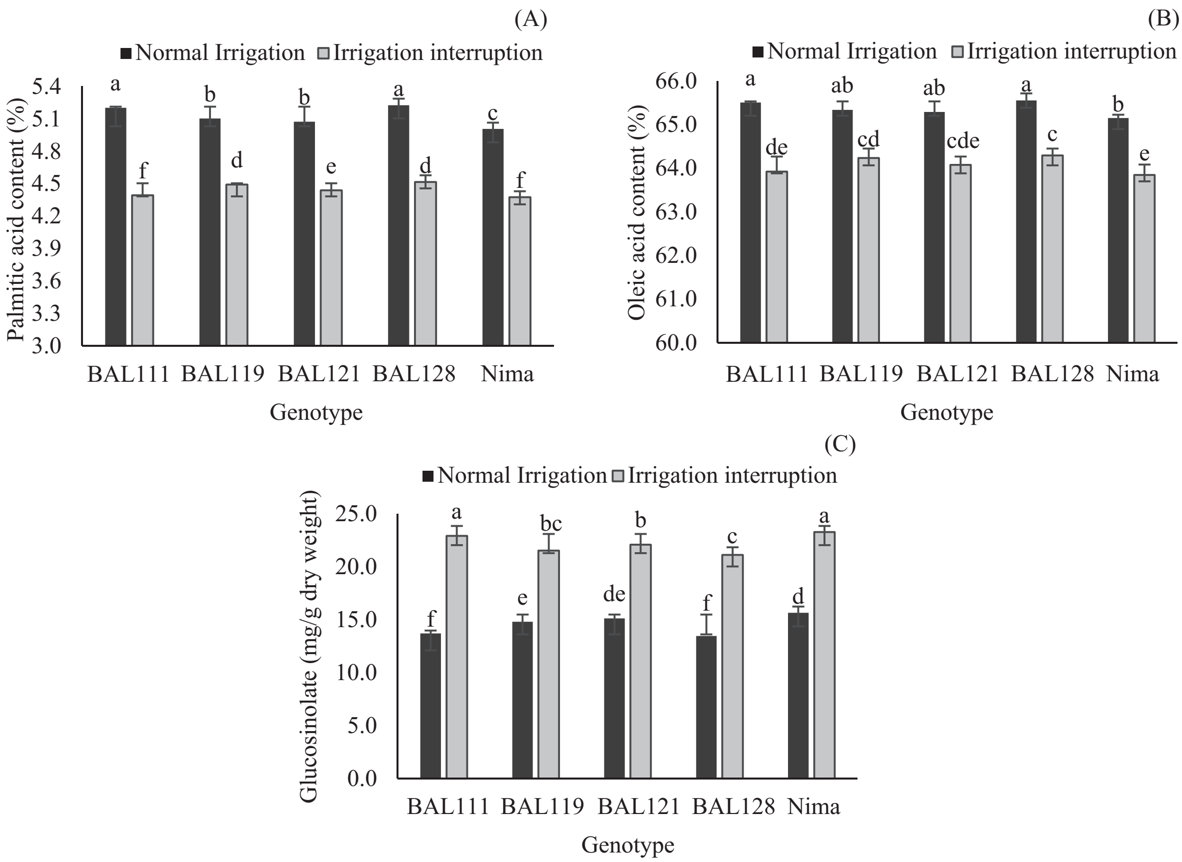

Fig. 5 Interaction effect of irrigation × genotype on rapeseed content of: (A) palmitic acid; (B) oleic acid; (C) , Glucosinolate, where different lowercase letters above bars indicate significant different ($p < 0.05$).

Evaluation of the current trait results during the two years of the experiment showed that the highest grain yield was obtained under normal irrigation with the application of ammonium sulfate. Among the genotypes, the highest seed yield and seed oil content were produced by the BAL128 genotype. On the other hand, the use of ammonium sulfate fertilizer reduced part of the negative effect of irrigation interruption on seed and oil yield losses. Therefore, the use of ammonium sulfate becomes more important when a plant is exposed to drought stress. Among the genotypes used in this research, the Nima genotype can be recommended for similar conditions to those in the study area.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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