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ARTICLE

Evaluation of the effect of organic soil amendments and irrigation regimes on the quantitative aspects of fatty acids in camelina seeds

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ABSTRACT This study aimed to assess the impact of soil moisture regimes (FI: full irrigation throughout the growing season, DI: deficit irrigation at 60% of field capacity during vegetative growth) and farmyard manure (FYM) levels (F0: 0, F10: 10, and F20: 20 t ha^{-1}) on the fatty acid profile of oil extracted from camelina seeds in the Razan region, western Iran. The highest linolenic acid content was recorded under FI+F10 and DI+F10 conditions. The application of F10 under FI and DI increased linoleic acid content by 2% and 1.4%, respectively. Water deficit stress significantly reduced eicosadienoic acid content (by 0.95%). The highest eicosadienoic acid content was observed under FI+F20 conditions (14.53%). Soil amendments and irrigation improved oleic acid content by approximately 3%. The highest palmitic acid content (5.20%) was obtained with F10 and F20 under FI conditions. Erucic acid content decreased under both soil moisture regimes as FYM application increased. The highest saturated fatty acid content was recorded under FI+F20. Plants grown with F20 had the highest polyunsaturated fatty acid content (69%).
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INTRODUCTION

Camelina (*Camelina sativa* L.) is an annual herbaceous oilseed crop from the Brassicaceae family, originating from central and eastern Europe. It is cultivated for edible, medicinal, and biofuel purposes (Neupane et al. 2022). Although camelina has been cultivated since 4000 BC, it remained underutilized for a long time. However, recent advances in breeding have revived interest in this crop among farmers (Berti et al. 2016). Compared to rapeseed, camelina requires less water for yield production and demonstrates higher resistance to early spring frosts. The oil extracted from camelina seeds contains approximately 50–60% unsaturated fatty acids and is rich in natural antioxidants such as tocopherols, giving it valuable qualitative characteristics (Bilska et al. 2024).

Despite these advantages, camelina cultivation in semi-arid regions faces challenges due to poor soil quality, including high pH, low micronutrient levels, limited water content, low water-holding capacity, and reduced microbial activity (Naorem et al. 2023). Consequently, effective soil management strategies, including organic amendments, are necessary to improve soil properties.

Livestock manure is a readily available and relatively inexpensive organic resource in semi-arid regions of Iran, where animal husbandry is a common practice. Organic fertilizers enhance soil conditions by gradually releasing essential nutrients, increasing organic matter content, and stimulating microbial activity. This, in turn, improves the biological, physical, and chemical properties of the soil (Pajura 2023). Additionally, the application of animal manure reduces soil bulk density and increases water-holding capillary pores, potentially mitigating water stress in semi-arid regions (Blanco-Canqui et al. 2015). Therefore, in areas with irregular rainfall and poor soil conditions, applying animal manure can significantly affect soil water retention and plant water relations (Brummerloh and Kuka 2023).

Research has shown that organic amendments, including different levels of animal manure, vermicompost, and biochar, influence the fatty acid composition of camelina oil in rainfed conditions. The application of 10 t ha^{-1} of vermicompost and biochar has been found to significantly enhance unsaturated fatty acids and oil quality under such conditions (Hazrati et al. 2022). Similarly, oil content, qualitative properties, and the proportion of saturated and unsaturated fatty acids in safflower have been influenced by foliar and soil applications of micronutrients and soil moisture. The highest oil yield was recorded under well-irrigated conditions with zinc application, while the highest linoleic acid content was obtained under nano-

Fe application (Pasandi et al. 2018). Furthermore, foliar application of silicon nanoparticles in safflower fields treated with manure resulted in greater improvements compared to control conditions (Janmohammadi et al. 2016). This suggests that soil enhancement with organic fertilizers can positively influence other agricultural management practices in semi-arid areas.

A recent study investigated the combined use of organic and chemical fertilizers along with stimulants and nanostructure protectors such as chitosan on camelina oilseeds in northwest Iran. The results demonstrated that applying 50% of the recommended chemical fertilizer along with biological fertilizers and nano-chitosan foliar spraying under supplemental irrigation conditions led to the highest oil yield and optimal fatty acid composition (Haghaninia et al. 2024).

While some studies have examined the impact of nutrient supply on the fatty acid composition of oilseed crops, there is limited information on the effects of animal manure under deficit irrigation on the fatty acid profile of camelina. In semi-arid regions of Iran, plants often experience heat stress and water shortages towards the end of the growing season due to declining rainfall, increased evaporation and transpiration, and rising solar radiation and air temperature. Therefore, this study aimed to evaluate the qualitative characteristics of camelina oil under varying manure application levels and moisture regimes (well-irrigation and deficit irrigation) in northwest Iran.

MATERIAL AND METHODS

Study Area and Experimental Design

A field experiment was conducted in the semi-arid highlands of Razan, Hamadan, western Iran, from 2023 to 2024. The experimental site is located at 35°39' N, 49°036' E, at an elevation of 1,810 m above sea level. According to De Martonne's climate classification, the region has a cold semi-arid climate with an average annual temperature of 15 °C, a maximum average of 21.3 °C, and a minimum average of 5.59 °C. The region receives an average annual precipitation of 311 mm.

The experiment followed a split-plot design based on a randomized complete block design (RCBD) with three replications. The main factor included two irrigation regimes: full irrigation (FI), where water was supplied at recommended intervals to maintain 100% field capacity (FC), and deficit irrigation (DI), where water supply was limited to 60% FC during the irrigation period. To prevent moisture leakage, a one-meter-wide uncultivated border was maintained between the main plots.

The subplots included three levels of organic amendments: F0 (no manure application), F10 (10 t ha^{-1} decomposed animal manure), and F20 (20 t ha^{-1} decomposed animal manure). Initial soil tillage was performed in October 2023, followed by secondary tillage, plot preparation, and manure application in February 2024.

Soil Properties and Preparation

Before fertilizer application, soil samples were collected from six locations across the experimental field at a depth of 0-30 cm. The soil was classified as loamy clay with a pH of 7.54, an electrical conductivity of 1.38 dS m^{-1}, and 14% calcium carbonate content. The soil analysis indicated the following properties: 287 mg kg^{-1} potassium, 14 mg kg^{-1} absorbable phosphorus, 0.12% total nitrogen, 0.49% organic carbon, and a cation exchange capacity of 12.2 C molc kg^{-1}. Micronutrient levels included 0.43 ppm zinc and 0.79 ppm iron.

Crop Establishment and Irrigation Management

Camelina seeds (Soheil intermediate cultivar) were obtained from Pakan Seed Company, Isfahan, Iran, and manually sown in ridge rows with a spacing of 20 × 3 cm on March 18, 2024. Irrigation was conducted using polyethylene pipes equipped with a volume meter (Iranensheab, TOROS30), while soil moisture was monitored using a time-domain reflectometer (TDR 200-Campbell Scientific, USA). The field capacity moisture content was 30.7% v/v, while the permanent wilting point was 14.5% v/v. Irrigation was applied when soil moisture decreased to 55% of available water under full irrigation and 45% under deficit irrigation conditions.

Yield Measurement and Harvesting

At physiological maturity, plants within a 1-m^2 quadrat were harvested using a sickle. Plant height was measured using a digital meter, and yield components were counted. The harvested plants were oven-dried at 70 °C, and the dry biomass per unit area was recorded. The plants were then threshed, and seeds were separated from the straw. The weight of 1,000 seeds was determined using a seed counter and a digital scale, while seed yield per unit area was also calculated. The harvest index was derived from the ratio of grain yield to total dry biomass.

Oil Extraction and Fatty Acid Analysis

To determine the fatty acid profile, oil was extracted from the seeds using diethyl ether solvent, and oil yield was calculated by multiplying seed yield and oil percentage.

Fatty Acid Methylation Process

For fatty acid identification, 5 ml of 2% methanolic soda and 2 mg of pentadecanoic acid (Sigma-Aldrich, USA) were added to 5 mg of extracted oil, followed by heating in boiling water for 10 min. Subsequently, 2.18 ml of

Table 1. Mean comparison for the effect of the application of animal manure in different soil moisture conditions on the components of saturated and mono-unsaturated fatty acids in *Camelina sativa* oil.

	MYR	PA	STE	OA	ARC	DOC	PAT	ERU
Irrigation								
FI	1.49b	4.81a	2.64a	15.27a	1.56b	0.33b	0.29b	4.18b
DI	1.65a	4.67b	2.70a	13.32b	1.81a	0.46a	0.32a	5.45a
Organic fertilizer								
F_0	1.96a	4.38c	2.41b	14.06b	1.90a	0.33c	0.35a	5.44a
F_{10}	1.50b	4.88a	2.48b	14.55a	1.55b	0.39b	0.29b	4.94b
F_{20}	1.26c	4.66b	3.12a	14.27ab	1.61b	0.46a	0.27c	4.07c
FI F_0	2.09a	4.37c	2.48cd	14.77b	1.70bc	0.32e	0.37a	4.80c
FI F_{10}	1.46c	5.20a	2.40de	15.63a	1.58cd	0.35c	0.27c	4.23d
FI F_{20}	0.93d	4.85b	3.04b	15.43a	1.41d	0.32e	0.22d	3.52e
DI F_0	1.83b	4.39c	2.33e	13.36c	2.11a	0.35cd	0.32b	6.07a
DI F_{10}	1.54c	4.56c	2.56c	13.48c	1.51cd	0.43b	0.32b	5.66b
DI F_{20}	1.59c	4.46c	3.20a	13.12c	1.81b	0.60a	0.32b	4.63c
Significance level								
I	*	**	NS	**	**	**	**	**
F	**	**	**	*	**	**	**	**
I×F	**	**	**	NS	**	**	**	NS

I: irrigation, F: farmyard manure. F_0, F_{10}, and F_{20}: application of 0, 10, and 20 T ha^{-1} farmyard manure as an organic soil amendment, respectively. FI: full irrigation, DI: deficit irrigation during vegetative growth. MYR: percentage of myristic acid (14:0) in extracted oil, PA: palmitic acid (16:0), STE: stearic acid (18:0), OA: oleic acid (18:1), ARC: arachidic acid (20:0), DOC: docosanoic acid (22:0), PAT: palmitoleic acid (16:1), ERU: erucic acid (22:1). Ns: Statistically insignificant, ** and * are significant at 1 and 5% level, respectively. Means with the same letter in each factor (such as irrigation, manure, or their interaction effects) do not have a statistically significant difference at the 5% level.

methanolic boron trifluoride was added, and the mixture was refluxed for 2–3 min. After cooling, 1.5 ml of hexane was introduced to dissolve the methyl-ester fatty acids, followed by 1 ml of saturated sodium chloride solution (Merck, Germany) to precipitate glycerol molecules. The upper phase was collected, and 0.5 g of sodium sulfate (Merck, Germany) was added for centrifugation at 2,500 rpm for 2-5 min to complete dehydration.

Gas Chromatography Analysis

The supernatant was injected into a Varian 6890 gas chromatography system (Agilent Chromatography, USA) equipped with a BPX 70 silica capillary column (30 m length, 0.22 mm diameter, 0.25 µm film thickness). The oven temperature was initially set to 158 °C, increasing at a rate of 2 °C per min until reaching 210 °C, where it was maintained for 20 min. The injection valve temperature was set to 230 °C, and the detector temperature was 240 °C. The carrier gas helium was used at a flow rate of 1.2 ml/min, with injections performed in fragmented mode to optimize separation.

Statistical Analysis

Prior to statistical analysis, a data normality test was performed. Statistical analyses were conducted using SAS software, and mean comparisons were performed using the least significant difference (LSD) test. Box plots were generated using SPSS Statistics, while principal component analysis (PCA) and genotype clustering were conducted using Genstat software.

RESULTS

Effect of Irrigation and Farmyard Manure on Saturated Fatty Acids

The evaluation of the total content of saturated fatty acids showed that irrigation had a statistically significant effect at the 5% level, while FYM alone had no significant effect. However, the interaction between irrigation and FYM was significant at the 1% level (Table 1).

The highest percentage of saturated fatty acids was recorded under DI+F20 (11.72%) and DI+F0 (11.17%), while the lowest percentage was found under FI+F20 (10.64%) and DI+F10 (10.77%) conditions.

Among specific saturated fatty acids, the interaction of irrigation and FYM was significant for myristic acid (tetradecanoic acid) at the 1% level. The highest myristic acid content (2.09%) was observed under full irrigation without manure application, whereas the lowest values (1.59% and 1.54%) were recorded under deficit irrigation with 10 and 20 t ha^{-1} FYM, respectively.

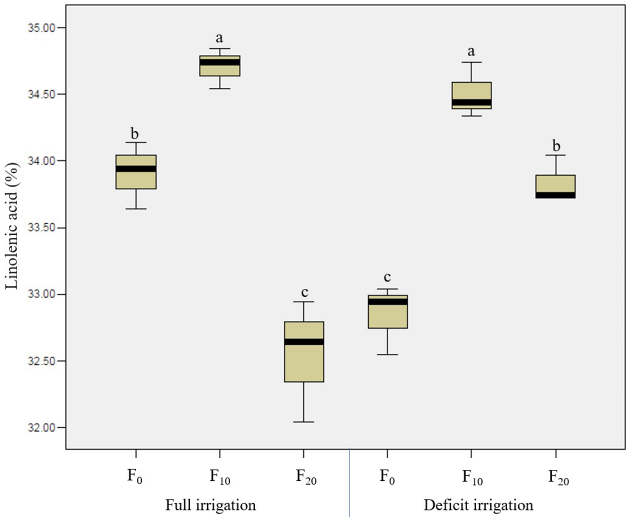

Figure 1. The effect of deficit irrigation and animal manure on the content of linolenic acid in camellia seeds grown in western Iran.

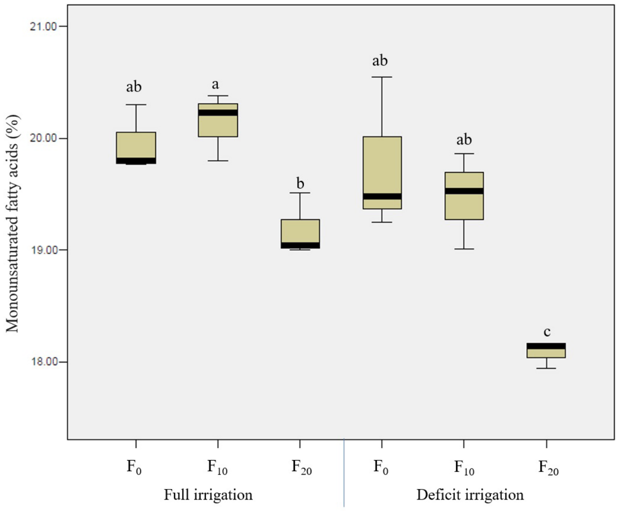

Figure 2. The percentage of monounsaturated fatty acids under the application of different levels of organic soil amendment and soil moisture regimes in the oil extracted from *Camelina sativa* seeds

For palmitic acid (hexadecanoic acid), the highest content (5.20%) was found under full irrigation with 10 t ha^{-1} FYM, while the lowest amount was recorded in plants grown under deficit irrigation and FI+F0 conditions (Table 1).

The amount of stearic acid (octadecanoic acid) was not significantly affected by irrigation regimes, but the interaction between irrigation and FYM was statistically significant. The highest stearic acid content (3.20%) was recorded under DI+F20 conditions, while the lowest (2.32%) was observed in DI+F0 conditions. The application of 20 t ha^{-1} FYM under full irrigation increased stearic acid content by 22% compared to the F0 condition.

Effect on Monounsaturated Fatty Acids

The main effects of irrigation and FYM on oleic acid (omega-9) were statistically significant (Table 1). The amount of oleic acid was approximately 2% higher in plants grown under full irrigation than under deficit irrigation conditions. The highest amount of oleic acid (14.55%) was obtained with F10 application.

For arachidic acid (icosanoic acid), the highest content (2.11%) was found under DI+F0 conditions, while the lowest amounts were recorded under FI+F10 (1.58%) and DI+F10 conditions. Under full irrigation, the absence of FYM resulted in the highest level of arachidic acid (Table 1).

The content of docosanoic acid (behenic acid) increased significantly with the application of 20 t ha^{-1} FYM under deficit irrigation. The content of this fatty acid in DI+F20 conditions was nearly twice as high as in FI+F0 conditions.

For palmitoleic acid (omega-7), the highest amount was recorded in plants grown under full irrigation without fertilizer application, while the lowest amount (0.22%) was found in FI+F20 conditions (Table 1). Under deficit irrigation, the content of omega-7 was about 10% higher than under full irrigation. The application of FYM reduced omega-7 content by 18% and 27% compared to the control.

The content of erucic acid increased by 30% when irrigation was reduced, while applying 10 and 20 t ha^{-1} FYM reduced it by 10% and 25%, respectively. The highest amount (6.07%) was observed under DI+F0 conditions, while the lowest amount (3.52%) was recorded under FI+F20 conditions.

Effect on Polyunsaturated Fatty Acids

Among the fatty acids in camelina seed oil, linolenic acid had the largest proportion. While irrigation alone had no significant effect, the interaction between irrigation and FYM was significant at the 1% level. The highest linolenic acid content was observed when 10 t ha^{-1} FYM was applied under both irrigation regimes. However, applying 20 t ha^{-1} FYM led to a significant reduction in linolenic acid content compared to the control (Fig. 1).

For linoleic acid (an omega-6 fatty acid), water deficit stress increased its content during the vegetative growth period. In addition, applying 20 t ha^{-1} FYM resulted in a 6% increase in linoleic acid content compared to F0 (Table 2).

The content of eicosadienoic acid was significantly affected by the interaction between irrigation and FYM at the 5% level. Deficit irrigation decreased its content by 8% compared to full irrigation, while 20 t ha^{-1} FYM application increased it by 9% compared to the control. The highest eicosadienoic acid content (14.45%) was recorded

Table 2. Profile of fatty acids in oil extracted from camelina sativa seeds grown under different levels of organic fertilizer and under deficit irrigation.

	ALA	LA	EIC	EI3	ARA	DSH
Irrigation						
FI	33.71a	18.54b	13.53a	1.62b	0.81b	0.44a
DI	33.73a	19.27a	12.58b	1.81a	0.99a	0.35b
Organic fertilizer						
F_0	33.37b	18.70b	12.68b	2.12a	0.89ab	0.35c
F_{10}	34.60a	18.16b	12.61b	1.71b	0.93a	0.37b
F_{20}	33.19b	19.86a	13.89a	1.35c	0.87b	0.46a
FI F_0	33.90b	18.01c	12.96b	2.16a	0.86c	0.42b
FI F_{10}	34.70a	17.66c	13.11b	1.63c	0.84c	0.41b
FI F_{20}	32.54c	19.95a	14.54a	1.16d	0.73d	0.51a
DI F_0	32.84c	19.39ab	12.40c	2.08a	0.93b	0.28d
DI F_{10}	34.50a	18.66bc	12.10c	1.79b	1.03a	0.34c
DI F_{20}	33.84b	19.78ab	13.25b	1.55c	1.02a	0.42b
Significance level						
I	NS	*	*	**	**	*
F	**	**	**	**	**	**
I×F	**	NS	*	**	**	*

I: irrigation, F: farmyard manure. F_0, F_{10}, and F_{20}: application of 0, 10, and 20 T ha^{-1} farmyard manure as an organic soil amendment, respectively. FI: full irrigation, DI: deficit irrigation during vegetative growth. ALA: linolenic acid (18:3), LA: acid linoleic (18:2), EIC: eicosadienoic acid (20:2), EI3: eicosatrienoic acid (20:3), ARA: arachidonic acid (20:4), DSH: docosahexaenoic acid (22:6). Ns: Statistically insignificant, ** and * are significant at 1 and 5% level, respectively. Means with the same letter in each factor (such as irrigation, manure, or their interaction effects) do not have a statistically significant difference at the 5% level.

under FI+F20 conditions.

Conversely, for eicosatrienoic acid (mead acid), water deficit stress increased its content by 11% compared to FI conditions. However, 10 and 20 t ha^{-1} FYM applications reduced eicosatrienoic acid content by 19% and 37%, respectively, compared to F0 (Table 2). The highest amount (2.08%) was recorded under DI+F0 conditions.

Comparison of Fatty Acid Groups

The content of monounsaturated fatty acids (MUFA) under irrigation and fertilization regimes is presented in Fig. 2. The application of FYM under DI conditions significantly reduced MUFA content, with the lowest MUFA content (18%) recorded under DI+F20 conditions. The highest MUFA content (20.45%) was observed under FI+F10 conditions. However, increasing FYM consumption under full irrigation conditions led to a decrease in MUFA content.

The content of polyunsaturated fatty acids (PUFA) increased significantly under both irrigation regimes following the application of 20 t ha^{-1} FYM (Fig. 3). These fatty acids are critical for the edible and industrial quality of vegetable oils. The highest PUFA content (69.91%) was found under DI+F10 conditions.

Correlation and Cluster Analysis

The correlation analysis (Fig. 4) showed that linolenic acid had a positive and significant correlation with arachidonic acid, arachidic acid, palmitoleic acid, erucic acid, myristic acid, and eicosatrienoic acid. The highest levels

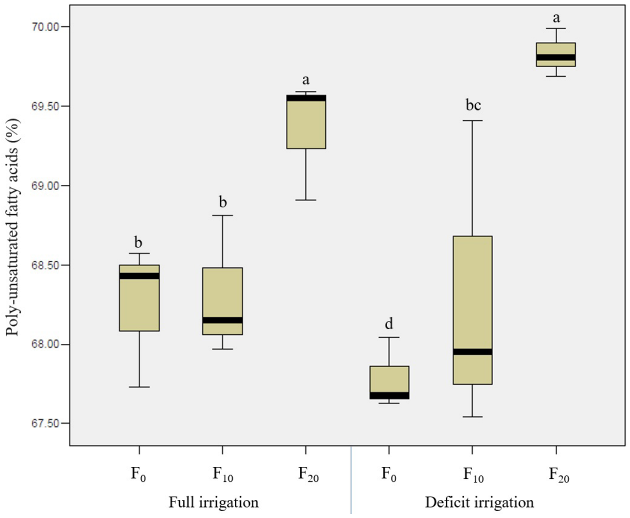

Figure 3. Evaluation of organic soil amendments and irrigation on polyunsaturated fatty acids in *C. sativa* grown in western Iran.

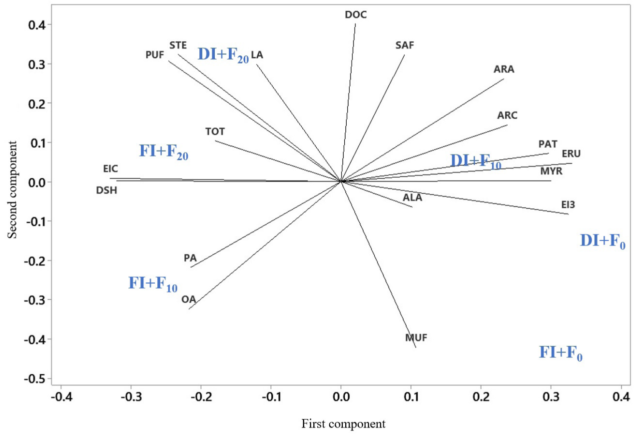

Figure 4. Principal component analysis (PCA) to interpret the angular correlation between fatty acids in camelina oil with the application of different levels of animal manure and irrigation. ALA: linolenic acid (18:3), LA: acid linoleic (18:2), STE: stearic acid (18:0), EIC: eicosadienoic acid (20:2), OA: oleic acid (18:1), PA: palmitic acid (16:0), ERU: erucic acid (22:1), STE: stearic acid (18:0), MYR: myristic acid (14:0), ARC: arachidic acid (20:0), EI3: eicosatrienoic acid (20:3), ARA: arachidonic acid (20:4), DOC: docosanoic acid (22:0), DSH: docosahexaenoic acid (22:6), PAT: palmitoleic acid (16:1), TOT: total identified fatty aides, SAF: saturated fatty acid percentage, MUF: monounsaturated fatty acid, PUF: polyunsaturated fatty acids, farmyard manure. F0, F10, and F20: application of 0, 10, and 20 t ha-1 farmyard manure as an organic soil amendment, respectively. FI: full irrigation, DI: deficit irrigation during the vegetative growth.

of these fatty acids were recorded under deficit irrigation combined with 20 t ha^{-1} FYM application.

- Cluster analysis (Fig. 5) classified the fatty acids in camelina seed oil into four distinct groups based on their responses to treatments:
- Cluster 1: Linolenic acid, docosanoic acid, and total saturated fatty acids, which were highest under DI+F20 conditions.
- Cluster 2: Erucic acid, arachidonic acid, palmitic acid, palmitoleic acid, and arachidic acid, which were most abundant when no FYM was applied.
- Cluster 3: Monounsaturated fatty acids, palmitic acid, and oleic acid, which increased significantly with 20 t ha^{-1} FYM under full irrigation.
- Cluster 4: Linoleic acid, eicosadienoic acid, docosahexaenoic acid, stearic acid, and total PUFA, which had the highest values under high FYM application in both irrigation regimes.

DISCUSSION

The characteristics of the soil in the tested area indicated that the organic matter content was low, and the availability of essential elements such as nitrogen, phosphorus, and micronutrients was highly restricted. Therefore, it was expected that the application of FYM would enhance the percentage of extractable fatty acids and oil content in camelina seeds. Although camelina has historically been an underutilized crop, often used as a substitute for grain crops, and information about its oil quality characteristics has been limited, the present study demonstrated that this species has remarkable fatty acid diversity. Furthermore, the composition of camelina oil was significantly affected by agronomic management practices.

The study area is in a semi-arid Mediterranean region prone to drought, where water deficit stress negatively affects plant growth and seed filling at the end of the reproductive growth period due to reduced rainfall. However, the results of this experiment indicate that reducing irrigation during the vegetative growth stage can significantly alter the fatty acid profile of camelina oil. Although deficit irrigation applied during the vegetative growth stage resulted in 220 mm of water savings compared to full irrigation, it also caused a 27% reduction in oil yield. From a source-sink relationship perspective, deficit irrigation during the vegetative phase likely reduces the strength of the source by limiting the photosynthetic area and decreasing the production of photoassimilates. This reduction in available assimilates affects secondary and temporary sinks, such as stems, thereby significantly decreasing the remobilization of resources during seed filling (Abdelmounaim et al. 2024).

The findings of this study emphasize the importance of climate-smart agronomic management for improving oil quality. The analysis of camelina oil showed a low proportion of saturated fatty acids and a high percentage of polyunsaturated fatty acids. However, the oil also contained notable amounts of monounsaturated fatty acids, including oleic acid (13-15%), erucic acid (4-6%), and palmitoleic acid (0.2-0.35%). The highest concentrations of fatty acids were observed for linolenic acid and linoleic acid, which fluctuated by approximately 2% throughout the experiment. However, greater fluctuations were recorded for erucic acid, oleic acid, and eicosatrienoic acid. The results of previous research confirm that the high linoleic and linolenic acid content makes camelina oil highly susceptible to oxidation, which is considered an undesirable characteristic for industrial applications (Rodríguez-Rodríguez et al. 2013).

Erucic acid, a monounsaturated fatty acid, was present in the oil extracted from plants grown under different moisture regimes and FYM levels at concentrations ranging from 3% to 6%. The biosynthesis of this fatty acid is common in crops from the Brassicaceae family. Although clinical studies suggest that erucic acid may have toxic effects on the cardiovascular system of laboratory mammals, these findings have not yet been confirmed in humans (Galanty et al. 2023). Nevertheless, from an agricultural management perspective, efforts should be made to minimize the accumulation of erucic acid in camelina oil. While the fatty acid composition of oilseed crops can be influenced by various agronomic practices, these changes may also impact numerous physiological processes by altering the structure, integrity, and function of biological membranes. Therefore, further research is needed to investigate the molecular aspects and interactions caused by modifications in fatty acid composition at the cellular and molecular levels.

Water deficit stress increased the content of arachidonic acid, a fatty acid known to interact with the signaling pathways of jasmonic acid and salicylic acid. Previous studies have shown that applying arachidonic acid externally to plant mutants lacking jasmonic acid and salicylic acid biosynthesis ability induces significant changes in gene expression related to biotic stress responses (Savchenko et al. 2010).

Although this study focused primarily on fatty acid profiles, other oil quality attributes that influence consumer health, such as α- and γ-tocopherols, carotenoid content, phytosterols, and phenolic compounds, should be evaluated in future studies to gain a more comprehensive understanding of camelina oil's nutritional and industrial value. Beyond edible applications, camelina oil has also gained attention as a potential feedstock for biodiesel production. In this context, optimizing the methyl esterification of fatty acids is critical for improving biodiesel quality (Chew 2020). Agricultural management strategies should aim to minimize trans-fat content in oil. Some studies on Brassicaceae species have indicated a correlation between increased oleic acid levels and reduced trans-fat content, suggesting that oleic acid could serve as a potential biomarker for assessing the impact of agronomic management on oil composition (Banaś et al. 2023).

The variations in fatty acid profiles observed in this study were primarily influenced by biosynthetic pathways associated with acetyl glycerides, hydroxylated fatty acids, medium-chain fatty acids, long-chain polyunsaturated omega-3 fatty acids, and omega-7 fatty acids such as palmitoleic acid (Yuan and Li 2020). In these processes, the roles of acetyl-CoA carboxylase and acyl-acyl carrier protein thioesterases are particularly significant (Rodríguez-Rodríguez et al. 2014). The findings suggest that the agricultural management strategies applied in this study altered fatty acid profiles through their influence on these key enzymatic pathways.

This conclusion aligns with the research conducted by Hazrati et al. (2022), who reported that the use of organic fertilizers significantly altered the fatty acid composition in camelina oil. In their study, the most pronounced changes were observed for palmitic acid, erucic acid, oleic acid, linoleic acid, and eicosadienoic acid. Some alterations in fatty acid content have been attributed to organic fertilizer application, improved soil moisture conditions, enhanced antioxidant system performance, increased photosynthetic pigment content, greater vegetative growth, and an improved supply of photoassimilates for fatty acid biosynthesis (Haghaninia et al. 2024).

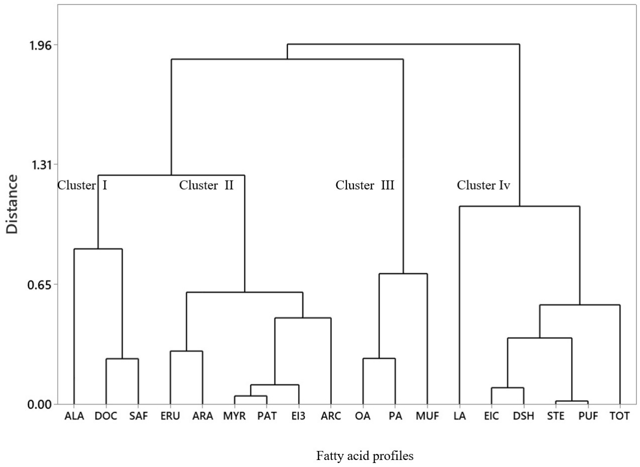

Figure 5. Principal component analysis (PCA) to interpret the angular correlation between fatty acids in camelina oil with the application of different levels of animal manure and irrigation. ALA: linolenic acid (18:3), LA: acid linoleic (18:2), EIC: eicosadienoic acid (20:2), OA: oleic acid (18:1), PA: palmitic acid (16:0), ERU: erucic acid (22:1), STE: stearic acid (18:0), MYR: myristic acid (14:0), ARC: arachidic acid (20:0), EI3: eicosatrienoic acid (20:3), ARA: arachidonic acid (20:4), DOC: docosanoic acid (22:0), DSH: docosahexaenoic acid (22:6), PAT: palmitoleic acid (16:1), TOT: total identified fatty aides, SAF: saturated fatty acid percentage, MUF: monounsaturated fatty acid, PUF: polyunsaturated fatty acids.

However, multiple factors contribute to the variability in fatty acid profiles, including genetic differences, environmental conditions, precipitation levels, soil characteristics, crop management practices, cultivation systems, weed competition, nutrient availability, and plant-specific metabolic pathways (Panjoo et al. 2014). As a result, achieving optimal and economically viable fatty acid profiles remains a complex challenge. Expanding knowledge in this field requires detailed, multi-variable experiments that take all influencing factors into account.

CONCLUSIONS

The results of this study demonstrated that the fatty acid composition of camelina seeds is significantly influenced by both organic amendments and soil moisture regimes. However, the response of different fatty acids to these treatments varied widely.

Linolenic acid (omega-3) made the largest contribution among polyunsaturated fatty acids in the extracted oil. The highest concentration of omega-3 was observed with the application of 20 t ha^{-1} of organic amendment under both soil moisture regimes. Water deficit stress increased the amount of linoleic acid, while long-chain polyunsaturated fatty acids showed a significant increase under full irrigation conditions when combined with organic amendments. In contrast, the levels of most fatty acids with 14 to 16 carbon atoms decreased following the application of organic amendments. This trend was also observed, to some extent, for certain long-chain fatty acids, such as arachidic acid.

The application of organic amendments increased the proportion of polyunsaturated fatty acids under both full and deficit irrigation conditions, but its effect was more pronounced under full irrigation. Overall, the highest proportion of unsaturated fatty acids and the best oil quality were recorded under full irrigation combined with organic amendments.

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