Cellular and Molecular Biology
E-ISSN : 1165-158X / P-ISSN : 0145-5680
www.cellmolbiol.org
Original Research

Effects of climate on fatty acid profile in *Camelina sativa*

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Received January 10, 2018; **Accepted** April 18, 2018; **Published** April 30, 2018

Doi: http://dx.doi.org/10.14715/cmb/2018.64.5.15

Abstract: Due to the importance of Camelina for low expectation (water and other inputs) and as an oil crop, Soheil cultivar was cultivated in Ardebil, Hamedan, Rasht, Ilam, Kermanshah, Karaj, Mashhad, Ahvaz and Bushehr Provinces. Fatty acids were measured with MG-Mass. Results showed that morphological traits were not very dependent on the climate, but the profile of the fatty acids was dependent. ANOVA of the effects of climate on the saturated fatty acid showed that there were significant differences between climates for all studied SFAs ($P<0.01$) with the exception of Lauric acid. Mean squares of the effects of climate on the Unsaturated Fatty Acids (MUFA) in showing that there were significant differences between climates for all studied MUFAs ($P<0.01$). Mean squares of the effects of climate on the amount of polyunsaturated fatty acids (PUFA), oil percentage and protein content of seeds indicated that there were significant differences between climates for all these studied traits. Mean squares of the effects of climate on the amount of polyunsaturated fatty acids (PUFA), oil percentage and protein content of seeds indicated that there were significant differences between climates for all these studied traits. The statistical analysis for the effects of Climate on the ratio of the Saturated Fatty Acid (SFA) in *Camelina sativa* showed that there were significant differences ($P<0.01$) for SFA, MUSFA, PUFA, MP, P:S and MP:S. Briefly, in the cold climates, the percentage of unsaturated fatty acids was higher. So it is possible to the cultivation of this plant in cold provinces for nutritional purposes and in tropical provinces for industrial and sanitary purposes.

Key words: Climate; Fatty acid profile; SFA; MUSFA; PUFA; *Camelina sativa.*

Introduction

Fatty acids are the most important part of the cells that should be taken into consideration in human nutrition. Fats and edible oils have a special place in human nutrition. The main role of lipids in the body is the supply of energy. The burning of 1 g fat produces about 9 kg energy, which is more than twice the energy from carbohydrates and proteins (1, 2).

The roles of oils and fats are participating in cell membrane structure, protection of the kidneys, heart and other body organs, maintain body heat, make part of essential body components such as hormones and bile acids, carry out fat-soluble vitamins, creating feelings of sentiment and delicious food. Fats and oils are an important source of fat-soluble vitamins (A, D, K and E) and essential fatty acids for humans and they are insoluble in water and have a plant (grain or fruit) or animal (dry or marine) origin(1, 3).

Oilseeds are one of the important sources of fatty acids. However, they are also a valuable source of protein, and the residue of the product is used for this purpose. Both oil and meal are just as important (1, 2).

Camelina sativa (L.) Crantz which has recently been very much considered is a member of the Brassicaceae family. Also, it receives a remarkable attention as a reemerging oilseed crop. This crop receives a remarkable attention as a reemerging oilseed crop (4, 5).

One of the key issues is that camelina is highly adaptable to adverse environmental conditions such as drought and chilling stress (6, 7). Camelina has large potential in the cold climates of the world such as northern portions of the United States and Canada as an alternative oilseed crop with a significant benefit to cold tolerance and short season (8).

Furthermore, camelina is adaptable to many other environmental stresses such as chilling, drought, heat and cockroaches and pollen-eating pests that are common in oilseeds (9) and the only true limitation of camelina is heavy clay soils and organic soils (10).

Seed quality in oilseed crops is very important (11). Camelina is a short life crop (about 95- day). It grows well in light to medium soils and the temperate climate. (12, 13).

Camelina is highly tolerant to water deficiency. There is little need for crop care and field interventions. There are very few pests and diseases camelina (11, 14-16).

It is important to pay attention to the cultivation area and climate of the camelina. The climate is a determinant factor in the cultivation of oilseed crops (17, 18).

Camelina grain, yield and fatty acids as Influenced by genotype and climate (19). Camelina and Canola have been introducing as new crops for cool-season production in California (7, 8). Previously, an adaptation of camelina genotypes to different climatic conditions (20) and freezing tolerance (13) has been tested.

The effect of climate in some oil crops on the mor-

phological, physiological, phenological and fatty acid profile has been reported (15, 18).

In Turkey climate, the fatty acid composition of four Centaurea L. taxa from was investigated (21).

It has been reported that the chemical content of plant products can be affected by the climate (22).

In a research in Serbia climate, sixteen fatty acids were identified and quantified, with the most abundant being oleic acid and linoleic acid in almond (23).

In a research on Red chillies (*Capsicum* sp.), low level of palmitic, stearic and α-linolenic acid and high level of linoleic acid resulted in Northeast India. Total polyunsaturates of seeds were higher than fruit (24).

Results of a research on lipid composition and emulsifying properties of *Camelina sativa* seed lecithin showed that camelina seed lecithin is a promising alternative PI-rich emulsifier for various food applications (25).

In a comprehensive research total, 320 samples of edible oils and fats (Oils-236; Vanaspati- 45; Ghee-39) were sampled from 107 sampling sites in India climate and were evaluated for their fatty acid profile. Results showed that coconut oil had the highest levels of saturated fatty acid (SFA) (26).

In this research, the effects of climate on fatty acid profile in *Camelina sativa* has been investigated in Iran provinces.

Materials and Methods

Plant material

In the current study, *C. sativa* cv. Soheil was the plant material. This cultivar has been produced via anther culture of F1 resulted in crossing between Blaine Greek and Calena cultivars. The regenerated plants were selfed, and the seed was produced. Then multiply the seed and tested in warm, temperate and cold climates in dryland farming conditions.

The studied climates and cultivation

The Soheil cultivar was cultivated in Ardebil, Hamedan (as cold climates), Rasht, Ilam, Kermanshah, Karaj, Mashhad (as temperate climates), Ahvaz and Bushehr (as warm climates) Provinces.

A seeding rate of 4 kg/ha was recommended, with a row interval of 15 cm. The seeding depth was not exceeding 1 cm. In order to control weeds, the amount of seed consumption was considered high. Because in the low plant density, the weed infestation increases. In each cluster, 50 plants were randomly selected for seed collection and oil extraction.

Oil extraction and fatty acid analysis

The oil of harvested grains was extracted via cold press methods. The oil extraction and fatty acid analysis were carried out in Zagros Bioidea Company in Razi University Incubator, Kermanshah, Iran. The fatty acid profiles were isolated and determined with gas chromatography (Varian CP3800) connected to the detector TR-CN100 poly[bicyanopropyl] siloxane capillary, with column length: 60 m, inner diameter: 0.25 µm, thickness: 2.0 mm. Helium gas was used as a carrier gas with a flow of 1 ml/min in the column. The gap ratio was 25: 1 in the injection chamber, the temperature program of the column began at 175 °C for 2 minutes, and then proceeded at a temperature of 3 °C/min to reach a temperature of 230 °C and then remained at that same temperature for 3 minutes.

The temperature of the injection chamber and the detector was 290 °C, and the volume of the extract was 1 µl for injection. Components of each sample were analyzed using Workstation software (V 6.4). The oil content of seed samples was calculated based on their dry weight and fatty acids content reported based on total oil content, and by comparing their summit level with standard samples (C: 12-C: 24, Sigma Aldrich).

Experimental design and statistical analysis

The experiment was carried out and analyzed based on completely randomized design with three replications. The Analysis of variance (ANOVA) and mean comparison were carried out by SPSS software (V24). Duncan's Multiple Range Test (DMRT) was used for mean comparison by significantly different at the 5% level.

Results

On average, 35% of the oil was obtained from camelina grains. Fatty acid profiles were determined by gas chromatography. A sample of chromatogram has been shown in Fig.1.

Analysis of saturated fatty acids (SFA)

The effects of climate on the saturated fatty acid showed that there were significant differences between

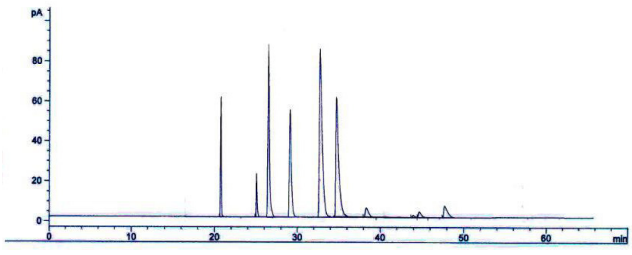

Figure 1. Chromatogram of Camelina fatty acids in the Ardabil Climate.

Table 1. Mean squares of the effects of Climate on the Saturated Fatty Acid (SFA) in *Camelina sativa*. Where C12:0 (Lauric acid), C14:0 (Myristic acid), C16:0 (Palmitic acid), C18:0 (Stearic acid), C20:0 (Arachidic acid), C21:0 (Heneicosanoic acid), C22:0 (Behenic acid) and C24:0 (Lignoceric acid).

		MS							
SOV	df	C12:0	C14:0	C16:0	C18:0	C20:0	C21:0	C22:0	C24:0
Climate	8	0.002	0.021**	0.942**	0.849**	0.563**	0.243**	0.319**	0.0432**
Error	18	0.002	0.001	0.029	0.009	0.006	0.005	0.003	0.0005
CV (%)		13.22	14.92	9.32	9.42	12.34	13.22	14.43	13.65

Table 2. Mean comparison of effect of the climate on the amount of saturated fatty acids (SFA) in *Camelina sativa*. Where C12:0 (Lauric acid), C14:0 (Myristic acid), C16:0 (Palmitic acid), C18:0 (Stearic acid), C20:0 (Arachidic acid), C21:0 (Heneicosanoic acid), C22:0 (Behenic acid) and C24:0 (Lignoceric acid).

Climate	C12:0	C14:0	C16:0	C18:0	C20:0	C21:0	C22:0	C24:0
Ardebil	0.00 B	0.0333A	4.2371 D	2.2739 E	1.4342 D	0.9355 D	0.2555 F	0.1532 D
Hamedan	0.00 B	0.0352 A	4.3565 D	2.4127 D	1.4823 D	1.0632 C	0.3023 E	0.1633 D
Rasht	0.00 B	0.0700 B	4.9439 C	2.5642 C	1.8243 C	1.2633 B	0.4345 D	0.2234 C
Ilam	0.00 B	0.0700 B	5.0487 C	2.5754 C	1.8345 C	1.2799 B	0.4543 D	0.2476 C
Kermanshah	0.00 B	0.0700 B	5.2300 B	2.6972 B	1.9367 B	1.3067 B	0.5433 C	0.2567 C
Karaj	0.00 B	0.0700 B	5.2333 B	2.7037 B	2.0345 B	1.3234 B	0.6446 B	0.2834 B
Mashhad	0.00 B	0.0700 B	5.2334 B	2.6993 B	2.0023 B	1.3222 B	0.6533 B	0.2855 B
Ahvaz	0.01 A	0.0900 A	6.0833 A	3.5133 A	2.1667 A	1.5800 A	0.9667 A	0.3700 A
Bushehr	0.00 B	0.0900 A	6.0733 A	3.5065 A	2.2000 A	1.5799 A	0.9500 A	0.3689 A

Table 3. Mean comparison of the effect of the climate on the amount of mono-unsaturated fatty acids (MUFA) in *Camelina sativa*. Where C16:1 (Palmitoleic acid), C18:1 (Oleic acid), C20:1 (Eicosenoic acid), C22:1 (Erucic acid) and C24:1 (Nervonic acid).

		MS				
SOV	df	C16:1	C18:1	C20:1	C22:1	C24:1
Climate	8	0.00015**	27.876**	14.654**	1.543**	0.008^{ns}
Error	18	0.00002	0.147	0.063	0.009	0.023
CV (%)		7.65	6.23	7.43	8.86	11.45

climates for all studied SFAs with the exception of Lauric acid (Table 1).

Mean comparison of the effect of the climate on the amount of saturated fatty acids (SFA) in *Camelina sativa* (Table 2) demonstrated that Ahvaz showed the highest amount for lauric acid (C12:0) (0.01%). There were no significant differences among other climates for this fatty acid. The climates were divided into two groups for myristic acid (C14:0). So that Ardebil, Hamedan, Ahvaz and Bushehr showed the highest and other climates indicated the lowest amounts of this fatty acid. The mean comparison showed that the climates could be in four groups for palmitic acid (C16:0). Ahvaz and Bushehr showed this highest. While Ardabil and Hamedan indicated the minimum amounts of this saturated fatty acid. Other climates showed as intermediate. These results showed that palmitic acid in warm climates (such as Ahvaz and Bushehr) might be in high and in cold climates in low amounts.

Ahvaz and Bushehr climates showed the highest percentages for stearic acid (C18:0) and Ardebil showed the lowest for this fatty acid. Then stearic acid in warm climates showed high and in cold ones indicated low.

Mean comparison showed the similar results for arachidic acid (C20:0), heneicosanoic acid (C21:0), behenic acid (C22:0) and lignoceric acid (C24:0) (Table 2).

Analysis of Mono-unsaturated Fatty Acids (MUFA)

Mean squares of the effects of climate on the Mono-Unsaturated Fatty Acids (MUFA) are showed that there were significant differences between climates for all studied MUFAs ($P<0.01$) with the exception of nervonic acid (C24:1) (Table 3).

The mean comparison of effect of the climate on the amount of mono-unsaturated fatty acids (MUFAs) (Table 4) showed that cold climates (Ardebil and Hamedan) showed the highest amounts for some of MUFAs such as palmitoleic acid (C16:1) and eicosenoic acid (C20:1) and these fatty acids were lowest in warm climates (Ahwaz and Bushehr). Reverse results were obtained for oleic acid (C18:1) and erucic acid (C22:1). As the highest amounts of this MUFAs resulted in warm climates (Ahwaz and Bushehr) and the cold climates (Ardebil and Hamedan) showed the minimum percentages for these MUFAs.

Table 4. Mean comparison of the effect of the climate on the amount of mono-unsaturated fatty acids (MUFA) in *Camelina sativa*. Where C16:1 (Palmitoleic acid), C18:1 (Oleic acid), C20:1 (Eicosenoic acid), C22:1 (Erucic acid) and C24:1 (Nervonic acid).

Climate	C16:1	C18:1	C20:1	C22:1	C24:1
Ardebil	0.1590 A	11.7489 D	16.6642 A	2.3154 D	0.7154 A
Hamedan	0.1588 A	12.0455 D	16.0354 B	2.2123 D	0.6987 A
Rasht	0.1363 B	14.5444 C	14.0365 C	1.3323 C	0.6765 A
Ilam	0.1365 B	14.3879 C	14.1543 C	1.2876 C	0.6645 A
Kermanshah	0.1333 B	15.6233 B	13.3067 D	1.1633 B	0.6533 A
Karaj	0.1323 B	15.8000 B	13.1987 D	1.1593 B	0.6634 A
Mashhad	0.1333 B	15.7546 B	13.2346 D	1.1580 B	0.6954 A
Ahvaz	0.1200 C	17.7700 A	13.1423 D	0.9654 A	0.6933 A
Bushehr	0.1187 C	17.6789 A	13.2321 D	0.9534 A	0.7002 A

Mean values followed by the same letter in each column indicates that is not significantly different at P = 0.05 to Duncan's test.

Table 5. Mean squares of the effects of climate on the amount of polyunsaturated fatty acids (PUFA), oil percentage and protein content of seeds in the *Camelina sativa*. Where C18:2 (Linoleic acid), C18:3 (α-linolenic acid), C20:2 (Eicosadienoic acid), C20:3 (Eicosatrienoic acid), OC (oil content) and PC (protein content).

		MS					
SOV	df	C18:2	C18:3	C20:2	C20:3	OC (%)	PC (%)
Climate	8	34.654**	95.651**	1.453**	1.245**	36.721**	24.365**
Error	18	0.047	0.219	0.015	0.033	0.170	0.043
CV (%)		8.32	7.23	5.32	12.42	9.43	8.32

Table 6. Mean comparison of the effect of the climate on the amount of poly-unsaturated fatty acids (PUFAs), Oil content Protein content in *Camelina sativa*. Where C18:2 (Linoleic acid), C18:3 (α-linolenic acid), C20:2 (Eicosadienoic acid), C20:3 (Eicosatrienoic acid), OC (oil content) and PC (protein content).

Climate	C18:2	C18:3	C20:2	C20:3	OC (%)	PC (%)
Ardebil	22.3876 A	38.3354 A	2.1984 A	2.1043 A	41.5437 A	27.1294 F
Hamedan	21.6549 B	38.8243 A	2.1974 A	1.9721 AB	38.9543 B	27.5003 E
Rasht	18.8436 C	34.1547 C	1.7355 B	1.7434 B	37.5434 B	29.3398 D
Ilam	18.3598 D	35.4364 B	1.7532 B	1.7365 B	36.2345 C	29.5004 C
Kermanshah	17.9067 E	30.1167 D	1.3667 C	1.2800 C	34.3500 C	31.2367 C
Karaj	17.6034 E	29.8456 D	1.2694 D	1.2732 C	34.0001 D	31.6323 B
Mashhad	17.6256 E	30.1145 D	1.2684 D	1.2673 C	33.8764 D	31.6356 B
Ahvaz	14.5467 F	25.8964 E	0.6543 E	0.5267 D	32.4345 E	33.6587 A
Bushehr	14.6534 F	25.8354 E	0.6555 E	0.5178 D	32.4576 E	33.6743 A

Mean values followed by the same letter in each column indicates that is not significantly different at P = 0.05 to Duncan's test.

Analysis of Poly-unsaturated Fatty Acids (PUFA)

Mean squares of the effects of climate on the amount of polyunsaturated fatty acids (PUFA), oil percentage and protein content of seeds indicated that there were significant differences between climates for all these studied traits (P<0.01) (Table 5).

Mean comparison of the effect of the climate on the amount of poly-unsaturated fatty acids (PUFA), Oil content Protein content in *Camelina sativa* (Table 6) showed that highest amounts of PUFAs were obtained in the cold climates (Ardebil and Hamedan) and highest PUFAs resulted in the warm climates (Ahwaz and Bushehr). These results also apply to oil content. However, these results are contrary to protein content. As the protein content is higher in warm climates.

Analysis of fatty acid ratios

The effects of climate on the ratio of the fatty acids in *Camelina sativa* showed that there were significant differences for SFA, MUFA, PUFA, UFAs (total unsaturated fatty acids), PUFA: SFA ratio and UFA: SFA ratio (Table 7).

Mean comparison of the effect of the climate on the ratio of the fatty acids in *Camelina sativa* (Table 8) showed that the highest SFA, MUFA and PUFA were found in warm climates (Ahwaz and Bushehr) and the lowest ones were showed in cold climates (Ardebil and Hamedan). Also, The maximum UFA, P:S, and UFA:S found in cold climates (Ardebil and Hamedan) and warm climates (Ahwaz and Bushehr) showed the lowest amounts of these indices.

Discussion

Gas chromatography has been used for analysis of fatty acids in many studies (27-30). The cause of an increase in unsaturated fatty acids in cold areas can be described as follows (31, 32).

One of the applications of fatty acids in plants in the cell's membrane, if it is fluid, the cell will be flexible against the cold. Unsaturated fatty acids make that oils become liquids and if they are present in the membrane of cells, this gives the cellular flexibility and helps keep the plant from cold. Of course, Camelina is completely inherently resistant to frost and this feature is not seen in any plant. Because many plants are destroyed by the cold.

A reduction in the atherogenic LDL-C is favourable, but a reduction in high-density lipoprotein (HDL)

Table 7. Mean squares of the effects of Climate on the ratio of the Saturated Fatty Acid (SFA) in *Camelina sativa*. Where SFA (Saturated Fatty acid), MSFA (Mono-unsaturated Fatty acid), PUFA (Poly-unsaturated Fatty acid, UFA (MUFA+ PUFA or Unsaturated Fatty acid), P: S (PUFA: SFA ratio), UFA: S (Unsaturated Fatty acid to saturated Fatty acid ratio).

		MS					
SOV	df	SFA	MUFA	PUFA	UFA	P:S	UFA:S
Climate	8	12.354**	1.987**	343.453**	304.546**	7.546**	14.756**
Error	18	0.012	0.1023	0.254	0.465	0.008	0.010
CV (%)		5.65	7,43	7.43	12.00	7.54	8.65

Where SFA: Saturated Fatty acid, MUSFA: Mono Unsaturated Fatty acid, PUFA: Poly Unsaturated Fatty acid, MP: MUSFA+ PUFA.

cholesterol has been reported to have a negative effect on coronary heart disease (CHD) in epidemiological studies. The dietary fatty acid composition is one of the most important factors determining plasma lipid concentrations and consequently affecting CHD risk. A high content of saturated fatty acids (SFA) in the diet leads to an increase in the concentrations of plasma total cholesterol and LDL-C, whereas a decrease can be achieved by replacing SFAs with polyunsaturated fatty acids (PUFA). In the past, monounsaturated fatty acids (MUFA) were considered to be neutral with regard to their influence on plasma lipids and lipoproteins (33).

Since 1985, however, studies using MUFA-rich diets have reported either no changes, decrease, or increase in the plasma HDL-C concentrations when compared with PUFA- or carbohydrate-rich diets (19).

Furthermore, Mono-Unsaturated Fatty Acid -rich diets are discovered to increase, decrease or leave unchanged plasma low-density lipoprotein cholesterol (LDL-C) concentrations when compared with Poly -Unsaturated Fatty Acid - or carbohydrate-rich diets. Subsequently, the effect of diets enriched in MUFAs on plasma lipids has been a controversial issue. These conflicting results are probably due to the variety of experimental designs used by different investigators (34).

The ratio of omega-6/omega-3 essential fatty acids under 4:1 may relate to human health (32).

Acknowledgements
Thanks to Biseton Shafa Co. and Zagros Bioidea Co., Razi University Incubator staffs for all supports.

Conflict of interest statement
None.

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