Effect of an electric field treatment on unsaturated fatty acid composition in crude chia (*Salvia hispanica* L.) oil

José Alberto Ariza-Ortega[1], Joel Díaz-Reyes[2], Luis Alberto Juárez–Morán [3], María Elena Ramos-Cassellis[4], Silvia Luna-Suarez[5], Maribel Cano Hernández*[6]

[1]Universidad Autónoma del Estado de Hidalgo, Instituto de Ciencias de la Salud, Área Académica de Nutrición, Carretera Actopan-Tilcuautla, Ex-Hacienda la Concepción, San Agustín Tlaxiaca, Pachuca, Hidalgo, 42086, México. (José Alberto Ariza-Ortega, email: jose19031975@hotmail.com).
[2]Centro de Investigación en Biotecnología Aplicada, Instituto Politécnico Nacional, Carretera Estatal Santa Inés Tecuexcomac, Km 1.5 Tepetitla de Lardizábal, Tlaxcala. 90700, México. (Joel Díaz-Reyes, email: Joel_diaz_reyes@hotmail.com).
[3]Benemérita Universidad Autónoma de Puebla, Facultad de Ciencias Fisicomatématicas, Avenida San Claudio y Boulevard 18 Sur s/n San Manual, Puebla, 72570, Puebla, México. (Luis Alberto Juárez-Moran, email: luisjumo13@hotmail.com)
[4]Benemérita Universidad Autónoma de Puebla, Facultad de Ingeniería Química, Avenida San Claudio y Boulevard 18 Sur s/n San Manual, Puebla, 72570, Puebla, México. (María Elena Cassellis-Ramos, email: cassellis71@yahoo.com.mx).
[5]Centro de Investigación en Biotecnología Aplicada, Instituto Politécnico Nacional, Carretera Estatal Santa Inés Tecuexcomac, Km 1.5 Tepetitla de Lardizábal, Tlaxcala. 90700, México. (Silvia Luna-Suarez, email: sluna73@hotmail.com).
[*6]Maribel Cano Hernández, corresponding author: maribel_cano@hotmail.com
Instituto Tecnológico del Altiplano de Tlaxcala
Carr. San Martin Tex- Tlaxcala Km 7.5, San Diego Xocoyucan Tlax

Abstract

The aim of this study was to evaluate the stability of mono- and polyunsaturated fatty acids in crude chia (*Salvia hispanica* L.) oil samples subjected to an electric field (voltage: 9 KV cm^{-1}; frequency: 720 Hertz; treatment time: 3 min). Fatty acid composition was analyzed by gas chromatography, and oil deterioration grade was assessed by quality parameters (acidity, peroxide, and iodine). Electric field is considered a suitable method to preserve oil quality and preventing *trans* fatty acids (TFA) formation. In this study was found that the application of an electric field does not cause changes on concentration of unsaturated fatty acids, in its quality and information of TFA in the crude chia oil.

Keywords Chia seed, Electric field, Oil, *Trans* fatty acids, Unsaturated fatty acids

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Introduction

Chia (*Salvia hispanica* L.) a plant capable to grow in arid environments, is increasingly recognized as an alternative crop for the oil industry. Chia seed is composed of protein (15%-25%), lipids (30%-33%), carbohydrates (26%-41%), dietary fiber (18%-30%), ash (4%-5%), vitamins, and dry matter (90%-93%) moreover it contains a high amount of antioxidants [1]. Currently, chia seed oil is not widely used for commercial purposes, even though its features are well suited for industrial applications and it can help to improve the human diet [1]. One of the main difficulties in preserving crude chia oil is the rapid deterioration of mono- and polyunsaturated fatty acids by singlet oxygen species, which oxidize these fatty acids and may cause the formation of *trans* isomers [2]. The consumption in excess of these *trans* isomers increases the risk of coronary diseases and obesity [3]. Moreover, unsaturated fatty acid oxidation affects the shelf life and nutritional quality of oils [1].

Emerging technologies such as the electric field treatment may offer a solution to this issue, being a non-thermal preservation method that inactivates enzymes and microorganisms [4]. Some studies on virgin olive oil [5] and peanut oil [6] have shown that oil quality is maintained by a decrease in oxidation rate, and that nutritional value is preserved after an electric field treatment. Hence, the aim of this study was to ascertain the impact of an electric field on the fatty acid stability in crude chia oil, with special attention to mono- and polyunsaturated fatty acids and the possible formation of *trans* fatty acids.

Results and discussion

Table 1 shows the FAMEs (Fatty acid methyl esters) found in chia crude oil before and after electric field treatment. According to the results here in reported, chia crude oil is one of th vegetables sources with highest essential fatty acids content: 51.21% linolenic acid and 23.3% linoleic acid, similar to linseed oil (58.8% linolenic acid and 14%-16% linoleic acid) [10], in contrast with canola oil (6%-14% and 18%-30%) [7], corn oil (0%-2% and 34%-62%) [8], soybean oil (5%-11% and 40%-57%) [9]. Factors such as cultivation environment may underlie the differences in chemical composition of these plant seeds [11].

Ayerza and Coates [12] conducted studies to assess the effects of chia seed consumption on rats. They reported that serum triglycerides (TG) and low-density lipoprotein (LDL) were significantly reduced, whereas high-density lipoprotein (HDL) and polyunsaturated fatty acid levels (ω-3) were increased; both effects are desirable in human food. While FAMEs identified in chia crude oil (C16:0, C18:0, C18:1, C18:2, and C18:3) were similar to those reported in other studies [13, 14] concentrations were different; C18:3 amount (51.21%) in this study was lower (Table 1) to the value reported by those researchers (68.52%, 62%,

and 58.8%, respectively). C18:2 (23.3%) was found in similar amounts by Segura-Campos et al. [13], with 20.4%; Craig and Sons [14] with 20.3%, and Ayerza and Coates [12] with 18.8%. and C18:1 (6.80%) was similar to the value reported by Craig and Sons [14] with 6.9%. The concentration of C16:0 was higher (13.5%) in this study than the value reported by Segura-Campos et al. [13] with 7.47%; Craig and Sons [14] with 6.7%; Ayerza and Coates [12] with 6.5%, and C18:0 amount (2.60%) was similar to that reported by Ayerza and Coates [12] with 2.9%.

Only negligible amounts (0.01%) of *trans* fatty acids were found in chia oil. In contrast, several studies [13, 15] have reported higher *trans* fatty acids contents in oils such as canola and avocado (about 3%). *Trans* fatty acid concentration in chia oil is within the Food and Drug Administration requirement of 0.5 g 100 g^{-1} (%) as the maximum permitted value [16]. FAMEs contents in chia crude oil after electric field treatment were similar to controls (samples not subjected to electric field treatment).

Acidity and iodine index were similar before and after treatment; i.e. the treatment did not change these values (Table 2). Meanwhile the peroxide index was lower in the treated oil (3.10 meq O_2 kg^{-1}) than the control (2.00 meq O_2 kg^{-1}), it may suggest that some peroxides maybe transformed into water or hydrogen molecules that volatilized from the oil under the electric field treatment. The peroxide value of 2.0 mEq O_2 kg^{-1} found in crude chia oil after electric field treatment, mean that unsaturated and polyunsaturated fatty acids were preserved with respect to controls (3.1 mEq O_2 kg^{-1}). This value is in accordance with those found in other chia crude oil studies (1.64 mEq O_2 kg^{-1} and 2.67 mEq O_2 kg^{-1}) [1, 17]. The value is similar than reported for flaxseed oil, (1.28-4.24 mEq O_2 kg^{-1}) [18]. On the other hand, international regulations [19] require a peroxide value up to 15 mEq O_2 kg^{-1} for virgin oils and cold-pressed fats and oils, and up to 10 mEq O_2 kg^{-1} for other fats and oils; the

results in this study were considerably lower than the values required, suggesting that crude chia oil did not exhibit high signs of oxidation.

Table 1. Percentage of FAMEs of chia crude oils with the applying of an electric field

FAMEs	Name	Control	Electric field treatment
C16:0	Palmitic acid	13.50 ± 1.00^{a} (0.67 g 100 g^{-1})	13.80 ± 1.01^{a} (0.68 g 100 g^{-1})
C18:0	Stearic acid	2.60 ± 0.80^{a} (0.13 g 100 g^{-1})	2.70 ± 0.82^{a} (0.13 g 100 g^{-1})
C18:1t	Elaidic acid	0.01 ± 0.00^{a} (0.0005 g 100 g^{-1})	0.01 ± 0.00^{a} (0.0005 g 100 g^{-1})
C18:1	Oleic acid	6.80 ± 2.19^{a} (0.34 g 100 g^{-1})	6.70 ± 2.20^{a} (0.33 g 100 g^{-1})
C18:2t	Linoleaidic acid	0.01 ± 0.00^{a} (0.0005 g 100 g^{-1})	0.01 ± 0.00^{a} (0.0005 g 100 g^{-1})
C18:2	Linoleic acid	23.30 ± 3.10^{a} (1.15 g 100 g^{-1})	23.10 ± 3.30^{a} (1.14 g 100 g^{-1})
C18:3t	Linolenic acid (*cis*-6, *trans*-9,12)	0.01 ± 0.00^{a} (0.0005 g 100 g^{-1})	0.01 ± 0.00^{a} (0.0005 g 100 g^{-1})
C18:3	Linolenic acid	51.21 ± 3.08^{a} (2.53 g 100 g^{-1})	53.40 ± 3.10^{a} (2.64 g 100 g^{-1})

Average of 3 replicates.

Different letters in superscripts in the same row indicate significant differences between treatments ($p<0.05$).

Table 2. Chemical analysis of chia crude oil with the applying of an electric field

Chemical analysis	Control	Electric field treatment
Acidity (% oleic acid)	0.74 ± 0.13^{a}	0.66 ± 0.15^{a}
Peroxide (Emeq O_2 kg^{-1} of oil)	3.10 ± 0.11^{a}	2.00 ± 0.12^{b}
Iodine value (cg I_2 g^{-1})	193.12 ± 1.32^{a}	194.67 ± 1.14^{a}

Average of 3 replicates ± SD.

Different letters in superscripts in the same row indicate significant differences between treatments ($p<0.05$).

Found acidity value is a little higher than that reported for chia oil (0.5-0.6%) [17] and it is due to the extraction conditions used. An iodine value of 190.12 cg I_2 g^{-1} was found for chia oil before electric field treatment, similar to that reported by Segura-Campos et al. [13], with 193.45 g I_2 100 g^{-1}, and it was a little lower than reported by Martínez et al. [17], (208-215 g I_2 100 g^{-1}), showing a high unsaturation grade in chia crude oil. Lalas [20] reported that a decrease in iodine value is the result of complex physicochemical changes, indicative of increased tendency toward oxidation. Iodine value in chia crude oil is comparable to the value in linseed oil [19], 187 g I_2 100 g^{-1}, and higher than flaxseed oil (170 g I_2 100 g^{-1}) [18] and it is higher than soybean oil (122 g I_2 100 g^{-1}) [20]. Electric field application preserved the labile double bonds of fatty acids (194.67 cg I_2 g^{-1} after treatment. These results corroborate the high unsaturation grade of fatty acids in the tested samples.

Lifetime of chia oil

Table 3 shows the results of the percentage of free fatty acid (% FFA) at an average room temperature (25°C) freshly extracted oil chia occur and the % FFA after 10 months, no significant difference after 12 months.

Table 3. % FFA of chia oil, initial and final

	% FFA initial	% FFA (10 months)	% FFA (12 months)
Acidity (% oleic acid)	0.74 ± 0.13^{a}	1.65 ± 0.15^{b}	1.66 ± 0.14^{b}

Average of 3 replicates.

Different letters in superscripts in the same row indicate significant differences between treatments ($p<0.05$).

In order to determine the shelf life time of the average temperature in the Puebla City (17.5°C), the %FFA chia oil at different temperatures was measured, the results are shown in Table 4.

The value of the rate constant of reaction (k) is determined by subjecting the experimental data of the % FFA determinations with respect to time to a linear regression analysis at different temperatures, from Labuza equation [25].

$$\frac{dFFA}{dt} = k\,FFA$$
$$\ln FFA = \ln FFA_0 + kt \qquad (1)$$
$$\log FFA = \log FFA_0 + \frac{kt}{2.302585}$$

Where *FFA*: Percentage of free fatty acids at time t; FFA_0: Percentage of initial free fatty acids; t: Time in days and *k*: reaction rate constant. The linear regression analysis of the data of Table 4, based on Eq. (1) yielded values of reaction rate constant (*k*) for each temperature, which are shown in Table 5.

Table 4. Variation of the content of free fatty acids (FFA) with respect to time at different temperatures

25°C		50°C		60°C		70°C	
Time (hr)	FFA (%)	Time (hr)	FFA (%)	Time (hr)	FFA (%)	Time (hr)	FFA (%)
0	0.74	0.0	0.72	0.0	0.71	0.0	0.72
96	0.75	1.0	0.72	1.0	0.73	0.9	0.72
312	0.79	2.0	0.75	2.0	0.75	1.9	0.76
672	0.81	3.2	0.76	3.1	0.77	3.0	0.76
2160	0.86	4.0	0.78	3.9	0.78	4.0	0.79
		7.0	0.76	7.0	0.80	6.8	0.83
		11.0	0.79	11.0	0.82	10.9	0.84
		15.0	0.80	15.0	0.86	14.9	0.92
		17.9	0.85	17.9	0.90	17.8	0.92

Tabla 5. Results of the linear regression applied to the experimental data

Temperature (°C)	*K*	Correlation Coefficient r^2
25	0.00369398	0.9917
50	0.00750766	0.8344
60	0.0116144	0.9601
70	0.0141188	0.9498

To determine the constant k at a temperature 17.5°C, with the data of Table 2 a Linear regression was performed using Equation 2 (exponential model) and by extrapolation (Fig. 1), the value of *k* was calculated to be 0.00284454 $days^{-1}$.

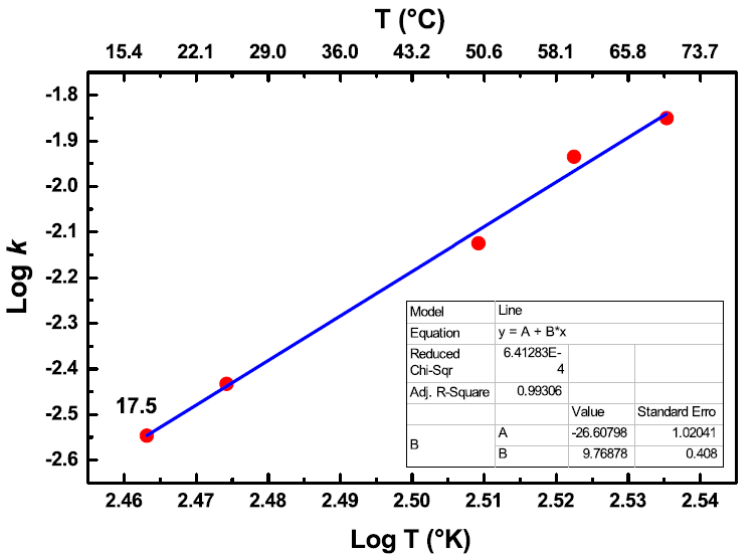

Figure 1. Extrapolation of the exponential model.

$$k = aT^b \quad (2)$$

Where: *k*: line slope that relating *A* (characteristic value at time *t*) and *t* (time); *a*, *b*: constants and *T*: temperature in Kelvin.

The model was linearized and replaced in it the values of used storage temperatures, in absolute units, and determined reaction constants. To determine the approximated lifetime of chia oil at temperature of 17.5°C the following equation was used:

$$logFFA_f = logFFA_i + \frac{k_{17.5}t}{2.302585} \quad (3)$$

Where: FFA_f: Percentage of free fatty acids end, equal to 1.65%; FFA_i: Percentage of initial chia oil newly extracted free fatty acids, equal to 0.74%; *t*: Lifetime storage at 17.5°C; $k_{17.5}$: reaction rate constant at 17.5°C. Substituting these values into Eq. (3) obtains a lifetime about 9.4 months.

Experimental

Samples

A random sample (150 g) of mature chia seeds (*Salvia hispanica* L.), from the State of Puebla, Mexico, was selected. Chia seeds were ground in a coffee mill for 20 s. A 40 g sample of seed flour was placed into a porous cartridge and deposited in a Soxhlet extractor. Oil was extracted with hexane 2:3 w/v (purity ≥95%, Sigma-Aldrich) as solvent. Temperature was maintained at 69±1°C for 4 hours [15]. Oil was recovered using a rotary

vacuum evaporator at 40°C for 10 min. The obtained oil was stored at 25°C in dark vessels until use. Extraction treatment was performed in triplicate for each sample.

Electric field treatment

Electric fields were applied on the samples in a scale electric field unit. The electric field system consisted of a generator module where high-voltage pulses are produced. The generator module is connected to a generator unit model 9412 A (Quantum Composers, Inc., Bozeman, MT) where the required waveform could be selected, a square form was selected for this work. The generator unit is connected to a chamber module. Two stainless steel connectors, acting as electrodes, are screwed to the final section of the chamber module. Voltage and frequency parameters were similar to those used by Castorena [22] to inactivate the polyphenol oxidase enzyme. Samples were collected after treatment and acidity, peroxide, and iodine were immediately determined. Additionally, fatty acids in the oils were derivatized to methyl esters. All experiments were performed in triplicate.

Chia crude oil characterization

Crude chia oil was characterized by the following chemical analyses: acidity, which defined as the quantity in mg of KOH required to neutralize the free fatty acids in 1.0 g of oil or fat. The peroxide index that is expressed as mEq of O_2 in the form of peroxide per kg of fat or oil, and iodine, defined as the quantity of unsaturated fatty acids in fats and oils expressed as the number of cg of I_2 absorbed per 1 g of oil sample (% of iodine absorbable) [23]. All analyses were performed in triplicate.

Gas Chromatography (GC)

Fatty acid content was calculated as the total percent of fatty acid methyl esters (FAMEs) as determined by GC. GC system consisted of a GC HP-5890 (Hewlett-Packard Company, Palo Alto, CA) equipped with a Flame Ionization Detector (FID). FAMEs were extracted as follows: crude chia oil was saponified and derivatized to methyl esters by treatment with methanolic KOH 1 N solution, following the IUPAC method [24]. Methyl esters were extracted by adding 10 mL of hexane and 10 mL of distilled water, and the organic and aqueous phases were then separated. The residue was dissolved in hexane, and the volume injected was of 2 µL sample (split ratio 20:2) that was injected into the GC-system sample port. Oven temperature was set at 100°C (4 min hold) and increased to 250°C at a rate of 3°C min^{-1} (10 min hold). GC-system injector and detector were maintained at 230 and 250°C, respectively. Nitrogen was used as carrier gas, and flow rate was set at 1.2 mL min^{-1}. Changes in fatty acids after electric field treatment of crude oil samples were assessed by comparison with a 37-component standard (Food Industry FAMEs Mix, Restek). Column specifications were, RT®-2560 fused silica capillary column (biscyanopropyl-polysiloxane) 100 m long, 0.25 mm ID, 0.2 µm film thickness (Restek Corporation, Bellefonte, PA).

Statistical analysis

Results were expressed as mean value ± SD. Significant differences were evaluated by analysis of variance (ANOVA). A value of α=0.05 was regarded as significant. The software used for these analyses was the Statistical Analysis System, version 6.1 (SAS Institute Inc., Cary, NC, USA).

Conclusions

Crude chia oil has a high content of essential fatty acids, beneficial to the human health. Electric field treatment did not affect the concentration and quality of fatty acids in chia crude oil. Being a non-thermal preservation method, electric field processing has good prospects to be used in the oil industry, and it could offer an alternative to preserve oil quality without adding synthetic antioxidant agents.

List of abbreviations

mEq O_2 kg^{-1}: milliequivalent of oxygen in the form of peroxide per kg of fat or oil; cg I_2 g^{-1}: Centigrams of iodine absorbed per 1 g of oil sample.

Competing interests

The authors have declared no conflict of interest.

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