Enhancement of Composition and Oxidative Stability of Chia (*Salvia hispanica* L.) Seed Oil by Blending with Specialty Oils

María Gabriela Bordón, Silvina Patricia Meriles, Pablo Daniel Ribotta, and Marcela Lilian Martinez

Abstract: Chia seed (*Salvia hispanica* L.) oil is mainly composed of ω-3 fatty acids (61% to 70%). Despite being nutritionally favorable, higher amounts of polyunsaturated fatty acids result in poorer oxidative stability. Thus, the aim of this work was to produce edible vegetable oil blends rich in ω-3 fatty acids and with greater oxidative stability than pure chia oil. Blending of chia with other specialty oils (walnut, almond, virgin, and roasted sesame oils) was assessed in the following respective proportions: 20:80, 30:70, and 40:60 (v/v). An accelerated storage test was conducted (40 ± 1 °C, 12 days). Primary and secondary oxidation products, free fatty acid content, antioxidant compounds, fatty acid composition, and induction time were determined. The blends presented higher oxidative stability indices than chia oil. Sensory analysis showed that, given a pure oil, judges did not identify statistically significant differences among the blends. The results suggest that blending of chia oil is an adequate alternative to obtain ω-3-enriched oils with higher oxidative stability indices.

Keywords: accelerated storage test, oil blends, oxidative stability, *Salvia hispanica* L., ω-3 fatty acids

Practical Application: Vegetable oil blending is a widely used practice in the edible oil industry to produce blended oils with enhanced stability and nutritional and sensory properties at affordable prices. The blends developed in this study from chia, sesame, walnut, and almond oils take advantage of the properties of each parent oil to yield products with improved oxidative stability, essential fatty acid presence, and sensory characteristics. To achieve a daily intake of 2.22 g/day of ω-3 fatty acids as recommended by the Intl. Society for the Study of Fatty Acids and Lipids (ISSFAL), it is necessary to consume approximately one spoonful of the formulated mixtures.

Introduction

Around 79% of the over 100 million tons of edible oils and fats produced worldwide annually are extracted from vegetable sources (Fasina, Craig-Schmidt, Colley, & Hallman, 2008). A diet rich in ω-3 fatty acids is associated with the prevention and treatment of certain noncommunicable diseases, such as coronary artery disease, diabetes, and cancer (Poudyal, Panchal, Waanders, Ward, & Brown, 2012). Chia seeds (*Salvia hispanica* L.) contain around 32% to 39% of oil, in which ω-3 fatty acids are present in high amounts (61% to 70%), being the richest vegetable source in ω-3 fatty acids known so far (Bodoira, Penci, Ribotta, & Martínez, 2017). Although it seems clear that such fatty acid composition (FAC) is favorable from a nutritional point of view, a higher content of polyunsaturated fatty acids (PUFAs) results in poorer oxidative stability and shorter shelf-life of the oil. When PUFAs are exposed to environmental factors, such as air, light, and temperature, oxidation reactions produce undesirable flavors, rancid odors, discoloration, and other forms of spoilage (Bodoira et al., 2017; Frankel, 2005). Also, radical oxygen species are produced that may cause irreversible damage when reacting with biological molecules, such as DNA, proteins, or lipids (Cabiscol, Tamarit, & Ros, 2000). As can be seen, lipid oxidation has harmful effects on both food quality and human health. Therefore, efforts must be made to improve the oxidative stability of lipid products (Li et al., 2014).

Blending of two or more oils with different characteristics is one of the simplest procedures to make new distinct products. Mixing different kinds of vegetable oils cannot only change fatty acid profiles, but also modify the levels of bioactive lipids and natural antioxidants in the blends, give better quality oils, as well as enhance oxidative and nutritional properties which lead to improved industrial applications at relatively low cost (Hashempour-Baltork, Torbati, Azadmard-Damirchi, & Savage, 2016). For instance, studies report the combination of sunflower oil with canola or palm oil (Farag, El-Agamy, & Abd El Hakeem, 2010) and the mixture of soybean oil with hydrogenated soybean oil, or corn oil with high-oleic sunflower oil (Naghshineh, Ariffin, Ghazali, Mirhosseini, & Mohammad, 2010). In addition, blending common edible oils with unconventional oils, such as rice bran oil, to reduce costs and meet industry demands is permitted (Choudhary, Grover, & Kaur, 2015). Hence, some researchers have studied the oxidative stability of different blends, such as walnut and virgin olive oils (Torres et al., 2011), chia and sunflower oils (Guiotto, Ixtaina, Nolasco, & Tomás, 2014), almond, camellia, corn, palm, peanut, rapeseed, sesame, soybean, sunflower, and zanthoxylum oils (Li et al., 2013), among others.

JFDS-2018-1800 Submitted 11/9/2018, Accepted 2/22/2019. *Authors Bordón, Meriles, and Ribotta are with Instituto de Ciencia y Tecnología de los Alimentos Córdoba (ICYTAC - CONICET), Univ. Nacional de Córdoba, Córdoba, Argentina. Authors Bordón, Ribotta, and Martinez are with Instituto de Ciencia y Tecnología de los Alimentos (ICTA), Facultad de Ciencias Exactas, Físicas y Naturales, Univ. Nacional de Córdoba, Córdoba, Argentina. Authors Bordón, Ribotta, and Martinez are also with Dept. de Química Industrial y Aplicada, Facultad de Ciencias Exactas, Físicas y Naturales, Univ. Nacional de Córdoba, Córdoba, Argentina. Author Martinez is with Instituto Multidisciplinario de Biología Vegetal (IMBIV, CONICET), Univ. Nacional de Córdoba, Av. Vélez Sársfield 1611, 5000, Córdoba, Argentina. Direct inquiries to author Martinez (E-mail: marcela-martinez78@hotmail.com, marcela.martinez@unc.edu.ar).*

doi: 10.1111/1750-3841.14580

Journal of Food Science A Publication of the Institute of Food Technologists

Nowadays, there is an increasing demand for specialty oils and fats which, besides having specific physical properties, contain bio-active compounds that offer health benefits, improve the oxidative stability of food products, or have a clinically proven health-friendly FAC (Bhattacharya, 2006). Therefore, the main goal of this study was to produce ω-3-enriched vegetable oil blends with greater oxidative stability than that of pure chia oil. Blending of chia with other specialty oils (walnut, almond, virgin sesame oil [VSO], and roasted sesame oil [RSO]) was explored. The cultivation of chia, sesame, walnut, and almond crops is gaining interest owing to the increasing demand of their seeds or nuts and their by-products around the world (Martínez & Maestri, 2015). Chia seeds are native from west central Mexico and northern Guatemala. At present, it is also grown in Bolivia, Paraguay, Argentina, and Australia (Martínez et al., 2012). Growing demands are foreseen in the next years, especially in the EU where chia seed oil placing was authorized in 2014 (Caruso et al., 2018). Worldwide productions of walnut and almond crops are about 3,400,000 and 19,34,817 tons, respectively (Martínez & Maestri, 2015). Both oils are produced mostly in France, Spain, Argentina, and the United States at a small scale (Martínez et al., 2017a). Walnut oil is composed mainly of triglycerides, in which PUFAs (linoleic and α-linolenic acids, 50% to 63% and 11% to 19%, respectively) are the most important. This oil source was selected for the present study due to its unique balance of ω-6/ω-3 fatty acids (4/1), the presence of important minor components (tocopherols, phospholipids, sterols, and so on), and its nutty flavor, which has a high sensory rating (Martínez, Barrionuevo, Nepote, Grosso, & Maestri, 2011). As regards almond oil, the major fatty acid present is oleic acid (50% to 70% of the total fatty acid content). The oxidative stability of almond oil is mainly related to its FAC and to its endogenous antioxidant substances, mainly tocopherols (about 450 ppm) (Martínez & Maestri, 2015). This particular chemical composition makes almond oil an interesting vegetable source for oil-blending. Main countries for sesame seed production include China, India, Sudan, Ethiopia, and Mexico. Also, the crop is little developed in the north of Argentina (Martínez & Maestri, 2015). The seeds have high economic impact due to their oil content (45% to 60%) for which annual production is around 4,756,000 tons (Martínez, Bordón, Lallana, Ribotta, & Maestri, 2017b). Sesame oil is characterized by the predominance of oleic and linoleic acids, which are present in very similar proportions and together represent, on average, 85% of the total oil (Martínez & Maestri, 2015). However, compared to other oils, sesame oil contains a relatively high proportion of unsaponifiable matter (up to 3% of the total oil), which includes sterols, tocopherols, and lignans (mainly sesamin, sesamolin, sesamol, and sesaminol), some of which have important antioxidant properties (Suja, Jayalekshmy, & Arumughan, 2004). VSO shows a remarkable stability owing to the presence of tocopherols and lignans despite its high levels of unsaturated fatty acids (Yoshida & Takagi, 1997). Roasted sesame seeds yield oils with a distinct flavor and a longer shelf-life, which is attributed to a synergistic action between sesamol, tocopherols, and melanoidins, produced by nonenzymatic browning reactions (Wan et al., 2015). Both VSO and RSO were selected for this study due to their unique antioxidant content, which may stabilize chia seed oil by oil-blending.

Finally, some physicochemical properties of the oil blends under accelerated storage conditions were studied and a sensory evaluation based on the "difference from control test" was carried out.

Materials and Methods

Materials

Chia and sesame seeds, walnuts, and almond nuts were obtained from commercial plantations located in Salta, Catamarca, and San Juan provinces, Argentina. The seeds and nuts were packed in polypropylene bags and kept at 5 ± 1 °C until use, according to Bodoira et al. (2017). 2,2- Diphenyl-1-picrylhydrazyl (DPPH) and heneicosanoic acid (C21:0) were purchased from Sigma Aldrich (St. Louis, MO, USA). Tocopherol standards were purchased from ICN Biomedicals (Costa Mesa, CA, USA). Spectrophotometric-grade cyclohexane (Cicarelli Laboratories, Argentina) was used for K232 and K270 analyses. Other chemical reagents were HPLC or analytical grade.

Extraction of vegetable oils

Extraction of oils from chia seeds (CO), walnuts (WO), almonds (AO), and sesame seeds (VSO) was carried out in a single step with a Komet screw press (Model CA 59 G; IBG Monforts, Mönchengladbach, Germany) according to Martínez, Mattea, and Maestri (2008, 2012, 2013, 2017b). RSO was extracted after the heat treatment of the seeds in a fluid bed dryer (Sherwood Scientific Ltd.) for 20 min, setting the air inlet temperature to the dryer at 180 ± 5 °C. The obtained extract (oil + solids) was subsequently centrifuged according to the methodology described by Martínez et al. (2008).

Blending of vegetable oils

The blends were prepared by mixing chia oil with walnut, almond, or sesame oils (VSO and RSO) in the following respective proportions: 20:80, 30:70, and 40:60 (v/v). The mixtures were uniformly stirred for 5 min according to the methodology described by Guiotto et al. (2014).

Chemical quality analysis

Free fatty acid content (FFAC), peroxide value (PV), specific extinction coefficients K232 (related to conjugated dienes, CD) and K270 (related to conjugated trienes, CT), and *p*-anisidine value (PAV) were determined according to standard methods of AOCS (2009). FAC was analyzed by gas chromatography (Perkin-Elmer, Shelton, CT, USA) according to procedures reported earlier (Torres et al., 2009). The quantification was done using heneicosanoic acid (C21:0) as internal standard. Iodine value (I_2V) and MUFA/PUFA relationship were calculated from fatty acid percentages (Torres et al., 2009). Total tocopherol content (TTC) and total lignan content (TLC) were measured according to Wong, Timms, and Goh (1988) and Bhatnagar, Hemavathy, and Krishna (2015), respectively. Individual tocopherols were analyzed by HPLC (Perkin-Elmer) and identified by comparison of their retention times with those of authentic standards according to the procedure described by Bodoira et al. (2017). The quantification was done by the external standard method, and the final concentration was expressed as mg tocopherol/ kg of oil sample.

The oxidative stability index (OSI) was determined by Rancimat analysis according to Oliveira, Rodríguez, and Bernardo-Gil (2002). Air flow rate was set at 20 L/hr and temperature of the heating block was maintained at 100 °C.

The antioxidant activity of pure vegetable oils and their blends was assessed according to Martínez and Maestri (2008). Antioxidant activity was expressed as IC_{50}, reflecting the depletion of the free radical (DPPH) to 50%. A lower IC_{50} value indicated higher antiradical activity.

Table 1–Oxidative parameters of walnut (WO), almond (AO), sesame (virgin [VSO] and roasted [RSO]), chia (CO) oils, and their blends.

	Oxidative parameters						
Oils	**FFAC**	**PV**	**K232**	**K270**	**PAV**	**OSI**	***K***
CO	1.94 f ± 0.01	0.45 a ± 0.07	1.990 d ± 0.100	0.460 g ± 0.005	3.49 c ± 0.12	2.57 a ± 0.11	1.461 g ± 0.007
WO	0.14 a ± 0.01	ND	1.140 a ± 0.010	0.090 b ± 0.001	ND	6.87 de ± 0.03	0.929 f ± 0.114
AO	ND	ND	1.120 a ± 0.080	0.040 a ± 0.003	ND	27.15 j ± 0.43	0.141 de ± 0.005
VSO	5.45 m ± 0.02	ND	2.980 gh ± 0.030	0.790 i ± 0.010	ND	18.94 i ± 1.05	0.000 ± 0.000
RSO	4.06 i ± 0.01	ND	3.170 i ± 0.050	0.850 j ± 0.020	8.33 f ± 0.03	26.94 j ± 0.96	0.083 cd ± 0.001
	Oil blends (v/v)						
CO:WO (20:80)	0.67 b ± 0.00	ND	1.358 bc ± 0.063	0.142 c ± 0.006	ND	5.23 c ± 0.02	1.665 h ± 0.013
CO:WO (30:70)	1.00 d ± 0.01	ND	1.360 bc ± 0.018	0.177 cd ± 0.003	ND	4.91 bc ± 0.11	1.685 h ± 0.021
CO:WO (40:60)	1.23 e ± 0.00	ND	1.489 c ± 0.044	0.239 ef ± 0.013	ND	4.17 b ± 0.18	2.254 i ± 0.026
CO:AO (20:80)	0.74 c ± 0.00	ND	1.319 b ± 0.012	0.170 cd ± 0.005	ND	9.70 f ± 0.30	0.142 de ± 0.001
CO:AO (30:70)	1.01 d ± 0.07	ND	1.321 b ± 0.006	0.193 de ± 0.008	ND	7.40 e ± 0.19	0.153 e ± 0.018
CO:AO (40:60)	1.19 e ± 0.00	ND	1.466bc ± 0.002	0.251 f ± 0.006	ND	6.22 d ± 0.09	0.148 e ± 0.007
CO:VSO (20:80)	4.95 l ± 0.00	ND	2.863 fg ± 0.043	0.700 h ± 0.017	1.24 a ± 0.03	10.97 g ± 0.33	0.018 ab ± 0.003
CO:VSO (30:70)	4.79 k ± 0.01	ND	2.765 ef ± 0.102	0.681 h ± 0.007	1.75 ab ± 0.31	8.86 f ± 0.15	0.053 bc ± 0.002
CO:VSO (40:60)	4.60 j ± 0.01	ND	2.668 e ± 0.126	0.694 h ± 0.068	1.97 b ± 0.02	7.08 e ± 0.11	0.078 bc ± 0.002
CO:RSO (20:80)	3.86 h ± 0.00	ND	3.021 hi ± 0.030	0.842 j ± 0.023	7.37 e ± 0.82	12.66 h ± 0.18	0.067 bc ± 0.001
CO:RSO (30:70)	3.86 h ± 0.01	ND	3.176 i ± 0.139	0.885 j ± 0.026	6.25 d ± 0.14	9.19 f ± 0.01	0.078 bc ± 0.007
CO:RSO (40:60)	3.72 g ± 0.04	ND	2.858 fg ± 0.016	0.721 h ± 0.012	7.09 e ± 0.09	7.63 e ± 0.41	0.092 cde ± 0.002

FFAC, free fatty acid content (mg KOH/g oil); PV, peroxide value (meq O_2/kg oil); K_{232}, conjugated dienes, K_{270}, conjugated trienes; PAV, *p*-anisidine value; OSI, oxidative stability index (h); *K*, oxidation rate apparent constant (meq O_2/(kg oil·day)); ND, not detected.
Mean values were the averages of three independent measurements. Values in each column with different letters present significant differences ($P \leq 0.05$) among oil samples.

Experimental design for oxidative stability test

An accelerated stability test (Schaal oven test [SOT]) was performed to evaluate the oxidative stability of the parent oils and blends (Li et al., 2013; Mohdaly, Sarhan, Mahmoud, Ramadan, & Smetanska, 2010). Three replicates of each oil and oil blend sample (30 mL each) were stored in 30-mL dark glass bottles without covers in a forced-draft air oven set at 40 ± 1 °C according to AOCS (2009) for 12 days. Samples of each treatment were removed periodically for evaluation of lipid oxidation. Each treatment was prepared in triplicate.

Sensory evaluation

Oxidation of PUFAs in chia seed oil results in the generation of volatile compounds which are responsible for off-flavors and may lead to poor consumer acceptance. However, sensory evaluation of chia seed oil from fresh chia seeds is qualified as good by consumers (Imran et al., 2016). It has been shown that oil-blending can be used to moderate the properties of each oil, yielding a more satisfactory product given the changes in odor profiles (Hashempour-Baltork et al., 2016). In this regard, an ω-3-rich edible oil obtained by blending chia oil and another vegetable oil with a better consumer acceptance is desired, but the perception of the former oil by the panelists should be minimal. Hence, the "difference from control test" method was selected. The objectives of the test were twofold: (a) to determine whether a difference exists between one or more samples and a control and (b) to estimate the magnitude of any such differences. The pure vegetable oil was designated as the "control" and all the blends (0:100; 20:80; 30:70; 40:60, chia oil: vegetable oil, respectively) were evaluated considering *how different* each sample is from the "control" (Meilgaard, Civille, & Carr, 1991). A 5-point scale was used to indicate the degrees of difference: 0 (no difference), 1 (little difference), 2 (moderate difference), 3 (large difference), and 4 (very large difference).

The 40 semitrained assessors were from Córdoba (Argentina) and were recruited according to the following criteria: between 25 and 55 years old; with no food allergies; nonsmokers; people who consume vegetable oils regularly; people interested in participating (Plemmons & Resurreccion, 1998).

Statistical analysis

Analytical determinations reported in this study were the averages of triplicate measurements from three independent oil samples for each treatment. Statistical differences among treatments for all parameters evaluated were estimated from the ANOVA test at the 5% level ($P \leq 0.05$) of significance, using the Statgraphics Centurion XVI.I software (Statpoint Technologies, Warrenton, VA, USA). Whenever ANOVA indicated a significant difference, a pair-wise comparison of means by least significant difference (LSD) was carried out. Multiple-variable analysis was also applied to establish correlations (Pearson correlations) between different pairs of variables.

Results and Discussion

Oil blends and their chemical quality

Table 1 shows initial values for hydrolytic (FFAC) and oxidative (PV, CD, CT, and PAV) degradation indicators of vegetable oils. In addition, oxidation rate apparent constants (*K*, see the next subsection) can be found in the same table. Pure and blended oils analyzed in this study had FFAC, PV, CD, CT, and PAV values comparable to other published data (Bodoira et al., 2017; Martínez, Penci, Marín, Ribotta, & Maestri, 2013, 2017b). PV values were in agreement with Codex Alimentarius (Codex, 2001) standards for cold-pressed oils (up to 15 meq O_2/kg oil). The initial PV for CSO was 0.45 meq O_2/kg oil, although it was not detected for the rest of pure vegetable oils. Walnut, almond, VSO, and RSO were present in the largest proportion in the formulated oil blends. Therefore, a dilution effect after oil-blending was observed for peroxides, which were present in a low concentration in chia seed oil from the beginning. As a result, PVs were so low that they fell below the detection limit of the volumetric standard method used for PV determination (AOCS, 2009). FFAC values from VSO, RSO, and CO were significantly higher ($P \leq$

0.05) than those from WO and AO. Moreover, FFAC values for VSO and CO:VSO blends were above Codex standards (4.0 mg KOH/g oil). This may be due to the conditioning of raw sesame seeds during harvest and postharvest storage (high water content and temperature) prior to the oil extraction process (Martínez & Maestri, 2015). Surprisingly, FFAC values for RSO and the corresponding blends were significantly lower ($P \leq 0.05$) than those for VSO. According to nonenzymatic browning reaction mechanisms published previously (Zamora & Hidalgo, 2005), carbonyl compounds derived from free unsaturated fatty acids may readily condense with protein-free amino groups. The contribution of both lipid hydroperoxides and secondary oxidation products to interaction pathways with amino acids and proteins results in a myriad of complex reactions. Nonetheless, the reaction of lipid oxidation products with amines, amino acids, and proteins has been related to the browning observed in many fatty foods after processing and storage (Zamora & Hidalgo, 2005). This may account in part for the lower FFAC values observed in RSO and CO:RSO blends after roasting of sesame seeds compared with VSO. As regards PAVs, they were present at significantly higher concentrations ($P \leq 0.05$) in pure RSO and CO. These oxidation products, saturated and unsaturated aldehydes of medium and high molecular weight, mainly arise from PUFAs (Martínez & Maestri, 2015).

FAC of the parent oils (CO, WO, AO, VSO, and RSO) and their blends is presented in Table 2. Except for stearic acid, oil blending significantly modified the FAC analyzed. The major changes were observed for oleic, linoleic, and linolenic fatty acid contents. For example, adding CO to WO at 20%, 30%, and 40% caused a gradual increase of 74%, 109%, and 146%, respectively, in linolenic acid proportions of the resulting blends when compared to pure WO. Greater increments were observed for CO:AO, CO:VSO, and CO:RSO blends. Therefore, the ω-3 fatty acid contents in the final oil blends were significantly higher than in the parent walnut, almond, and sesame oils. Several studies mentioned similar effects of blending oils: Guiotto et al. (2014) found that blending of sunflower kernel oil with chia oils could modify the blends' fatty acid profile. In addition, Li et al. (2014) reported that blending *Moringa oleifera* oil with sunflower oil and soybean oil in different proportions can yield an increase in oleic acid and a reduction of linoleic acid. In the present study, we have found that, to achieve a daily intake of 2.22 g/day of ω-3 fatty acids, as recommended by the Intl. Society for the Study of Fatty Acid and Lipids (ISSFAL) (Rubilar et al., 2012), it is necessary to consume approximately one spoonful of the formulated mixtures.

OSIs, determined by Rancimat analysis (Table 1), confirmed that CO has very low thermal stability; the OSI value obtained (2.57 hr) was in good agreement with data published previously (Bodoira et al., 2017). The OSI of WO, AO, SVO, and RSO was much higher than that of pure CO; as a consequence, the oxidative stability of the resulting vegetable oil blends was significantly greater than that of CO ($P \leq 0.05$). Similar results were reported by Guiotto et al. (2014) for chia and sunflower oils blends. In addition, OSI showed a negative correlation with linolenic acid content and a positive correlation with TLC ($P \leq 0.05$).

Tocopherols and lignans in CO, WO, AO, VSO, and RSO have previously been identified as the main components responsible for antioxidant activity and oxidative stability. The TTC, TLC, and individual tocopherol content are shown in Table 3. The values are within the ranges reported by others (Kochhar, 2002; Martínez, Labuckas, Lamarque, & Maestri, 2010).

The DPPH·assay is widely used for the determination of total antioxidant activity associated with the concentration of bioactive components present in vegetable oils (Bhatnagar, Prasanth Kuma, Hemavathy, & Gopala Krishna, 2009). AO and its blends showed the lowest IC_{50} values (Table 3). The same trend was observed for TTC, for which statistically significant differences were found among treatments ($P \leq 0.05$). Moreover, the antiradical activity showed a positive correlation with TTC, as well as with OSI ($P \leq 0.05$). These results were in agreement with those of Bhatnagar et al. (2009) who reported that natural antioxidant contents and DPPH scavenging activity of coconut oil and other vegetable oils correlated well ($r = 0.97$).

Although sesame oil contains, on average, 30% less oleic acid than almond oil, CO:VSO and CO:RSO blends presented higher oxidative stability. This fact could be due to the presence of biologically active compounds of the sesame seed, called lignans, as shown by the correlation analysis. Sesamin, sesamolin, sesamol, sesaminol, and sesamolinol are the predominant fat-soluble lignans present in sesame seed. According to Suja et al. (2004), sesamol shows high antioxidant activity, compared with the other fat-soluble lignans. In our study, the TLC (expressed as sesamol equivalents) varied between 9.53 and 10.19 g/kg oil, both for RSO and VSO, respectively. On the other hand, Wu (2007) found an average content of total lignans of 11.5 g/kg in commercial sesame oil, while Rangkadilok et al. (2010) reported values of sesamin and sesamolin in the range of 0.93 to 2.89 g/kg and 0.30 to 0.74 g/kg, respectively. In addition, sesame lignans have been found to display a synergistic effect on the antioxidant activity of tocopherols (Kochhar, 2002). Although TTC determined in this work was higher for almond oil and its blends in relation to the rest of the treatments (Table 3), the greater oxidative stability associated with sesame oil (both virgin and roasted) and their mixtures could be attributed to a synergistic effect between the TTC and the lignans present in the lipid matrix (Wan et al., 2015). It is important to highlight that indicators of oxidative degradation were in good agreement with Codex standards and with data published previously (Martínez et al., 2017b), despite the initial FFAC for VSO and CO:VSO blends, supporting the aforementioned antioxidant activity of sesame seed tocopherols and lignans. As regards RSO and CO:RSO blends, the greater oxidative stability could be explained by the synergistic action between sesamol, tocopherols, and melanoidins, produced by nonenzymatic browning reactions during the roasting of sesame seeds (Rostami, Farzaneh, Boujmehrani, Mohammadi, & Bakhshabadi, 2014). These molecules could have the capacity to trap positively charged electrophilic species, oxygenated radicals, or metal cations to form inactive complexes (Delgado-Andrade, Rufián-Henares, & Morales, 2005). Curiously, in our study, it was observed that the "red" component of the color of the oil was significantly enhanced (33.02 ± 0.80) by the rise in the treatment temperature prior to the pressing process, which could be due to the increase in the content of melanoidins. This increase in the color development of RSO was significantly different from the oil of the untreated seeds (VSO, 23.26 ± 0.40).Therefore, all these antioxidant compounds may react rapidly with conjugated free radicals, thus breaking lipid chain oxidation reactions and retarding hydroperoxide formation.

Oil blends and their performance under accelerated storage conditions

Figure 1 to 3 show the effects of blending CO with WO, AO, VSO, and RSO on the development of PV, K232, and K270 during the accelerated stability test (SOT). Despite differences in their initial composition, chia oil and its blends with

Table 2–Fatty acid composition of walnut (WO), almond (AO), sesame (virgin [VSO] and roasted [RSO]), chia (CO) oils, and their blends.

	FAC (mg/g oil)								
Oils	[a]16:0	[b]16:1	[c]18:0	[d]18:1	[e]18:2	[f]18:3	I_2V	MUFA	PUFA
CO	70.26 c ± 0.36	0.39 a ± 0.00	32.70 g ± 0.09	74.61 a ± 0.39	197.14 a ± 0.61	607.21 j ± 2.28	42.51 a ± 0.15	7.50 a ± 0.04	80.43 l ± 0.29
WO	64.06 a ± 0.39	0.22 a ± 0.08	23.11 a ± 0.19	202.05 e ± 3.30	576.68 o ± 2.37	129.94 c ± 4.33	122.79 m ± 0.12	20.22 e ± 0.34	70.66 i ± 0.67
AO	73.30 d ± 2.51	2.47 c ± 0.49	28.64 e ± 1.45	664.10 m ± 3.29	228.85 d ± 1.34	0.99 a ± 0.01	101.46 j ± 0.49	66.66 m ± 0.28	22.98 a ± 0.13
VSO	96.82 j ± 0.97	0.59 a ± 0.07	48.63 k ± 0.07	405.97 i ± 0.25	438.08 l ± 0.87	4.29 a ± 0.25	116.02 l ± 0.18	40.65 i ± 0.02	44.24 d ± 0.06
RSO	98.21 j ± 0.25	0.66 a ± 0.01	48.12 k ± 0.53	407.54 i ± 0.09	434.84 k ± 0.08	4.16 a ± 0.30	115.58 l ± 0.03	40.82 i ± 0.01	43.90 d ± 0.04
Oil blends (v/v)									
CO:WO (20:80)	64.41 a ± 0.37	0.34 a ± 0.01	25.00 b ± 0.46	178.40 d ± 3.51	505.23 n ± 1.58	226.62 e ± 2.76	107.72 k ± 0.03	17.87 d ± 0.35	73.18 j ± 0.43
CO:WO (30:70)	65.46 ab ± 0.16	0.33 a ± 0.03	26.32 c ± 0.05	169.35 c ± 1.69	463.65 m ± 1.48	272.13 h ± 1.21	99.36 i ± 0.12	16.97 c ± 0.17	73.58 j ± 0.27
CO:WO (40:60)	67.01 b ± 1.08	0.40 a ± 0.03	27.48 d ± 0.30	160.07 b ± 1.33	422.18 j ± 0.97	319.18 i ± 1.78	91.01 g ± 0.05	16.05 b ± 0.14	74.13 k ± 0.27
CO:AO (20:80)	70.60 c ± 1.73	2.45 c ± 0.08	29.23 e ± 0.32	544.93 l ± 3.22	226.23 c ± 0.69	126.57 bc ± 0.44	90.27 f ± 0.16	54.74 l ± 0.32	35.28 b ± 0.11
CO:AO (30:70)	71.99 cd ± 0.36	2.24 c ± 0.02	30.33 f ± 0.09	485.64 k ± 0.42	222.44 b ± 0.08	185.04 d ± 0.01	84.23 c ± 0.05	48.79 k ± 0.04	40.75 c ± 0.01
CO:AO (40:60)	72.68 d ± 0.34	1.60 b ± 0.91	31.12 f ± 0.04	427.34 j ± 0.11	220.47 b ± 1.37	245.54 f ± 1.76	78.57 b ± 0.14	42.89 j ± 0.10	46.60 e ± 0.31
CO:VSO (20:80)	91.06 h ± 0.77	0.56 a ± 0.01	45.70 j ± 0.12	338.90 h ± 0.69	390.44 i ± 0.23	126.53 bc ± 0.05	101.35 j ± 0.02	33.95 h ± 0.07	51.70 f ± 0.03
CO:VSO (30:70)	88.62 fg ± 0.95	0.46 a ± 0.18	43.88 i ± 0.43	307.95 g ± 0.37	367.09 g ± 0.03	186.51 d ± 0.15	94.32 h ± 0.02	30.84 g ± 0.02	55.33 g ± 0.01
CO:VSO (40:60)	86.45 e ± 0.36	0.51 a ± 0.02	42.69 h ± 0.19	276.01 f ± 1.37	342.50 f ± 0.23	246.38 f ± 1.03	86.99 e ± 0.16	27.65 f ± 0.13	58.89 h ± 0.08
CO:RSO (20:80)	96.37 i ± 0.95	0.67 a ± 0.04	45.89 j ± 0.83	341.96 h ± 0.46	387.05 h ± 1.05	125.88 b ± 0.47	101.02 j ± 0.28	34.26 h ± 0.05	51.29 f ± 0.23
CO:RSO (30:70)	89.92 gh ± 0.14	0.52 a ± 0.04	43.90 i ± 0.34	308.26 g ± 2.64	364.80 g ± 1.27	187.78 d ± 3.80	93.94 h ± 0.36	30.88 g ± 0.26	55.26 g ± 0.25
CO:RSO (40:60)	87.19 ef ± 0.38	0.54 a ± 0.03	42.39 h ± 0.25	274.04 f ± 0.88	339.66 e ± 1.02	250.77 g ± 2.12	86.30 d ± 0.26	27.46 f ± 0.08	59.04 h ± 0.11

FAC, fatty acid content (mg/g oil); I_2V, iodine value; MUFA, monounsaturated fatty acid (%); PUFA, polyunsaturated fatty acid (%).
[a]Palmitic acid. [b]Palmitoleic acid. [c]Stearic acid. [d]Oleic acid. [e]Linoleic acid. [f]α-Linolenic acid.
Mean values were the averages of three independent measurements. Values in each column with different letters present, significant differences ($P \leq 0.05$) among oil samples.

Table 3–Natural antioxidant contents and antioxidant capacity of walnut (WO), almond (AO), sesame (virgin [VSO] and roasted [RSO]), chia (CO) oils, and their blends.

Oils	TTC	TLC	IC_{50}	α-Tocopherol	β-Tocopherol	γ-Tocopherol	δ-Tocopherol
CO	345.08 b ± 3.24		560.33 i ± 6.87	Tr	ND	330.00 e ± 2.83	14.00 f ± 1.82
WO	404.93 e ± 4.08		638.36 k ± 2.29	39.00 d ± 1.41	ND	350.90 g ± 2.05	12.50 ef ± 2.05
AO	544.42 j ± 4.11		411.48 a ± 3.29	539.50 h ± 0.71	ND	4.20 a ± 0.14	ND
VSO	437.17 f ± 6.19	10.19 c ± 0.08	524.59 g ± 1.46	ND	ND	430.00 k ± 2.82	6.50 bcd ± 0.77
RSO	325.99 a ± 0.12	9.53 c ± 1.15	475.36 d ± 0.78	ND	ND	325.60 e ± 0.18	ND
Oil blends (v/v)							
CO:WO (20:80)	386.61 c ± 2.28		599.22 j ± 3.16	30.00 c ± 2.21	ND	343.60 fg ± 2.20	12.80 ef ± 1.18
CO:WO (30:70)	396.23 d ± 4.52		566.56 i ± 4.87	28.00 b ± 0.98	ND	341.40 f ± 2.28	12.00 ef ± 1.31
CO:WO (40:60)	382.51 c ± 4.64		674.20 l ± 5.34	24.00 a ± 0.85	ND	339.20 f ± 2.36	13.10 f ± 1.59
CO:AO (20:80)	516.09 l ± 6.11		414.14 a ± 8.25	432.00 g ± 0.56	ND	68.56 b ± 0.45	2.40 a ± 0.56
CO:AO (30:70)	493.11 h ± 6.91		436.34 b ± 1.46	377.30 f ± 0.49	ND	111.80 c ± 0.75	4.80 ab ± 0.84
CO:AO (40:60)	449.78 g ± 5.43		449.54 c ± 2.51	321.40 e ± 0.44	ND	122.92 ± d 1.13	5.60 abc ± 0.13
CO:VSO (20:80)	410.77 e ± 5.58	6.22 a ± 0.13	487.85 e ± 0.56	ND	ND	401.60 j ± 2.83	8.40 cd ± 0.26
CO:VSO (30:70)	416.29 e ± 1.53	6.99 ab ± 0.23	500.53 f ± 5.13	ND	ND	397.40 i ± 2.82	8.70 cd ± 1.62
CO:VSO (40:60)	411.66 e ± 5.11	6.43 ab ± 0.11	518.54 g ± 2.10	ND	ND	387.20 h ± 2.88	9.80 de ± 0.98
CO:RSO (20:80)	331.97 a ± 4.16	6.55 ab ± 0.04	520.22 g ± 3.94	ND	ND	323.80 e ± 3.11	2.40 a ± 0.56
CO:RSO (30:70)	333.38 a ± 2.34	7.35 b ± 0.06	549.09 h ± 10.13	ND	ND	326.05 e ± 3.27	4.20 ab ± 0.84
CO:RSO (40:60)	350.61 b ± 3.14	7.17 ab ± 0.35	684.67 m ± 3.39	ND	ND	344.20 f ± 3.04	5.40 abc ± 0.13

TTC, total tocopherol content (mg/kg oil); TLC, total lignan content (g/kg oil); IC_{50}, radical-scavenging activity (mg oil/mg DPPH); Tr, trace; ND, not detected.
Mean values were the averages of three independent measurements. Values in each column with different letters, present significant differences ($P \leq 0.05$) among oil samples.

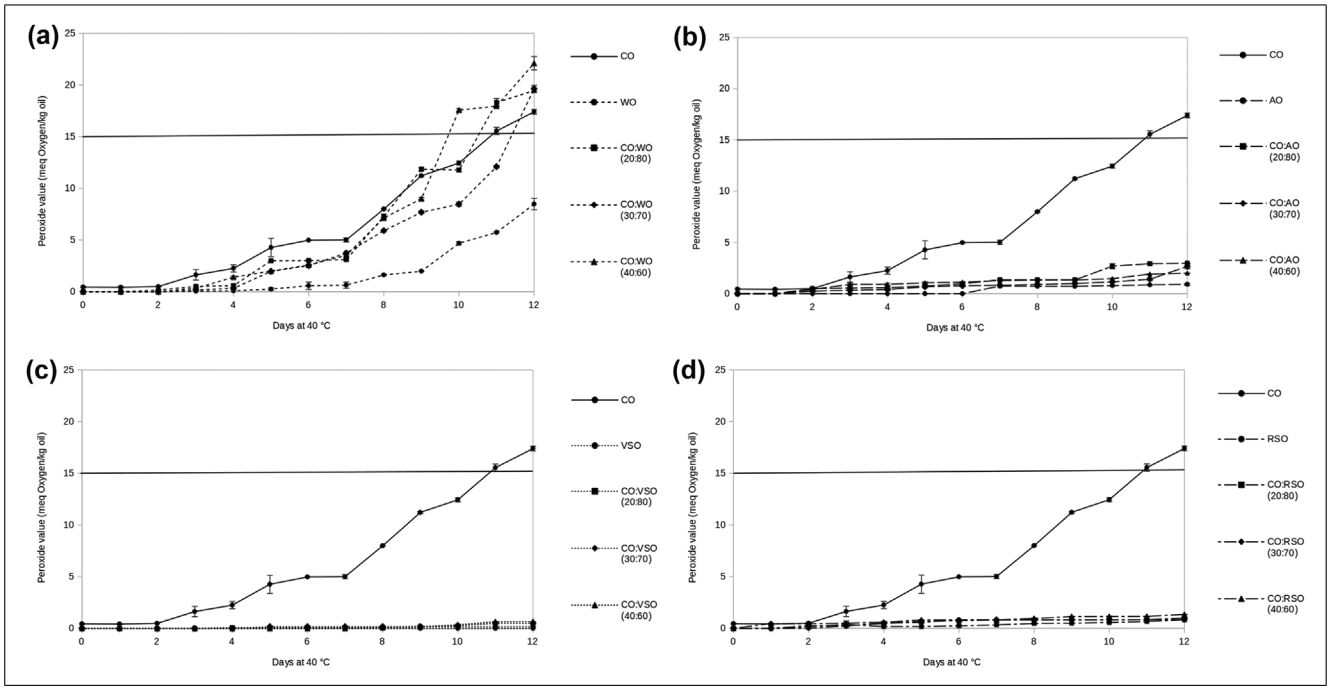

Figure 1–Kinetic curve of peroxide accumulation during oxidation of CO, WO, AO, VSO, RSO, and their blends in the Schaal oven test. Plotted values are means of three independent determinations ± standard deviation. CO: (a), (b), (c), and (d). WO and CO: WO blends: (a). AO and CO:AO blends: (b). VSO and CO:VSO blends: (c). RSO and CO:RSO blends: (d).

WO, 20:80, 30:70, 40:60 (CO:WO) showed similar oxidative deterioration patterns, whereas the pure WO revealed the highest stability. Those treatments exceeded 10 meq O_2/kg oil between days 9 and 11, reaching final PV values of 17.75, 19.46, 19.63, and 22.10 meq O_2/kg oil, respectively (Figure 1a). The results show that the incorporation of CO to WO in the studied proportions significantly increased ($P \leq 0.05$) the production of primary oxidation compounds after the fourth day of the SOT. The low oxidative stability associated with these treatments is consistent with its FAC, which dictates the oxidation rates. In this regard, at 100 °C, the relative oxidation rates of stearic (C18:0), oleic (C18:1), linoleic (C18:2), and linolenic (C18:3) acids are 1:100:1000/1500:2000/3500, respectively (Frankel, 2005). After 12 days of storage at 40 °C, WO did not reach the induction period (the time needed for the PV of the sample to reach 10 meq O_2/kg oil). This sample presented a higher oxidative stability, 8.47 meq O_2/kg oil, even after 12 days of storage. Nevertheless, AO, VSO, and RSO, and their respective blends, showed a low generation of primary oxidation products. The final PV values for these treatments were (Figure 1b to d) lower than 3 meq

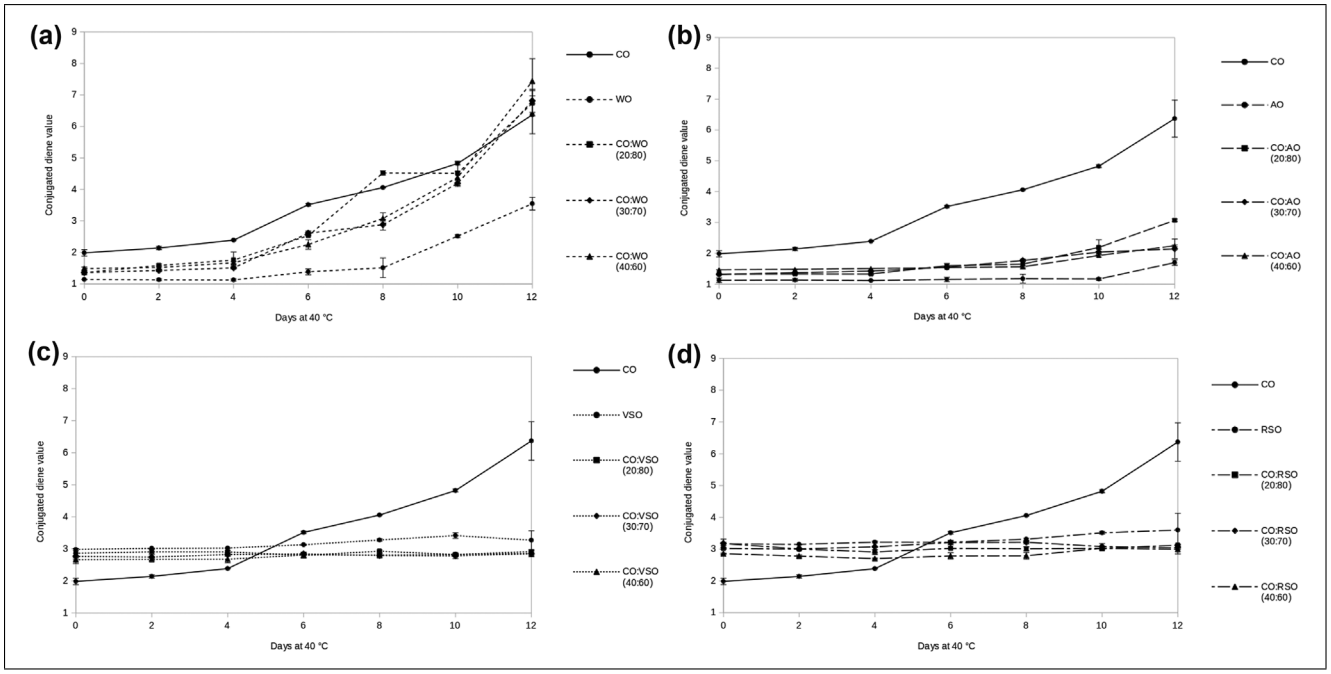

Figure 2–Kinetic curve of conjugated diene values during oxidation of CO, WO, AO, VSO, RSO, and their blends in the Schaal oven test. CO: (a), (b), (c), and (d). WO and CO: WO blends: (a). AO and CO:AO blends: (b). VSO and CO:VSO blends: (c). RSO and CO:RSO blends: (d). Plotted values are means of three independent determinations ± standard deviation.

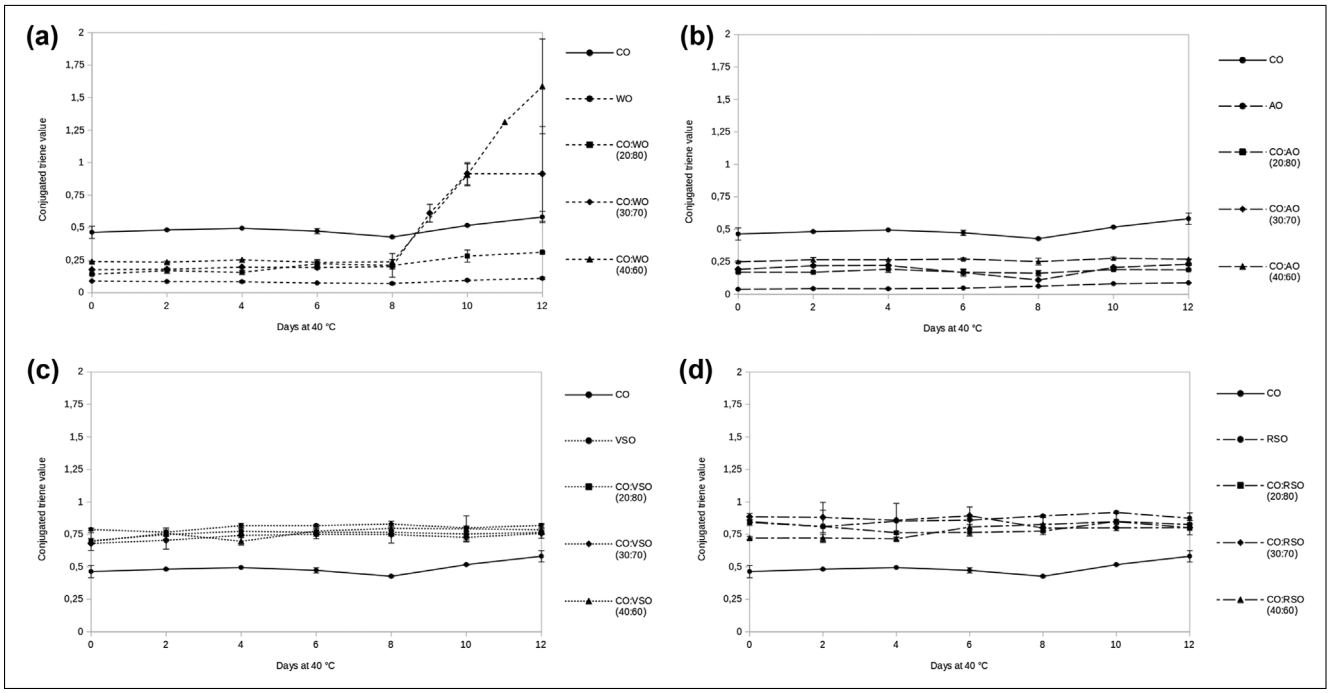

Figure 3–Kinetic curve of conjugated triene values during oxidation of CO, WO, AO, VSO, RSO, and their blends in the Schaal oven test. CO: (a), (b), (c), and (d). WO and CO: WO blends: (a). AO and CO:AO blends: (b). VSO and CO:VSO blends: (c). RSO and CO:RSO blends: (d). Plotted values are means of three independent determinations ± standard deviation.

O_2/kg oil throughout the entire SOT, in agreement with Codex standards. Prescha, Grajzer, Dedyk, and Grajeta (2014) reported up to 4.13 meq O_2/kg in oil samples stored for 12 months, at 20 °C, in a 12:12 hr light/dark storage study. However, the oxidative stability of pure WO, AO, VSO, and RSO significantly decreased with CO incorporation ($P \leq 0.05$). CO:AO ([20:80], [30:70], [40:60]) and CO:VSO ([30:70] and [40:60]) blends presented a significant PV increase after the second and tenth day of the SOT. It is important to emphasize that the CO:SVO (20:80) sample did not show statistically significant differences when compared to VSO during storage ($P \leq 0.05$). In addition, the CO:RSO (20:80) sample presented the longest induction time of all the studied blends; however, in relation to the CO:SVO (20:80) sample, it developed a higher PV throughout

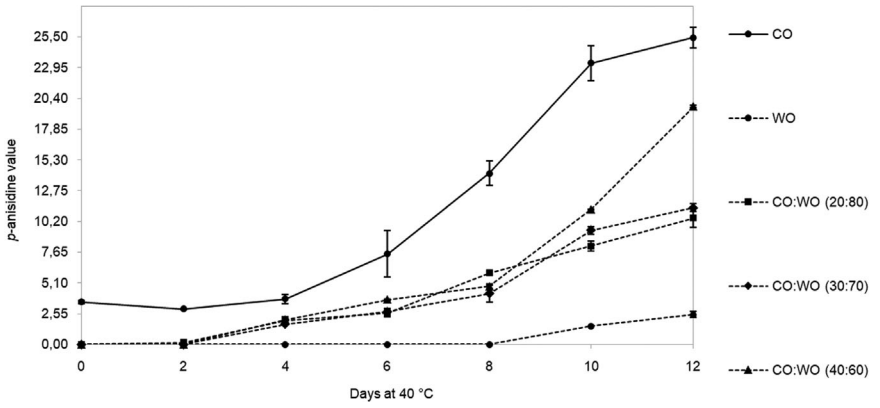

Figure 4–Kinetic curve of *p*-anisidine values during oxidation of CO, WO, and their blends in the Schaal oven test. Plotted values are means of three independent determinations ± standard deviation.

the entire SOT (Figure 1c and d). This is due to the fact that during the heat treatment of the seeds, prior to the oil extraction, primary oxidation compounds and various volatile substances are generated (aldehydes, ketones, alcohols, pyrazines, furans, and pyrroles) (Li et al., 2014). Even so, the greater oxidative stability of CO:RSO blends could be explained by the synergistic action between sesamol, tocopherols, and melanoidins, as stated above. Finally, the CO:RSO (40:60) blend showed a significantly lower oxidative stability than pure RSO after day 2 ($P \leq 0.05$); meanwhile, 30:70 and 20:80 mixtures showed a similar PV evolution during the SOT ($P \leq 0.05$).

In each treatment, the plotted curve for peroxide accumulation approximately coincided with that of CD and CT, indicating that the formation of lipid hydroperoxides and that of conjugated double and triple bond fatty acids matches (Figures 1 to 3).

Figure 4 presents the changes in the level of PAV in CO, WO, and their blends during 12 days of storage under oxidation conditions. In these samples, PAVs rose with the length of storage period. The PAV of CO was in a range of 3.49 to 25.43. The results show that the incorporation of CO to WO in the studied proportions significantly promoted the generation of secondary oxidation compounds (WO, 0 to 2.45 and CO:WO [20:80], 0 to 10.45; [30:70], 0 to 11.31; [40:60], 0 to 19.71) ($P \leq 0.05$). The rest of the samples, in agreement with the oxidative stability, presented no significant increment in the production of secondary compounds (data not shown). Choe and Min (2007) reported that the incorporations of sesame oil to soybean oil at 10% and 20% (v/v) seem to be successful in reducing the formation of *p*-anisidine-reactive substances up to a certain degree.

In accordance with the trends observed in primary and secondary oxidation parameters during SOT, the oxidation rate apparent constants (*K*) (Table 1) of the blends were dramatically reduced in relation to pure CO, excluding the blends with WO ($K = 1.461$ meq O_2/((kg oil)* (day)), $R^2 = 0.919$; $K = 1.660$ meq O_2/((kg oil)* (day)), $R^2 = 0.923$; $K = 1.685$ meq O_2/((kg oil)* (day)), $R^2 = 0.970$; $K = 2.254$ meq O_2/((kg oil)* (day)), $R^2 = 0.893$) for CO, CO:WO (20:80), CO:WO (30:70), CO:WO (40:60), respectively. The rest of the mixtures presented apparent constant values between 0.018 meq O_2/((kg oil)* (day)), $R^2 = 0.927$ (C0: SVO (20:80)) and 0.153 meq O_2/((kg oil)* (day)), $R^2 = 0.951$ (CO:AO (30:70)).

Regarding the evolution of FFAC, no statistically significant differences were observed in any of the treatments between the initial time and 12 days of storage ($P \leq 0.05$). This indicates that both, pure oils and their blends, are stable against the hydrolytic degradation of glycerides even under thermooxidation conditions (Table 1). A similar trend was reported by Shiela, Sreerama, and Gopala Krishna (2004) who observed that FFAC of pure and blended groundnut, sunflower seed, mustard seed, palm olein, rice bran, and sesame oils did not increase appreciably during the 6 month of storage, at 27 and 40 °C, compared with their initial values.

Table 4–"Difference from control test" results for chia seed oil blends, including blind control samples.

Oil samples (v/v)	"How different from pure oil"
CO:WO (0:100)	0.34 a ± 0.17
CO:WO (20:80)	1.28 b ± 0.99
CO:WO (30:70)	1.45 b ± 1.19
CO:WO (40:60)	1.31 b ± 1.15
CO:AO (0:100)	0.00 a ± 0.00
CO:AO (20:80)	2.10 b ± 1.15
CO:AO (30:70)	2.17 b ± 0.98
CO:AO (40:60)	2.00 b ± 1.13
CO:VSO (0:100)	0.10 a ± 0.05
CO:VSO (20:80)	1.30 b ± 0.95
CO:VSO (30:70)	0.89 b ± 0.75
CO:VSO (40:60)	1.30 b ± 0.97
CO:RSO (0:100)	0.14 a ± 0.02
CO:RSO (20:80)	1.30 b ± 1.03
CO:RSO (30:70)	1.48 b ± 0.94
CO:RSO (40:60)	1.67 b ± 0.90

Mean values were the averages of 40 independent measurements. Values in each group of oils with different letters present significant differences ($P \leq 0.05$) according to the LSD Fisher test. Scale correspondence: "0" (no difference), "1" (little difference), "2" (moderate difference), "3" (large difference), and "4" (very large difference).

Sensory evaluation

In order to find sensory differences or similarities among blends and the control sample, a sensory analysis was carried out. The ANOVA showed that the judges perceived a statistically significant difference among the blends and their respective pure oils ($P \leq 0.05$). The differences ranged from little (walnut, VSO, and RSO) to moderate (almond oil). However, for a given pure oil, judges did not perceive statistically significant differences among its blends ($P \geq 0.05$) (Table 4).

The slight differences found for CO:WO, CO:VSO, and CO:RSO blends compared with pure WO, VSO, and RSO oils, respectively, may be attributed to the sensory profile of the pure oils. Fresh WO is mainly characterized by high-intensity ratings of nutty and oily film, and lesser ratings for pungent and astringent attributes (Martínez et al., 2011). Sesame oil has a pleasant

taste and a strong characteristic flavor of sesame seed, which are intensified after roasting (Yoshida & Takagi, 1997). Roasting of the seeds represents a key operation for the development of desirable color and flavor, as well as for the enhancement of the oxidative stability, as explained above (Wan et al., 2015). Yoshida and Takagi (1997) reported that roasting temperatures higher than 220 °C yielded poor-quality RSO with burnt and bitter tastes, and dark-brownish color. Therefore, according to the authors, roasting temperatures should be below 200 °C to obtain optimum flavor scores. Finally, when specialty oils with such intense attributes are mixed with chia seed oil, the perception of this latter oil is little.

On the other hand, AO is characterized by a very low-intensity sour and bitter basic taste attributes typical of almond nuts (Civille, Lapsley, Huang, Yada, & Seltsam, 2010). Hence, these low-intensity sensory attributes yielded moderate differences among CO:AO blends and pure AO, and not minor ones.

Conclusions

According to the above results, vegetable oil blending is a physical, economical, and simple procedure to change FAC, to increase bioactive components and natural antioxidants, and to make products with specific properties. More precisely, the development of chia oil blends with other specialty oils offers an opportunity to obtain lipid matrices rich in ω-3 fatty acids, and with greater oxidative stability indices than pure chia oil. An SOT was performed to evaluate the oxidative stability of the parent oils and blends, and to compare different oil-blending formulations. The same trends were observed with SOT and Rancimat analysis: sesame oil blends (both virgin and roasted) were the most stable, followed by CO:AO blends; CO:WO blends were the least stable. The final PV values for these latter blends were above Codex standards (15 meq O_2/kg oil) for cold-pressed and virgin oils, whereas for CO:AO, CO:VSO, and CO:RSO blends, PV values were below 3 meq O_2/kg by the end of the SOT. Despite the initial FFAC for VSO and CO:VSO blends (above 4,0 mg KOH/g oil), the generation of primary and secondary oxidation products was the lowest throughout the thermo-oxidation test, which could be attributed to a synergistic effect between total tocopherols and lignans present in the oil. Nonenzymatic browning reactions during roasting of sesame seeds yield melanoidins, which may contribute to the high oxidative stability of RSO and CO:RSO observed in this study by a synergistic action with sesamol and tocopherols.

The perception of chia oil in the final blends ranged from little (CO:WO, CO:VSO, and CO:RSO blends) to moderate (CO:AO blends), according to the sensory evaluation results, which means that new distinct products may be formulated.

Further research is needed to establish the actual shelf-life of the formulated blends under static conditions (found in retail markets) and dynamic conditions (where the head-space volume increases over time). In summary, the formulation of chia oil blends represents a novel alternative for the food industry, which is currently interested in nonconventional oils and in offering new food products to improve health and human nutrition.

Acknowledgments

This research was financed with grants from Consejo de Investigaciones Científicas y Técnicas (CONICET), Secretaría de Ciencia y Tecnología de la Univ. Nacional de Córdoba (SeCyT-UNC), and Fondo para la Investigación Científica y Tecnológica (FONCyT, BID PICT 2014-2283) from Argentina. The authors also acknowledge the Iberoamerican Project CYTED 119RT0567.

Author Contributions

M.G. Bordón designed and performed the experiments, which are part of her Ph.D. thesis, analyzed the data, and drafted the manuscript. S.P. Meriles helped perform the experiments and analyze data. P.D. Ribotta and M.L. Martínez conceived and designed the experiments, provided materials and analysis tools, and drafted the manuscript as Ph.D. thesis advisors.

References

AOCS. (2009). *Official methods and recommended practices of the American Oil Chemists' Society* (5th ed.). Champaign, IL: AOCS Press.

Bhatnagar, A., Hemavathy, J., & Krishna, A. (2015). Development of a rapid method for determination of lignans content in sesame oil. *Journal of Food Science and Technology*, *52*, 521–527.

Bhatnagar, A., Prasanth Kuma, P., Hemavathy, J., & Gopala Krishna, A. (2009). Fatty acid composition, oxidative stability, and radical scavenging activity of vegetable oil blends with coconut oil. *Journal of the American Oil Chemists' Society*, *86*, 991–999.

Bhattacharya, K. (2006). Specialty oils and their applications in food. In F. D. Gunstone (Ed.), *Modifying lipids for use in food* (pp. 539–566). Cambridge, England: CRC Press.

Bodoira, R., Penci, M., Ribotta, P., & Martínez, M. (2017). Chia (*Salvia hispanica* L.) oil stability: Study of the effect of natural antioxidants. *LWT – Food Science and Technology*, *75*, 107–113.

Cabiscol, E., Tamarit, J., & Ros, J. (2000). Oxidative stress in bacteria and protein damage by reactive oxygen species. *International Microbiology*, *3*, 3–8.

Caruso, M. C., Favati, F., Di Cairano, M., Galgano, F., Labella, R., Scarpa, T., & Condelli, N. (2018). Shelf-life evaluation and nutraceutical properties of chia seeds from a recent long-day flowering genotype cultivated in Mediterranean area. *LWT – Food Science and Technology*, *87*, 400–405.

Choe, E., & Min, D. (2007). Chemistry of deep fat frying oils. *Journal of Food Science*, *72*, 77–86.

Choudhary, M., Grover, K., & Kaur, G. (2015). Development of rice bran oil blends for quality improvement. *Food Chemistry*, *173*, 770–777.

Civille, G. V., Lapsley, K., Huang, G., Yada, S., & Seltsam, J. (2010). Development of an almond lexicon to assess the sensory properties of almond varieties. *Journal of Sensory Studies*, *25*, 146–162.

Codex Alimentarius. (2001). *Fats, oils and related products* (2nd ed.). Rome, Italy: FAO/WHO Food Standards Programme.

Delgado-Andrade, C., Rufián-Henares, J., & Morales, F. (2005). Assessing the antioxidant activity of melanoidins from coffee brews by different antioxidant methods. *Journal of Agricultural and Food Chemistry*, *53*(20), 7832–7836.

Farag, R., El-Agamy, M., & Abd El Hakeem, B. (2010). Effects of mixing canola and palm oils with sunflower oil on the formation of trans fatty acids during frying. *Food and Nutrition Sciences*, *1*, 24–29.

Fasina, O. O., Craig-Schmidt, M., Colley, Z., & Hallman, H. (2008). Predicting melting characteristics of vegetable oils form fatty acid composition. *LWT – Food Science and Technology*, *41*, 1501–1505.

Frankel, E. N. (2005). Hydroperoxide formation. In Barnes & Associates (Eds.), *Lipid oxidation* (pp. 25–46). Bridgwater, England: The Oily Press.

Guiotto, E., Ixtaina, V., Nolasco, S., & Tomás, M. (2014). Effect on storage conditions and antioxidants on the oxidative stability of sunflower-chia oil blends. *Journal of the American Oil Chemists' Society*, *91*, 767–776.

Hashempour-Baltork, F., Torbati, M., Azadmard-Damirchi, S., & Savage, G. P. (2016). Vegetable oil blending: A review of physicochemical, nutritional and health effects. *Trends in Food Science & Technology*, *57*, 52–58.

Imran, M., Nadeem, M., Manzoor, M. F., Javed, A., Ali, Z., Nadeem Akhtar, M., . . . Hussain, Y. (2016). Fatty acids characterization, oxidative perspectives and consumer acceptability of oil extracted from pre-treated chia (*Salvia hispanica* L.) seeds. *Lipids in Health and Disease*, *15*, 162.

Kochhar, S. P. (2002). Sesame, rice-bran and flaxseed oils. In F. D. Gunstone (Ed.), *Vegetable oils in food technology* (pp. 297–326). Oxford, UK: Blackwell Publishing, CRC Press.

Li, H., Fan, Y., Li, J., Tang, L., Hu, J., & Deng, Z. (2013). Evaluating and predicting the oxidative stability of vegetable oils with different fatty acid compositions. *Journal of Food Science*, *78*(4), 633–641.

Li, Y., Ma, W.-J., Qi, B.-K., Rokayya, S., Li, D., Wang, J., . . . Jiang, L.-Z. (2014). Blending of soybean oil with selected vegetable oils: Impact on oxidative stability and radical scavenging activity. *Asian Pacific Journal of Cancer Prevention*, *15*, 2583–2589.

Martínez, M., Barrionuevo, G., Nepote, V., Grosso, N., & Maestri, D. (2011). Sensory characterization and oxidative stability of walnut oil. *International Journal of Food Science & Technology*, *46*, 1276–1281.

Martínez, M., Bordón, M., Lallana, R., Ribotta, P., & Maestri, D. (2017b). Optimization of sesame oil extraction by screw-pressing at low temperature. *Food and Bioprocess Technology*, *10*(6), 1113–1121.

Martínez, M., Labuckas, D., Lamarque, A., & Maestri, D. (2010). Walnut (*Juglans regia* L.): Genetic resources, chemistry, by-products. *Journal of the Science of Food and Agriculture*, *90*, 1959–1967.

Martínez, M., & Maestri, D. (2008). Oil chemical variation in walnut (*Juglans regia* L.) genotypes grown in Argentina. *European Journal of Lipid Science and Technology*, *110*, 1183–1189.

Martínez, M., & Maestri, D. (2015). Aceites no tradicionales. In *Aceites vegetales no tradicionales: Guía para la producción y evaluación de la calidad* (1st ed.). Córdoba, Argentina: Encuentro Grupo Editor.

Martínez, M., Marín, M., Salgado Faller, C., Revol, J., Penci, M., & Ribotta, P. (2012). Chia (*Salvia hispanica* L.) oil extraction: Study of processing parameters. *LWT – Food Science and Technology*, *47*(1), 78–82.

Martínez, M., Mattea, M., & Maestri, D. (2008). Pressing and supercritical carbon dioxide extraction of walnut oil. *Journal of Food Engineering*, *88*, 399–404.

Martínez, M., Penci, M., Marín, M., Ribotta, P., & Maestri, D. (2013). Screw press extraction of almond (*Prunus dulcis* (Miller) D.A. Webb): Oil recovery and oxidative stability. *Journal of Food Engineering*, *119*, 40–45.

Martínez, M. L., Bordón, M. G., Bodoira, R. M., Penci, M. C., Ribotta, P. D., & Maestri, D. M. (2017a). Walnut and almond oil screw-press extraction at industrial scale: Effects of process parameters on oil yield and quality. *Grasas y Aceites*, *68*(4). https://doi.org/10.3989/gya.0554171

Meilgaard, M., Civille, G., & Carr, T. (1991). *Sensory evaluation techniques* (2nd ed., pp. 81–82). Boca Raton, FL: CRC Press Inc.

Mohdaly, A. A. A., Sarhan, M. A., Mahmoud, A., Ramadan, M. F., & Smetanska, I. (2010). Antioxidant efficacy of potato peels and sugar beet pulp extracts in vegetable oils protection. *Food Chemistry*, *123*(4), 1019–1026.

Naghshineh, M., Ariffin, A., Ghazali, H., Mirhosseini, H., & Mohammad, A. (2010). Effect of saturated/unsaturated fatty acid ratio on physicochemical properties of palm olein-olive oil blend. *Journal of the American Oil Chemists' Society*, *87*, 255–262.

Oliveira, R., Rodríguez, M. F., & Bernardo-Gil, M. A. (2002). Characterization and supercritical carbon dioxide extraction of walnut oil. *Journal of the American Oil Chemist's Society*, *79*, 225–230.

Plemmons, L., & Resurreccion, A. (1998). A warm-up sample improves reliability of responses in descriptive analysis. *Journal of Sensory Studies*, *13*, 359–376.

Poudyal, H., Panchal, S., Waanders, J., Ward, L., & Brown, L. (2012). Lipid redistribution by α-linolenic acid-rich chia seed inhibits stearoyl-CoA desaturase-1 and induces cardiac and hepatic protection in diet-induced obese rats. *Journal of Nutritional Biochemistry*, *23*, 153–162.

Prescha, A., Grajzer, M., Dedyk, M., & Grajeta, H. (2014). The antioxidant activity and oxidative stability of cold-pressed oils. *Journal of the American Oil Chemists' Society*, *91*, 1291–1301.

Rangkadilok, N., Pholphana, N., Mahidol, C., Wongyai, W., Saengsooksree, K., Nookabkaew, S., & Satayavivad, J. (2010). Variation of sesamin, sesamolin and tocopherols in sesame (*Sesamum indicum* L.) seeds and oil products in Thailand. *Food Chemistry*, *122*, 724–730.

Rostami, M., Farzaneh, V., Boujmehrani, A., Mohammadi, M., & Bakhshabadi, H. (2014). Optimizing the extraction process of sesame seed's oil using response surface method on the industrial scale. *Industrial Crops and Products*, *58*, 160–165.

Rubilar, M., Morales, E., Contreras, K., Ceballos, C., Acevedo, F., Villarroel, M., & Shene, C. (2012). Development of a soup powder enriched with microencapsulated linseed oil as a source of omega-3 fatty acids. *European Journal of Lipid Science and Technology*, *114*, 423–433.

Shiela, P., Sreerama, Y., & Gopala Krishna, A. (2004). Storage stability evaluation of some packed vegetable oil blend. *Journal of the American Oil Chemists' Society*, *81*, 1125.

Suja, K., Jayalekshmy, A., & Arumughan, C. (2004). Free radical scavenging behavior of antioxidant compounds of sesame (*Sesamum indicum* L.) in DPPH system. *Journal of Agricultural and Food Chemistry*, *52*, 912–915.

Torres, M., Martínez, M., Pierantozzi, P., Albanese, M., Nasjleti, A., & Maestri, D. (2011). Contribution of compositional parameters to the oxidative stability of olive and walnut oil blends. *Journal of the American Oil Chemists' Society*, *88*, 755–762.

Torres, M., Pierantozzi, P., Cáceres, M., Labombarda, P., Fontanazza, G., & Maestri, D. (2009). Genetic and chemical assessment of Arbequina olive cultivar grown in Córdoba province, Argentina. *Journal of the Science of Food and Agriculture*, *89*, 523–530.

Wan, Y., Li, H., Fu, G., Chen, X., Chen, F., & Xie, M. (2015). The relationship of antioxidant components and antioxidant activity of sesame seed oil. *Journal of the Science of Food and Agriculture*, *95*, 2571–2578.

Wong, M., Timms, R., & Goh, E. (1988). Colorimetric determination of total tocopherols in palm oil, olein and stearin. *Journal of the American Oil Chemists' Society*, *65*, 258–261.

Wu, W.-H. (2007). The contents of lignans in commercial sesame oils of Taiwan and their changes during heating. *Food Chemistry*, *104*(1), 341–344.

Yoshida, H., & Takagi, S. (1997). Effects of seed roasting temperature and time on the quality characteristics of sesame (*Sesamum indicum*) oil. *Journal of the Science of Food and Agriculture*, *75*, 19–26.

Zamora, R., & Hidalgo, F. J. (2005). Coordinate contribution of lipid oxidation and Maillard reaction to the non-enzymatic food browning. *Critical Reviews in Food Science and Nutrition*, *45*(1), 49–59.