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A robust stripping method for the removal of minor components from edible oils

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Abstract

Column chromatographic techniques have commonly been used for effective stripping of edible oils from their minor components. However, this method is time consuming, which may lead to oil oxidation. Thus, in the present study, the oils of camelina seed, chia seed, sophia seed, corn, olive, and a docosahexaenoic acid single cell oil (DHASCO) were subjected to a simplified stripping method by using the stationary phase material and examining their minor components such as tocopherols, carotenoids, and chlorophylls as well as their oxidative stability. The results demonstrated that stripped oils prepared by using the simplified stripping method for 2 h were devoid of any tocopherol, chlorophylls and carotenoids and this was as effective as column chromatographic method. Thus, the simplified stripping method provides a facile means of producing stripped oil with better oxidative stability compared to the column chromatographic method.

Keywords: Camelina seed oil, Chia seed oil, Sophia seed oil, Algal oil, Olive oil, Corn oil, Fatty acids, Column stripping, Stripping by silicic acid and charcoal, Stationary phase, Tocopherols, Pigments, Chlorophylls, Carotenoids

Introduction

Fats and oils from different sources are important to human health and the food industry due to their role in providing energy, essential fatty acids, fat-soluble vitamins, and other bioactive compounds (Salas et al. 2000). Edible oils generally consist of 95% triacylglycerols (TAG) with non-triacylglycerols as minor components constituting the other 5%. The latter compounds are primarily composed of mono- and diacylglycerols, free fatty acids, phospholipids, tocopherols, tocotrienols, other phenolic compounds, pigments (chlorophylls, and carotenoids), and sterols (Hamilton 1994; Shahidi and Shukla 1996). The stability of the oils is dictated by their degree of unsaturation, positional distribution of fatty acids in the TAG, the type and content of minor components, as well as storage conditions.

Camelina, chia, and sophia seed oils are important emerging oils that may be used in different food and non-food applications. These seed oils are abundant in oleic (18:1), linoleic (18:2 n-6) and α-linolenic (18:3 n-3) acids and are a rich source of essential polyunsaturated fatty acids (PUFA). The potential health benefits of these oils are expected to lead to their rapid commercial development and use in a variety of products for human consumption, animal feed, and cosmetic applications.

Several chromatographic techniques have been developed and used to remove minor components from the oils and stripped corn oil has been commercially available and used as such for examining the antioxidant potential of different compounds or extracts. To strip the oils from their minor components, one study used a dry column packed with silicic, charcoal, sugar, and celite in order to prepare large amounts of stripped soybean oil (Mistry and Min 1988). The product (stripped oil) was odorless, colorless, tasteless and free from minor components such as tocopherols, carotenoids, phospholipids, free fatty acids, as well as mono- and diacylglycerols. However, this technique was not always effective. When used for stripping of rapeseed oil, Lampi et al. (1992) found that the stripped oil still contained about 60% γ-tocopherol and up to 35% α-tocopherol. Khan and Shahidi (2000) later improved this technique by using a column packed with silicic acid and activated charcoal as the middle layer; the oil sample, dissolved in the same amount of hexane, was passed through the column while applying a slight vacuum in order to hasten the process and minimize oil oxidation. This technique improved

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the removal of minor components from evening primrose, hemp, flax, soybean and olive oils (Lampi et al. 1992; Khan and Shahidi 2001; Abuzaytoun and Shahidi 2006b). Another study used this technique to strip soybean oil by using a column chromatographic separation process, but with a lesser amount of the two layers of silicic acid (22.5 g) and activated charcoal (5.625 g), and by employing hexane as eluent (Tian et al. 2013). Li et al. (2016) further improved this technique with a minor change by using 45 g of activated silicic acid, followed by 45 g of charcoal and another 45 g of activated silicic acid to strip blackberry, black raspberry, and blueberry seed oils. The results proved that stripped seed oils so obtained were devoid of any tocopherol or tocotrienol, therefore confirming that this method was quite effective in removing minor components from the tested oils. However, this column packing chromatographic technique is very time consuming and laborious. Packing the column itself can be tricky but also collecting the resultant purified oils is a real challenge in terms of being time-consuming and may also lead to oil oxidation. Generally, collecting stripped oil from column takes up to12 hours and this does not include procedure of packing the column. Thus, a novel simplified method was proposed to improve the limitation of column chromatographic technique. The stationary materials (silicic acid and charcoal) and oil can be mixed in hexane and allowed to stand for a set period of time. Subsequently, the stationary phase material can be removed by suction filtration. In this way, the processing time of stripping procedure can be reduced significantly. In order to examine the new method, comparison between the newly proposed simplified stripping method was tested by using stationary phase material for 1 h, 2 h, and 1 h twice. To the best of our knowledge, this is the first time to report on a new and simplified stripping method and comparing the results with those from the commonly used column stripping method. The efficiency of removal of minor components and their effect on oxidative stability were also examined in this study. For this, three seed oils (camelina, chia, and sophia) were first used and then tested with 3 other oils from different origins and minor components. In addition, commonly used cooking oil (corn oil; sold and used also as a stripped oil for stability testing studies), oils containing a high amount of pigment such as olive oil and docosahexaenoic acid single cell oil (DHASCO) were also employed.

Materials and methods

Materials

The samples of camelina (*Camelina sativa*) seeds were obtained from Professor C. Parrish, Memorial University, St. John's, NL, Canada. Chia seeds (*Salvia hispanica*) used in this work were bought from Costco Wholesale, St. John's, NL, Canada. Meanwhile, Sophia seeds were a product of Daghdaghabad, near Hamedan city in Iran, and purchased from the Tavazo store in Toronto, ON, Canada. Corn oil (Great Value) and olive oil (Gallo) were bought from Walmart, St. John's, NL, Canada. DHA single cell oil (DHASCO) containing 40% DHA was obtained from DSM (Columbia, MD, USA). The compounds 2-thiobarbituric acid, silicic acid powder (mesh size: 100–200, acid-wash), activated charcoal, and standards of tocopherols were purchased from Sigma-Aldrich (Mississauga, ON, Canada). Compressed air was from Canadian Liquid Air Ltd. (St. John's, NL, Canada). Methanol, hexane, acetonitrile, ethanol, sulphuric acid, isopropanol, isooctane, 1-butanol and all other chemicals were obtained from Fisher Scientific Co. (Nepean, ON, Canada), and were used without any further purification. All solvents were of ACS grade or better, unless otherwise specified. Some of the oils used were extracted from the seeds as their oils are not yet commercially available.

Fat extraction with hexane

The oils from crushed camelina, chia, and sophia seeds were extracted according to the method described by Miraliakbari and Shahidi (2008) with minor modifications. Fifty grams of seed sample were ground into powder, then combined with 250 mL of hexanes, followed by homogenization using a blender (Waring Blender model 51BL30, Waring commercial, Phoenix, AZ, USA) for 2 min. The resultant mixture was filtered twice through a Whatman number 1 filter paper with a Buchner funnel. The residue was re-extracted five times, and the extracts were combined and the solvent removed using a rotary evaporator at 40 °C. The resultant oil was weighed, flushed with nitrogen and stored at − 80 °C until use. The procedure was repeated, if needed, to obtain a sufficient amount of oil for experimentation.

Removal of minor components using column chromatography

The seed oils from the camelina, chia, and sophia were stripped of their minor constituents according to Abuzaytoun and Shahidi (2006) using a 40 cm long chromatographic column with an internal diameter of 3.4 cm. The chromatographic column was filled consecutively with 45 g of activated silicic acid, then 45 g of charcoal, and finally 45 g of activated silicic acid. It is crucial to point out that 100 g of silicic acid was activated by washing three times using a total of 3 L of distilled water after each treatment, the silicic acid was allowed to settle for an average of 30 min, after that the liquid was discarded. Finally, the silicic acid was washed with methanol and the supernatant discarded.

An estimated 60 mL of hexane was used to dilute 60 g of oil. The mixture was then passed through the chromatographic column followed by introduction of

an additional 200 mL of hexane. The solvent from the stripped oil eluate was removed under vacuum at 50 °C. Traces of solvents were then removed by nitrogen flushing. Afterwards, the column stripped oils were flushed with nitrogen and stored at −80 °C for up to one month before use.

Removal of minor components using stationary phase material

All stripped oils were also prepared according to a simplified stripping method (using stationary phase material). The oil (60 g), mixed with hexane (60 mL), was stirred with activated silicic acid (90 g) and charcoal (45 g) for1 h, 2 h, and for 1 h twice under nitrogen (atmosphere). This operation was carried out in a fume hood at 27.5 °C, followed by suction filtration. In addition, 200 mL of hexane were used to wash the material during filtration. The solvent was removed using a rotary evaporator at 40 °C, followed by nitrogen flushing; stripped oils were then stored at -80 °C prior to use.

Determination of tocopherols

To determine the content of tocopherols in camelina, chia, and sophia seed oils, the oil samples were prepared by dissolving 0.1 g of oil in 2 mL of methanol/acetonitrile/isopropanol (41:59:300, v/v/v). Tocopherol standards were prepared by dissolving a known amount of tocopherol mixture that consisted of 4 tocopherols in the same solvent followed by serial dilution. Before the HPLC analysis, the samples, as well as the standards, were filtered by using a 0.45 μm Whatman syringe-filter. Tocopherol contents in the prepared samples and standards were determined by a reversed phase HPLC-MS, using an Agilent 1100 HPLC unit (Agilent Technologies, Palo Alto, CA, USA), equipped with a UV–diode array detector (UV-DAD). Separation was achieved on a C-18 column (4.6 mm × 250 mm coupled to a guard column, Agilent) by gradient elution with methanol/acetonitrile/isopropanol as the mobile phase at a flow rate of 0.8 mL/min; the fractions were detected at 295 nm. The mobile phase was initially methanol/acetonitrile/isopropanol (41:59:0, v/v/v) and maintained there for 15 min followed by gradual change to methanol/acetonitrile/isopropanol (16.5:23.5:60, v/v/v) from 15 to 25 min, and then changed to 100% isopropanol from 25 to 35 min. The mobile phase was changed to its initial setting, methanol/acetonitrile/isopropanol (41:59:0, v/v/v) in 5 min, and then kept there for 10 min. The analyses were performed by using a mass spectrometric detector (LC-MSD-Trap-SL, Agilent, Palo Alto, CA, USA) using positive ion APCI (atmospheric pressure chemical ionization). The operating conditions used were 121 V for the fragments with a drying temperature of 350 °C, APCI temperature of 400 °C, nebulizer pressure of 60 psi, drying gas flow of 7 L/min for each tocopherol standard and sample (50 μL) that was injected. Tocopherols were detected at 295 nm by using a UV detector and identified by comparing their retention times with those of known tocopherol standards. A standard curve was constructed for each tocopherol. Tocopherol concentrations in the samples were calculated using the corresponding standard curves and expressed as mg/kg of oil.

Determination of pigments (chlorophylls and carotenoids)

Measurement of pigments in the non-stripped and stripped oil samples was carried out by following the absorbance at 430–460 nm for carotenoids and 550–710 nm for both chlorophylls and their related products. Hexane (1:1, v/v) was mixed with the oil samples. The mixture was then placed in quartz cuvettes (Abuzaytoun and Shahidi 2006), and the absorbance was read using an 8453A UV-Visible spectrophotometer (Agilent Technologies, Palo Alto, CA, USA) and by recording the absorption spectrum between 430 and 710 nm.

Determination of lipid oxidation

The oxidation of the stripped and non-stripped oils was evaluated by measuring conjugated dienes for primary and thiobarbituric acid reactive substances (TBARS) for secondary oxidation products.

Determination of conjugated dienes

The IUPAC (1987) method was used to determine the content of conjugated dienes of oil samples. An estimated 0.02–0.04 g of oil was weighed and transferred to a 25 mL volumetric flask. The weighted oil samples were then dissolved in isooctane (2,2,4-trimethylpentane). The same solvent (isooctane) was added to the mixture to reach the volume mark.

A Hewlett-Packard 8456A diode array spectrophotometer was used to read the absorbance values at 234 nm using a 10-mm Hellma quartz cell. Pure isooctane was used as the blank. The following equation was used to compute the values of conjugated dienes (CD).

$$CD = A/(Cxd)$$

where C represents the concentration of the solution in grams per 100 mL solution (g/100 mL), while A represents the absorbance of the solution at 234 nm and the length of the cell is represented by d (in cm).

Determination of 2-thiobarbituric acid-reactive substances (TBARS)

The steps outlined by the American Oil Chemists' Society (AOCS 1990) were followed to analyze the oil samples

(0.05–0.20 g) for their contents of TBARS. The oil samples to be tested were accurately weighted and transferred to 25 mL volumetric flasks. A small volume of 1-butanol was used to dissolve the oil samples in volumetric flasks which were then filled to the mark with the same solvent (1-butanol).

A portion of the sample solution (approximately 5.0 mL) was placed into a dry test tube. A 5 mL portion of a solution of 200 mg 2-TBA dissolved in 100 mL 1-butanol was added to the tube containing the sample solution. The above test tubes were then placed in a water bath at 95 °C and allowed to stand for two hours followed by cooling under a stream of cold water. Afterward, a Hewlett-Packard 8452A diode array spectrophotometer was used to read the absorbance of the resultant coloured complex so produced at 532 nm.

Statistical analysis

All experiments were conducted in triplicate. ANOVA, which is a single-way evaluation of variance, together with Tukey's standardized test, were used at $p < 0.05$ by employing Minitab statistical software for the statistical treatment of the data. Both Tukey's standardized test and ANOVA were utilized to evaluate the significance of differences.

Results and discussion

Tocopherols in stripped and non-stripped oils

The concentration of tocopherols in camelina seed oil, chia seed oil, sophia seed oil, corn oil, olive oil, and DHASCO and their stripped counterparts using column stripping and stripping by the stationary phase for 1 h, 2 h, and for 1 h twice are shown in Table 1. The total contents of tocopherols in non-stripped camelina seed oil, chia seed oil, sophia seed oil, corn oil, olive oil, and DHASCO were 1262.54, 341.06, 1150.93, 538.89, 208.28, and 1211.98 mg/kg, respectively. All oils stripped by column and simplified stripping (2 h) were devoid of any tocopherols. However, oils stripped by stationary phase for 1 h, still retained some tocopherols. The amount in camelina seed oil (20.79 mg/kg of oil) was higher than that in sophia seed oil (3.63 mg/kg of oil), corn oil (0.61 mg/kg of oil), and chia seed oil (0.01 mg/kg of oil). Although 1 h period for this procedure was found inadequate for total removal (> 98%) of tocopherols. The oils stripped by simplified stripping (twice, each 1 h) also retained a near-negligible amount of tocopherols in camelina seed oil, sophia seed oil, olive oil and DHASCO, but no tocopherols were found in corn oil and chia seed oil by using this method. Thus, column-stripping and stripping by stationary phase for 2 h were found effective to completely remove the endogenous tocopherols in the oils tested. According to Jung et al. (1989), the removal of chlorophylls and tocopherols in soybean oil via the processes of degumming, refining, bleaching and deodorization was 100% and approximately 32%, respectively. Abuzaytoun and Shahidi (2006a, 2006b) reported that they were able to remove all tocopherols in different types of single cell oils (arachidonic acid single-cell oil, docosahexaenoic acid single-cell oil and a single-cell oil rich in both docosahexaenoic acid and docosapentaenoic acid), flax oil and hemp oils by conventional column stripping method. Khan and Shahidi (2002) reported that tocopherols in borage oil was totally removed using column chromatographic techniques, whereas around 25% tocopherol was remaining in evening primrose oil after stripping process. Meanwhile, camelina seed oil, sophia seed oil, and DHASCO had higher amounts ($P < 0.05$) of total tocopherols than chia seed oil, corn oil and olive oils, which might contribute to its oxidative stability.

Pigments in stripped and non-stripped oils

Pigments such as carotenoids, with absorbance between 430 and 460 nm (Blekas et al. 1995) were present in high amounts in camelina seed oil, sophia seed oil, olive oil, and DHASCO (Fig. 1). Meanwhile, chlorophylls, which absorb light between 550 and 710 nm (AOCS 1990) were present in higher quantities in olive oil than in corn oil. On the other hand, no chlorophylls were found in non-stripped DHASCO. In addition, chlorophylls existed in higher levels in non-stripped sophia seed oil than camelina and chia seed oils. It is noteworthy that column stripping, and simplified stripping by 1 h, 2 h, and for 1 h twice of camelina, chia, and sophia seed oil were efficient in removing the pigments present. Li et al. (2016) reported that all pigments (chlorophylls and carotenoids) were removed upon the column stripping process.

By comparing the pigments found in non-stripped oils and their counterparts, it is clear that stripped oils by the methods employed (column stripped, stripped by stationary phase 1 h, 2 h, and for 1 h twice) had no or less ($p < 0.05$) pigments than their non-stripped counterparts as indicated by monitoring their absorbance at different wavelengths. The absorbance at 430 nm for non-stripped sophia seed oil was 0.75, which is higher ($p < 0.05$) than that of the one stripped by column (0.013) and by stationary phase 1 h (0.20), 2 h (0.15), and for 1 h twice (0.016). Similarly, the absorbance at 460 nm for non-stripped chia seed oil was 0.23, which is much higher ($p < 0.05$) than that of its column stripped and stripped by stationary phase for 1 h, 2 h, and 1 h twice (0.03, 0.015, and 0.016, respectively). The absorbance at 430 nm for DHASCO was 1.16 which was higher $p < 0.05$ than that of column

Table 1 Tocol concentration (mg/kg of oil) in the original, column stripped, and simplified stripped method (1 h, 2 h, and 1 h twice) of camelina seed, chia seed, sophia seed, corn, olive oils, and DHASCO[1,2]

Tocols	Non-stripped oils	Column stripped oils	Simplyfied stripped oil (1 h)	Simplyfied stripped oil (2 h)	Simplyfied stripped oil (2 × 1 h)
	Camelina Seed Oil				
α-tocopherol	114.73 ± 2.95[a]	nd	8.26 ± 0.58[b]	nd	2.10 ± 0.00[c]
β/γ-tocopherol	677.40 ± 17.73[a]	nd	12.53 ± 0.00[b]	nd	4.21 ± 0.11[c]
δ-tocopherol	470.41 ± 48.21[a]	nd	nd	nd	nd
Total tocols	1262.54 ± 68.89[a]	nd	20.79 ± 0.58[b]	nd	6.31 ± 0.11[c]
	Chia Seed Oil				
α-tocopherol	10.94 ± 1.65[a]	nd	nd	nd	nd
β/γ-tocopherol	282.68 ± 1.21[a]	nd	nd	nd	nd
δ-tocopherol	47.44 ± 1.21[a]	nd	0.01 ± 0.0[b]	nd	nd
Total tocols	341.06 ± 4.07[a]	nd	0.01 ± 0.0[b]	nd	nd
	Sophia Seed Oil				
α-tocopherol	tr	nd	nd	nd	nd
β/γ-tocopherol	977.52 ± 4.37[a]	nd	2.14 ± 0.01[b]	nd	1.50 ± 0.01[c]
δ-tocopherol	173.41 ± 5.98[a]	nd	1.47 ± 0.13[c]	tr	2.73 ± 0.01[b]
Total tocols	1150.93 ± 10.35[a]	nd	3.63 ± 0.14[c]	tr	4.23 ± 0.02[b]
	Corn Oil				
α-tocopherol	64.47 ± 3.26[a]	nd	nd	nd	nd
β/γ-tocopherol	445.99 ± 4.65[a]	nd	nd	nd	nd
δ-tocopherol	28.43 ± 4.81[a]	nd	0.61 ± 0.01[b]	nd	nd
Total tocols	538.89 ± 12.78[a]	nd	0.61 ± 0.01[b]	nd	nd
	Olive Oil				
α-tocopherol	179.98 ± 7.09[a]	nd	nd	nd	0.89 ± 0.01[b]
β/γ-tocopherol	28.30 ± 7.50[a]	nd	nd	nd	nd
δ-tocopherol	nd [a]	nd	nd	nd	nd
Total tocols	208.28 ± 14.59[a]	nd	nd	nd	0.89 ± 0.01[b]
	DHASCO				
α-tocopherol	759.28 ± 3.10	nd	nd	nd	nd
β/γ-tocopherol	202.07 ± 3.89[a]	nd	nd	nd	6.12 ± 0.02[b]
δ-tocopherol	250.63 ± 1.36[a]	nd	nd	tr	2.17 ± 0.02[b]
Total tocols	1211.98 ± 8.35[a]	nd	nd	tr	8.29 ± 0.02[b]

[1]Values are mean of triplicate determination ±standard deviation. Values with different superscript in each row are significantly different from each other ($P < 0.05$)

[2]Abbreviation: *nd* not detected, *tr* trace (< 0.02)

Values in each row with different letters are significantly different from one another

stripped, stripped by stationary phase for 1 h, 2 h, and for 1 h twice (0.38, 0.52, 0.42, and 0.04), respectively. Similarly, the absorbance at 430 nm for olive oil was 0.82 which was also higher ($p < 0.05$) than that of column stripped, stripped by stationary phase for1 h, 2 h, and for 1 h twice (0.05, 0.09, 0.04, and 0.16), respectively. Meanwhile, column stripping and stripping by stationary phase for 2 h were more effective compared to other stripping methods.

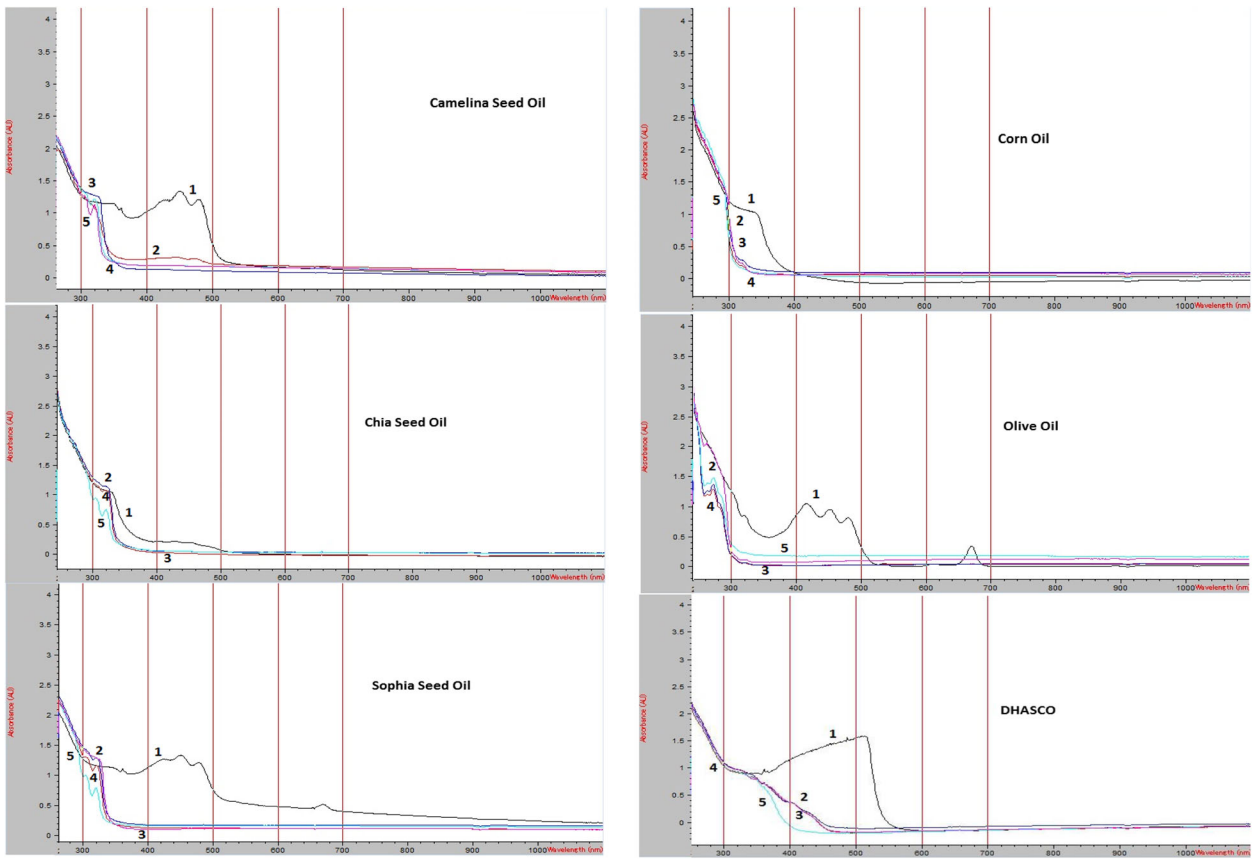

Fig. 1 Visible spectra of pigments in seed oils (1) original oil, (2) simplyfied stripped oil 1 h, (3) simplyfied stripped oil 2 h, (4) simplyfied stripped oil (twice, 1 h), and (5) column stripped oil

Formation of conjugated dienes in stripped and non-stripped oils

All oil samples were carefully handled to minimize exposure to light during the experiments. Figure 2 presents the trend for the formation of the primary oxidation products by measuring the conjugated dienes in non-stripped, column stripped, and stripped by stationary phase for 1 h, 2 h, and 1 h twice of camelina seed oils, chia seed oils, sophia seed oil, corn oil, olive oil, and DHASCO. All oils stripped for 1 h by stationary phase twice showed the highest level. However, there was no significant difference between both columns stripped oils, and oils tripped by the stationary phase for 2 h except chia seed oil. In addition, all stripped seed oils were less stable than their non-stripped counterparts. This is primarily due to the removal of minor components that function as antioxidants against oxidation of unsaturated fatty acids. Thus, minor antioxidative components present in tested seed oils, such as tocopherols, chlorophylls, and carotenoids played a significant role in stabilizing the non-stripped oils. Similar results were observed in the literature. Miraliakbari and Shahidi (2008) reported that all stripped tree nut oils (almond, Brazil nut, hazelnut, pecan, pine nut, pistachio, and walnut) showed more conjugated diene formation than non-stripped tree nut oils. Abuzaytoun and Shahidi (2006a) compared oxidative stability of non-stripped and stripped algal oils (arachidonic acid single-cell oil, docosahexaenoic acid single-cell oil and a single-cell oil rich in both docosahexaenoic acid and docosapentaenoic acid) and found that all non-stripped oils showed less aldehydes values than their stripped counterparts. They also studied oxidative stability of flax and hemp oils and these oils showed a similar pattern (Abuzaytoun and Shahidi 2006b).

Formation of TBARS in stripped and non-stripped oils

The secondary oxidation products of non-stripped oils, column-stripped oils, and oils stripped by

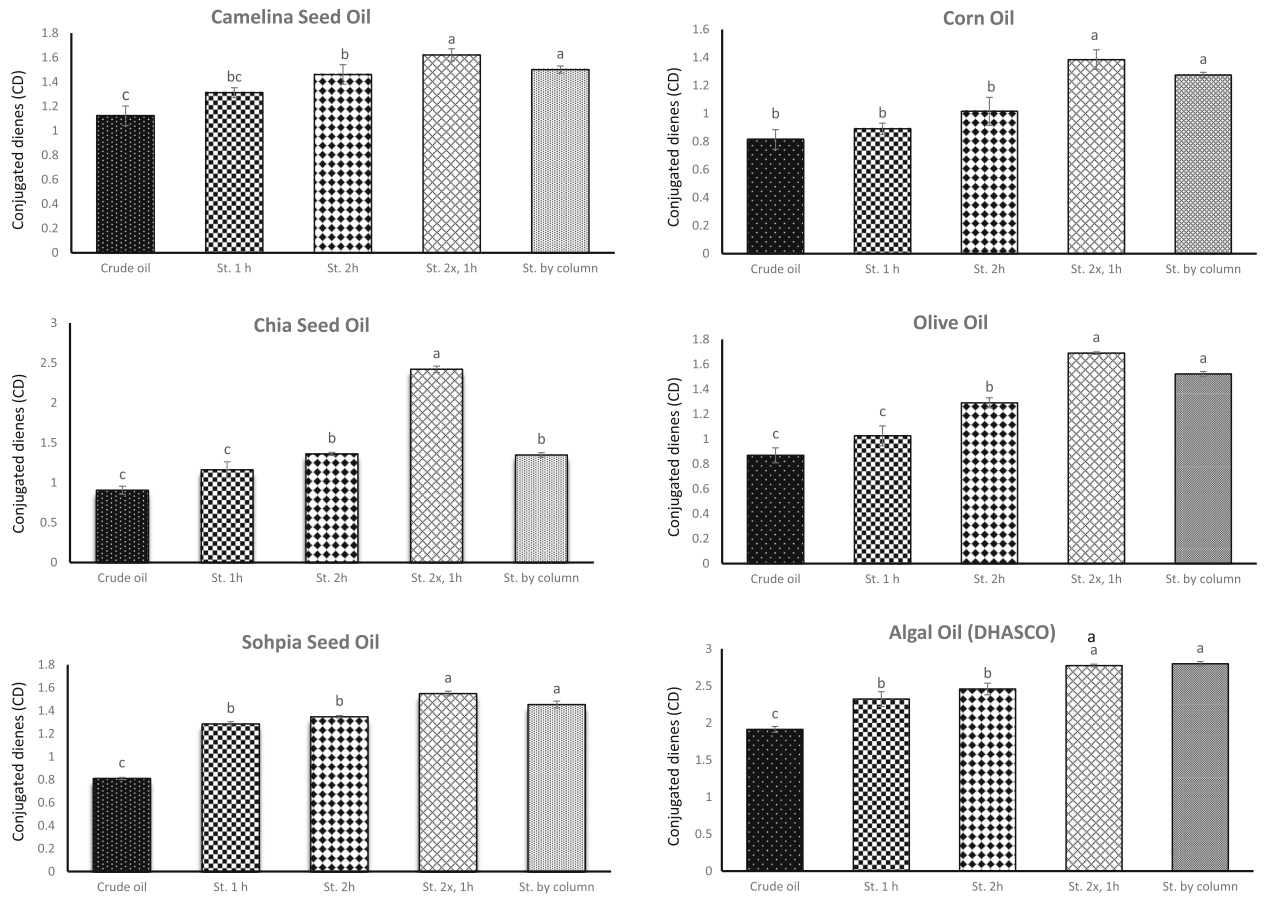

Fig. 2 Conjugated dienes of stripped and non-stripped camelina seed oil, sophis seed oil, chia seed oil, corn oil, olive oil, and DHASCO. (crude oil, non-stripped oil; St. 1 h, simplyfied stripped oil 1 h; St. 2 h, simplyfied stripped oil 2 h; St. 2 × 1 h, simplyfied stripped oil twice for 1 h; and St. by column, column stripped oil)

stationary phase 1 h, 2 h, and 1 h twice were determined by examining the production of TBARS. This test is based on the determination of colour intensity of the TBA-MDA (malondialdehyde) and other relevant compounds at 532 nm and expresses the results as μmol malondialdehyde equivalents per gram (g) of oil.

Figure 3 shows the trend for the formation of secondary oxidation products in tested camelina seed oil, chia seed oil, sophia seed oil, corn oil, olive oil, and DHASCO before and after the stripping process. All samples of stripped and non-stripped oils shared a similar trend of conjugated dienes formation; all tested stripped oils were less stable than their non-stripped counterparts. This lower stability of the stripped oil might be due to the absence of minor components in the oil. Shahidi and Zhong (2010) reviewed the factors affecting oxidative stability of oils and mentioned that tocopherols and carotenoids can retard lipid oxidation. Chen et al. (2011) reported that since tocopherol acts as antioxidant, tocopherol concentration in bulk oil decreased during storage period. On the other hand, chlorophylls can delay the lipid oxidation only when they are in the dark. The formation of TBSRS increased from 1 h to 2 h and to 1 h twice stripped samples; the TBRAS of all column stripped samples was highest and as removal of minor compounds, it is suspected that the long period (average 24 h) of the column stripping process may have led to the formation of TBARS.

Conclusion

In order to overcome drawbacks of traditional column chromatographic stripping method, a novel and robust process using stationary phase material was proposed and tested in this study. Six oils, namely camelina seed oil, chia seed oil, sophia seed oil, corn oil, olive oil, and DHASCO were employed and found

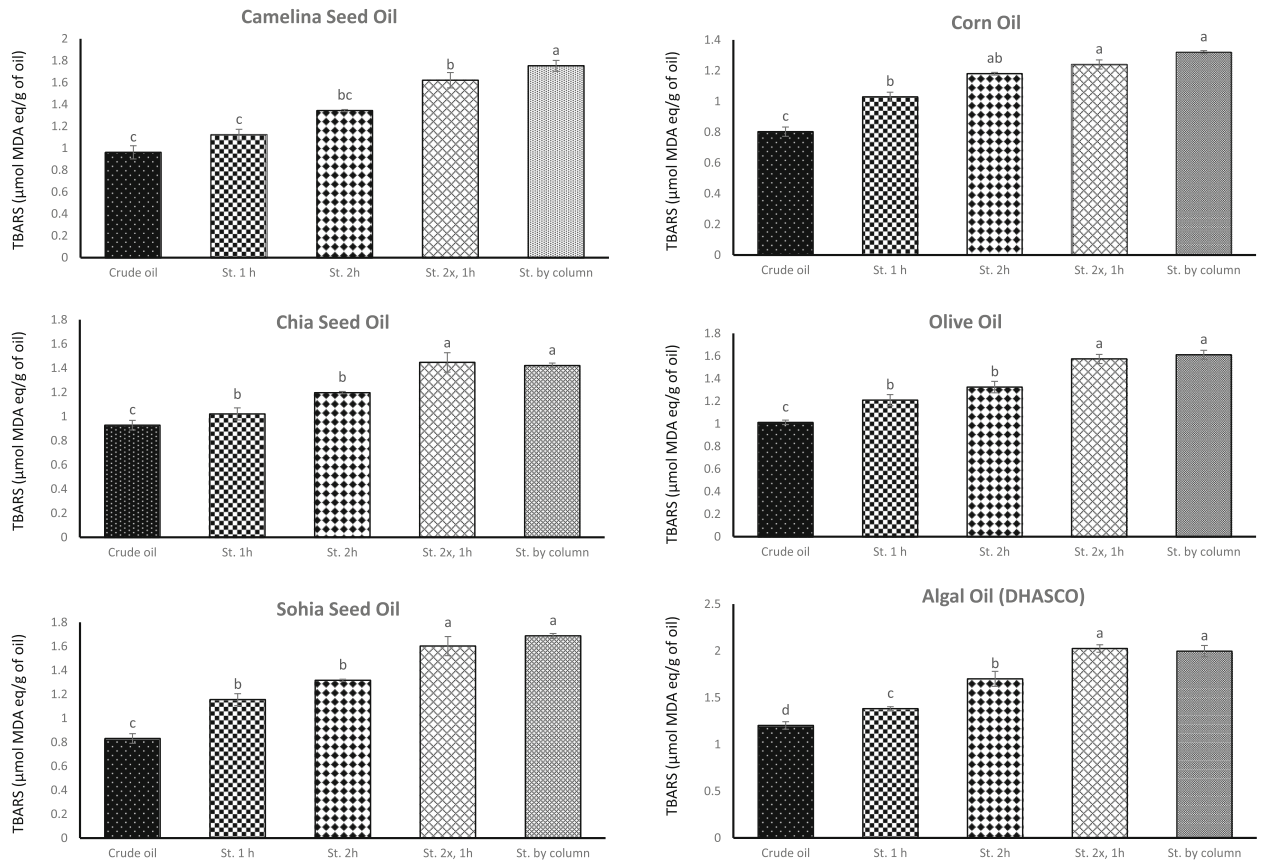

Fig. 3 TBARS (MDA equiv.) of stripped and non-stripped camelina seed oil, sophis seed oil, chia seed oil, corn oil, olive oil, and DHASCO

to successfully remove minor components with tocopherols in all oils fully eliminated by both column stripping and simplified stripping method for 2 h. However, a 1 h contact period left 1.6% residual tocopherols only in camelina oil. Meanwhile, the pigments, namely carotenoids and chlorophylls were effectively removed by all stripping procedures. In terms of oxidative stability, non-stripped oil showed the highest oxidative stability followed by simplified stripping for 1 h > simplified stripping for 2 h > simplified stripping for 1 h, twice = column stripping. These results demonstrated that the simplified stripping method for 2 h could be utilised to prepare stripping oil instead of conventional column stripping method.

Abbreviations

DHASCO: docosahexaenoic acid single cell oil; PUFA: polyunsaturated fatty acids; TAG: triacylglycerols

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Authors' contributions

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Availability of data and materials

Please contact authors for data request.

Competing interests

The authors declare that they have no competing interests.

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