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Changes in chemical composition of some oils extracted from seeds roasted at different temperatures

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RESEARCH ARTICLE

Abstract

Oil seeds are commonly used in cooking, frying and as salad oil and have commercial and economic importance. Since the seeds are roasted before pressing of the oil, changes occur in their composition; thus it is crucial to modify roasting process to minimise adverse effects. This study reflects the effects of different roasting temperatures (90, 150 and 210 °C for 10 min. in conventional oven) on the oil constituents and some chemical properties of oils from the seeds of sesame, sunflower, soybean, flaxseed and poppy along with comparison to those of unroasted corresponding seed oils. Lipids from roasted seeds of sesame, flax and soybean exhibited relatively higher viscosity and free fatty acids, than lipids from unroasted seeds. With an increase in roasting temperatures the colour of the oils were slightly darker even though the changes were not significant in most cases. The content of α- and γ-tocopherols in oils (except soybean oil) gradually decreased as roasting temperature increased. β-tocopherol was higher in the oils of roasted seeds, while the amount of δ-tocopherol showed different trends with roasting depending on the type of seeds. For sesame and poppy oils, after roasting at 210 °C, stearic and oleic acids showed higher percentages when compared to the levels in oils roasted at 90 and 150 °C.

Keywords: fatty acids, oil seeds, roasting, tocopherols

1. Introduction

Seed oils have been used as natural salad oil, cooking oil, or seasoning ingredient and considered as a healthy food (sesame), and in the industrial manufacturing of products such as liquid shortenings, margarines, non-dairy creamers, and confectionery products (Gunstone, 2002). Oil seeds are roasted in order to promote the flavour, desired colour and changes in texture which ultimately increase the overall palatability of the product. Roasting also improves microbiological safety, digestibility, sensory quality, and shelf life of food products, inactivates enzymes, facilitates oil extraction by destroying cell barriers, and destroys toxic thermolabile substances in nuts and seeds (Karleskind, 1996; Yeganeh, 2013). It induces the formation of health-promoting components, such as antioxidants (tocols and phenolic compounds), but also leads to the formation of heat-induced contaminants such as acrylamide, furans and furfurals, may also induce the isomerisation of double bonds, leading to the formation of trans fatty acids, lipid peroxidation, may increase the primary (hydroperoxides) and secondary (aldehydes/ketones) lipid oxidation products (Durmaz and Gökmen, 2010).

Lipids, carbohydrates and proteins/amino acids are involved in the chemical reactions responsible for both desired and undesired changes in nuts and seeds during roasting. The pathways of possible chemical reactions are interrelated and strongly dependent on the composition of raw food, and the roasting conditions. Thus it has been recommended in previous studies to modify the roasting process and optimisation of roasting time, temperature and other factors to minimise adverse effects while improving advantages (Durmaz and Gökmen, 2010; Kahyaoğlu and Kaya, 2006; Krysiak, 2011).

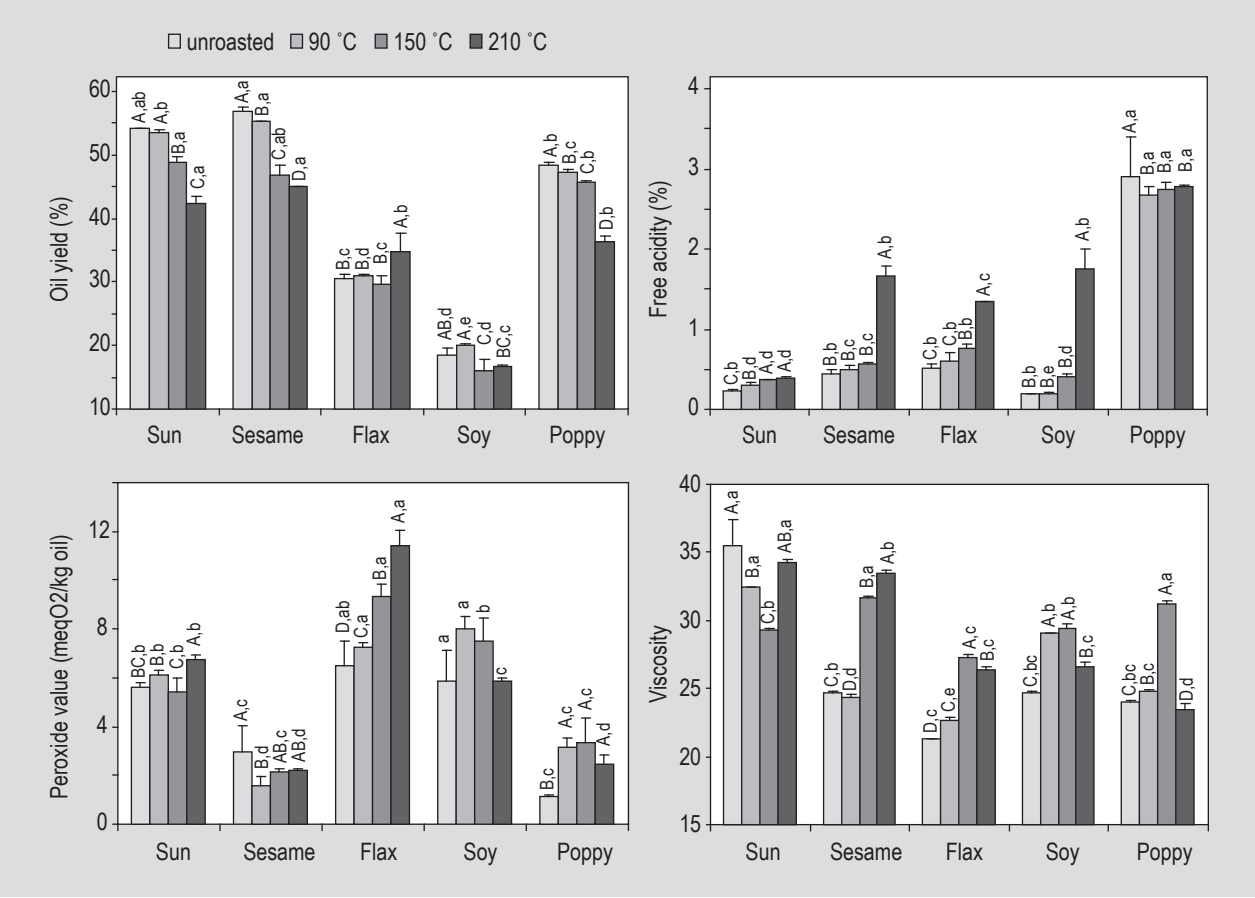

Figure 1. Changes in some physical and chemical characteristics of oils prepared from the seeds, unroasted or roasted at different temperatures. For each temperature, significant differences between seed types are shown by different small letters (a-e) (*P*<0.05). for each lipid type, significant differences between roasting temperatures are shown by different capital letters (A-D) (*P*<0.05).

The aim of this study was to investigate the changes in fatty acid composition, colour formation and minor components, such as tocopherols and some physico-chemical properties of the oil prepared from sunflower, sesame, flax, soybean and poppy seeds roasted at different temperatures.

2. Materials and methods

Materials and roasting process

Untreated sunflower (*Helianthus annuus* L.), soybean *(Glycine max* L.*)*, sesame (*Sesamum indicum* L.), flax (*Linum usitatissimum* L.) and poppy (*Papaver somniferum* L.) seeds were obtained from local markets. Seeds were carefully cleaned to remove contaminates and were stored in an airtight container at 20 °C.

Sunflower seeds were dehulled before roasting. 150 g of each type of seeds were weighed on an aluminium tray as a single layer and placed into an electric oven set at 90, 150 and 210 °C for 10 min. where the seeds were stirred every 2 min. in order to get a homogenised roasting. The sample was stirred (10-15) in the vessel by a wooden spatula with heat resistant gloves worn and then the door of the oven is closed. This cycle of heating and stirring was repeated five times until the temperature was the same at each place of the sample. At the end of roasting the sample was taken away from the oven with a delay approximately 1 min. Roasted seeds were ground in a coffee grinder and were stored at airtight containers in refrigerator (4 °C) until they were further used for experiments.

Standards used for tocopherol analysis (α-,β-,γ- and δ-tocopherol) were purchased from Merck (Darmstadt, Germany). Reagents and chemicals used were of the highest purity available.

Cold extraction of oils

Oil from seeds was extracted using n-hexane for 5 h with shaking in every 10 min at ambient temperature (22 °C). A cold extraction procedure was repeated 3 times and was followed by solvent removal under vacuum at 40 °C. The oil so obtained was dried under a stream of nitrogen and then stored in a refrigerator (4 °C) for subsequent analysis.

Total lipid content

The seed oil content was determined using Soxhlet extraction according to the official method (AOAC, 1960). From each cultivar and each treatment 50 g of seeds were ground and then extracted with petroleum ether in a Soxhlet apparatus for 6 h. Petroleum ether was evaporated under reduced pressure using a rotavapour. Lipid content was expressed as g/100 g of seed dry weight.

Determination of free fatty acid and peroxide value

Free fatty acid (FFA) and peroxide value (PV) of olive oils were determined following the analytical methods described in Regulation European Economic Commission (EC, 1992). FFA, given as percentage of oleic acid, were determined by titration of a solution of oil dissolved in ethanol/ether (1:1, v/v) with 0.1 mol/l potassium hydroxide ethanolic solution. PV, expressed in milli equivalents of active oxygen per kilogram of oil (meq/kg), was determined as follows: a mixture of oil and chloroform-acetic acid was left to react with a solution of potassium iodide in darkness; the free iodine was then titrated with a sodium thiosulfate solution.

Viscosity measurements

The viscosity of the oils was measured using a vibro-viscometer (SV-10; A&D Co., Ltd., Tokyo, Japan). This type viscometer measures viscosity by controlling the amplitude of the sensor plates immersed in a sample and measuring the electric current required to drive the sensor plates. To perform a measurement, firstly the thin sensor plates were immersed into a sample. When the spring plates were vibrated with a uniform frequency, the amplitude varied in response to the quantity of the frictional force produced by the viscidity between the sensor plates and the sample. The vibro-viscometer controls the driving electric current to vibrate the spring plates in order to make uniform amplitude. Since the frictional force of viscidity is directly proportional to the viscosity, the driving electric current (driving power) for vibrating the spring plates with a constant frequency to make uniform amplitude is also directly proportional to the viscosity of each sample. The vibro-viscometer measures the electric current required to vibrate the sensor plates with a uniform frequency and amplitude, and then the viscosity is given by the positive correlation between the driving electric current and the viscosity (Anonymous, 2005; Gumus *et al.*, 2010).

Determination of tocopherols

Tocopherols were evaluated according to the IUPAC 2432 method (IUPAC, 1992): 1.5 g oil was dissolved in 10 ml hexane and injected into the high-performance liquid chromatography system with a LiChroCART, Si 60 column (25 cm × 4 mm × 5 µm; Merck). The chromatographic separation was performed using a Shimadzu liquid chromatograph equipped with an isocratic pump LC-20AT prominence, a CTO-10AS VP heater (column temperature 22 °C), a SIL-20A prominence autosampler and a SPD-M20A Prominence diode-array detector (Shimadzu, Kyoto, Japan). The mobile phase was 0.5% isopropanol in n-hexane. The total run time was 40 min and the injection volume was 20 µl. The detector was a DAD operated at a fixed wavelength of 295 nm. Tocopherols were quantified by an external standard method; α-, β-, γ- and δ-tocopherol standards were obtained from Sigma-Aldrich (St. Louis, MO, USA).

Fatty acid analysis

For the determination of fatty acid composition of the oils, fatty acid methyl esters (FAMEs) were prepared from the oils, using cold transmethylation (Stefanoudaki *et al.*, 1999). The fatty acids were converted to FAMEs before analysis by shaking a solution of 0.2 g oil and 3 ml of hexane with 0.4 ml of 2 N methanolic potassium hydroxide. A Shimadzu gas chromatograph, equipped with a flame ionisation detector and a split/splitless injector, was employed. Separations were made on a Teknokroma TR-CN100 (Barcelona, Spain) fused-silica capillary column (60 m·× 0.25 mm i.d.,·0.20 µm film thickness). The carrier gas was nitrogen, with a flow rate of 1 ml/min. The temperatures of the injector and the detector were held at 220 and 250 °C, respectively. The initial oven temperature of 90 °C was maintained for 7 min, raised to 240 °C at a rate of 5 °C/min, where it was maintained for 15 min. The injection volume was 1 µl. Peaks were identified by comparison of their retention times with those of authentic reference compounds (Sigma-Aldrich). FAMEs were identified by comparison of their retention time with respect to pure standard FAMEs purchased from Sigma and analysed under the same conditions. The oil seeds FAMEs were quantified according to their percentage area, obtained by integration of the peaks. The results were expressed as a percentage of individual fatty acids in the lipid fraction.

Assessment of instrumental colour

A colorimeter (Minolta Chroma meter CR 400; Konica Minolta Sensing Inc., Osaka, Japan) was used to assess the oil colour and the CIELAB colorimetric system was applied. The colorimeter was calibrated against a standard calibration plate of a white surface and set to CIE standard illuminant C. Each time 20 ml of sample was placed in a glass petri dish, and the liquid probe of the instrument was immersed into the dish sitting on the white tile, and readings of the CIE lab coordinates were recorded. The colour brightness coordinate L* measures the whiteness value of a colour and ranges from black at 0 to white at 100. The chromaticity coordinate a* measures red when positive and green when negative, and chromaticity coordinate b*

measures yellow when positive and blue when negative. The L*, a*, b* values are averages of ten readings (Criado *et al.*, 2004).

Statistical analysis

Each reported value is the mean of determinations for triplicate samples prepared from each roasting condition, and the data were analysed by ANOVA and Duncan's multiple range test (Duncan's test). Statistical significance was accepted at a level of $P<0.05$ (SPSS, 1999).

3. Results and discussion

Total lipids

Sunflower and sesame seeds contained higher lipid levels than the other oil seeds, with averages of 49.7 and 51.0%, respectively (Figure 1). Poppy and flax seeds followed them with an average yield of 44.4 and 31.4%, respectively. The lowest total lipid content was determined in soybean seeds (17.8%). Total lipid yields of the seeds diminished when they were roasted at high temperatures with the exception of flaxseed. The lipid content of flaxseed was higher from the samples which were roasted at 210 °C, while there were no significant differences between the lipid yield of unroasted and roasted (90 and 150 °C) flaxseeds.

Free fatty acids

Poppy oils showed the highest levels (%) of FFA, while the lowest levels were determined in sunflower oils (Figure 1). The poppy oil showed the highest FFA content among the oils from unroasted seeds, which was probably due to its lower saturated and higher polyunsaturated fatty acid composition. Flaxseed oil followed by higher FFA content which has a close fatty acid profile to poppy oil.

The FFA content of oils increased with roasting, except poppy oil which did not show a significant change in terms of FFA after roasting at different temperatures. The increase in FFA was not very high in sunflower oil (from 0.22 to 0.38%), whereas there were dramatic increases for sesame, soybean and flaxseed oils, from 0.45 to 1.66% for sesame oil, from 0.52 to 1.35% for flaxseed oil, and from 0.20 to 1.75% for soybean oil, when the seeds roasted at 210 °C. An increase in FFA content with roasting was observed for 150 and 210 °C temperatures, while after roasting at 90 °C there were no significant changes in FFA contents of oils.

Peroxide values

Soybean and flaxseed oils had the highest, while sesame and poppy oils showed the lowest levels of PV for unroasted and roasted seed oils (Figure 1). PV of sunflower oil increased when the seeds were roasted at 210 °C. There was a regular increase in PV of flaxseed oil with roasting. Roasting led to an increase in PV of poppy oils too, though the roasting temperature had no significant effect on PV. The PV of soybean and sesame oils were not influenced by seed roasting, and a slight decrease was observed in the sesame oils from roasted seeds. Durmaz *et al.* (2010) reported that the oils from 5- and 10-min roasted samples had a higher PV than those of unroasted apricot kernel samples. Açar *et al.* (2009) also reported that the roasting conditions, the amount of Maillard reaction reactants (carbohydrates and proteins) determine the final total antioxidant capacity of roasted nuts, seeds and pulses. They attributed the decrease of total antioxidant capacity to the degradation of naturally occurring antioxidants. On the other hand, oils obtained from roasted seeds were reported to contain lower primary (Lee *et al.*, 2004) and secondary (Wijesundera *et al.*, 2008) oxidation products compared to the oils from unroasted seeds. Lee *et al.* (2004) attributed the greater antioxidative stability of safflower oil prepared from safflower seeds roasted at higher temperatures due to non-enzymatic reaction products formed during the roasting process; as the Maillard reaction products formed during roasting, reportedly show strong antioxidant activities (Açar *et al.*, 2009; Elizade *et al.*, 1992; Jung *et al.*, 1999; Lee *et al.*, 2004).

Viscosity

As shown in Figure 1, oil viscosity increased as the roasting temperature was increased, except for sunflower oil which showed a decrease in viscosity with roasting and an increase when the seeds were roasted at 210 °C. On the contrary, the viscosity of soybean and poppy oils decreased at the oils roasted at 210 °C unlike the samples roasted at lower temperatures. Oil viscosity was reported to increase due to formation of polymers (Besbes *et al.*, 2005; Bracco *et al.*, 1981) polymerisation and formation of high molecular weight compounds including carbon-carbon and carbon-oxygen-carbon bridges between fatty acids (Stevenson *et al.*, 1984).

Fatty acid composition

Fatty acid compositions of seed oils from unroasted and roasted seeds are given in Table 1. The fatty acid profiles of sunflower, sesame and poppy oils were broadly similar with the exception that poppy oil had a higher content of linoleic acid and a lower content of oleic and stearic acid than the other two oils. Soybean oil was found to have a higher content of linolenic acid than sunflower, sesame and poppy oil but the highest content of linolenic acid was measured in flaxseed oil at approximately 55% (Table 1).

The level of palmitic acid in poppy oil decreased gradually when roasting temperatures were raised, while there was an increase for flax seed oil and no significant change was determined in soybean and sesame seed oils. The level of

Table 1. Fatty acids of lipids extracted from oilseeds unroasted or roasted at different temperatures.[1,2]

Lipid types	Heat treatment	Fatty acids (%)				
		Palmitic	Stearic	Oleic	Linoleic	Linolenic
Sunflower	unroasted	5.85±0.30 Ab	8.18±0.43 Aab	28.43±2.01 Cb	51.53±2.18 Bb	<1 Ab
	90 °C	5.86±0.35 Ac	4.79±0.45 Db	30.13±1.21 Ba	50.00±2.51 Cc	<1 Ac
	150 °C	5.97±0.36 Ad	6.67±0.35 Ba	31.27±1.34 Aa	53.25±2.44 Ab	<1 Ac
	210 °C	5.57±0.35 Bd	5.84±0.35 Cb	29.05±1.05 Cb	50.04±2.77 Ca	<1 Ac
Sesame	unroasted	9.56±0.40 Aa	5.50±0.37 Ac	36.82±2.16 Aa	42.70±1.89 Ab	<1 Ab
	90 °C	7.65±0.19 Cb	3.62±0.25 Bd	29.03±0.78 Bb	49.92±1.91 Ac	<1 Ac
	150 °C	5.61±0.35 De	3.91±0.34 Bd	29.93±1.87 Bb	50.40±2.35 Ac	<1 Ac
	210 °C	8.74±0.30 Bb	5.18±0.40 Ac	38.44±1.90 Aa	42.35±2.01 Ac	<1 Ac
Flaxseed	unroasted	5.10±0.37 Cb	4.63±0.23 Ac	16.30±1.00 Ad	18.50±1.33 Ac	54.95±1.10 ABa
	90 °C	4.89±0.40 Cd	3.97±0.42 Bc	13.87±1.84 Bd	15.70±1.15 Ad	57.70±3.44 Aa
	150 °C	7.90±0.50 Ac	4.11±0.30 Bc	12.94±1.77 Be	13.07±1.41 Ad	53.36±2.72 Ca
	210 °C	7.15±0.73 Bb	3.32±0.25 Ce	12.99±1.91 Be	12.39±0.90 Ad	55.31±1.65 Ba
Soybean	unroasted	10.62±1.19 Aa	5.90±0.78 Bbc	24.18±2.31 Ac	52.38±3.04 Ab	7.39±0.43 Ab
	90 °C	10.35±0.17 Ba	7.45±0.40 Aa	20.52±1.22 Ac	52.13±2.24 Ab	6.46±0.30 Bb
	150 °C	10.52±0.40 Aa	4.54±0.40 Cb	23.55±1.05 Ac	50.33±2.67 Ac	6.10±0.33 Cb
	210 °C	10.54±0.38 Ca	3.75±0.41 Dd	22.46±1.14 Ad	48.27±2.18 Ab	6.40±0.35 Bb
Poppy	unroasted	9.20±0.41 Aa	2.50±0.33 Bd	15.50±1.13 Bd	71.60±3.31 Aa	<1 Ab
	90 °C	8.71±0.40 Cb	2.32±0.30 Be	14.38±1.22 Cd	72.74±2.66 Aa	<1 Ac
	150 °C	8.84±0.35 Bb	2.50±0.31 Be	15.17±1.06 BCd	69.91±2.14 Aa	<1 Ac
	210 °C	6.80±0.36 Dc	11.51±0.80 Aa	26.05±2.00 Ac	47.12±3.15 Bb	<1 Ac

[1] Mean value ± standard deviation.

[2] Different lower case letters indicate that mean values of the same heat treatment differ significantly ($P \leq 0.05$) (comparison between lipid types). Different upper case letters indicate that mean values of the same lipid type differ significantly ($P \leq 0.05$) (comparison between heat treatments)

this fatty acid remained almost the same too, but showed a decrease at 210 °C roasting for sunflower oil. Sesame oil had the lowest percentages of palmitic, stearic and oleic acids at 90 and 150 °C roasting. Stearic acid levels decreased in soybean, sunflower and flaxseed oils when the seeds roasted, whereas it showed an increase in poppy oils. There were no regular changes in stearic acid levels of soybean and sesame oils with increasing roasting temperatures. Linoleic and linolenic acids were the individual fatty acids where roasting generally had almost no influence, only in poppy and soybean oils did the levels of linoleic and linolenic acids decrease with roasting. 210 °C is a critical roasting temperature for sesame oil as palmitic, stearic and oleic acids were higher when compared to 90 and 150 °C. For poppy oils, 210 °C was again critical as stearic and oleic acids showed the highest percentages even more than the levels of unroasted poppy seed oil. 150 °C was also critical for palmitic acid levels in flax and soybean oils as the levels of this fatty acid were higher than the levels of other roasted seed oils and linoleic acid in sunflower oil showed the same trend too.

It was previously reported that higher roasting temperatures of soybeans and hazelnuts resulted in higher relative percentages of saturated fatty acids and oleic acids and lower percentages of polyunsaturated fatty acids (Jung *et al.*, 1997; Murkovic *et al.*, 2004), even the contents of palmitic and stearic acids were reported to remain stable when the seeds were roasted (Boge *et al.*, 2009; Lee *et al.*, 2004; Murkovic *et al.*, 2004). The decrease in saturated fatty acids can be attributed to triglyceride degradation during seed roasting (Durmaz and Gökmen, 2010).

Tocopherols

Sunflower and flaxseed oils showed higher α-tocopherol levels than the other types of oils, however these oils contained lower amounts of δ-tocopherols (Figure 2). The β-tocopherol contents of soybean and poppy oils were higher than those of other oils, while flax seed oil had higher levels of γ-tocopherol compared to other oils. The content of tocopherols decreased with roasting. α-tocopherol in sunflower oil diminished consistently with increasing roasting temperatures. In flaxseed oil the decrease in α-tocopherol level was significant only for

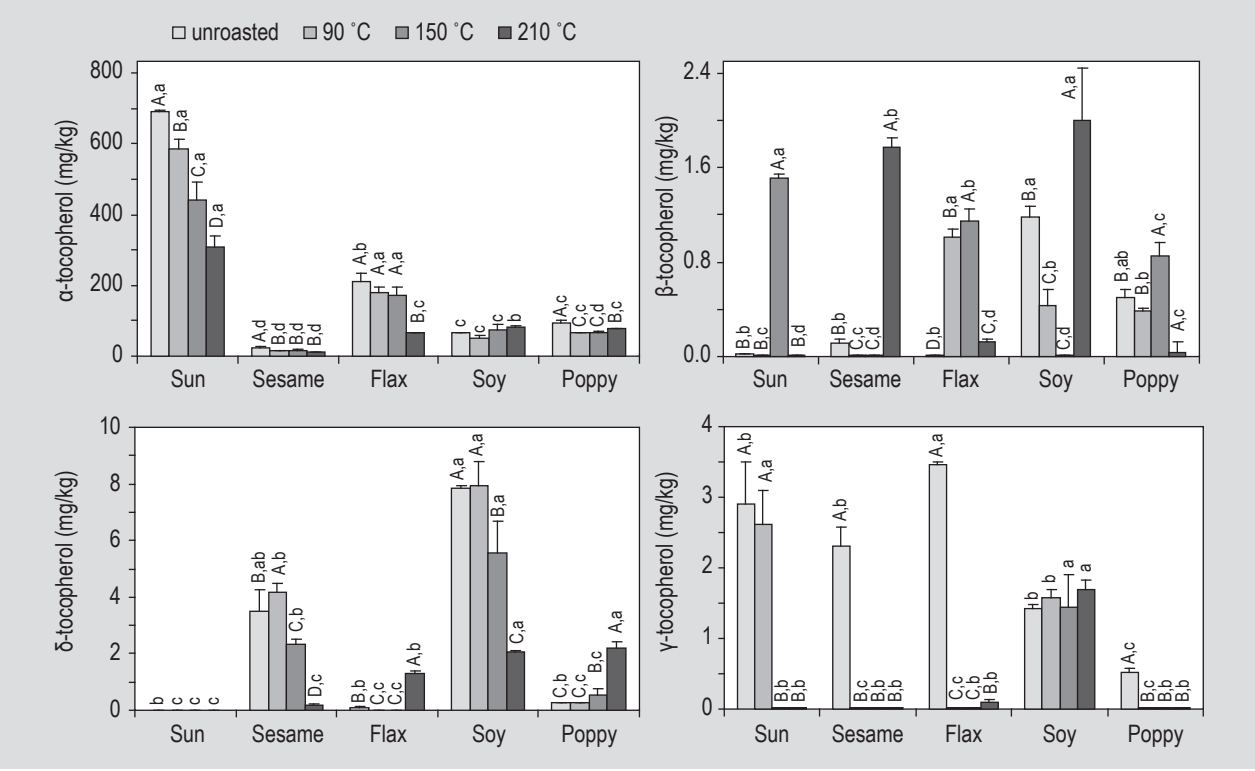

Figure 2. Changes in tocopherol contents of oils prepared from the seeds, unroasted or roasted at different temperatures. For each temperature, significant differences between seed types are shown by different small letters (a-e) (*P*<0.05). For each lipid type, significant differences between roasting temperatures are shown by different capital letters (A-D) (*P*<0.05).

oils from 210 °C roasted samples, whereas there was no significant decrease in α-tocopherol content of soybean oil with roasting. β-tocopherol was higher in roasted samples, the values were very high when compared to other roasted and unroasted samples, such as the oils from roasted seeds at 150 °C for sun flower and poppy oils, 90 and 150 °C for flax oil, and 210 °C for sesame and soybean oils. The same trend was reported by Lee *et al.* (2004), that the content of β-tocopherol in safflower oil gradually (P<0.05) increased as roasting temperature increased. The amounts of γ-tocopherol showed noticeable reductions in almost all the oil types, except in soybean oil which did not exhibit any significant change with roasting. The content of δ-tocopherol was reduced in sesame and soybean oils, while its content increased in flax and poppy oils with roasting process.

Murkovic *et al.* (2004) reported that at the beginning of roasting of pumpkin seeds the vitamin E concentration decreased in their oil due to oxidation reactions; while after 40 min, when the oil emerges from the cellular structure, the measured vitamin E concentration increased because of increased extraction efficiency. Sunflower oil was found to contain trace levels of δ-tocopherol in both unroasted and roasted seeds. A previously reported study has shown that the content of α-tocopherol in oils of *Pistacia terebinthus* seeds decreased within 5 min roasting, but this level increased when the seeds were roasted for 40 min. Some of the previous studies reported that roasting leads to no significant change in tocopherols of oils from several seeds (Chiou and Tsai, 1989), some reported increases (Kim *et al.*, 2002; Lee *et al.*, 2004; Yen, 1990) and some reported decreases (Anjum *et al.*, 2006; Durmaz and Gökmen, 2011). The decrease in tocopherols was attributed to thermal degradation or microstructural changes in seeds that take place at elevated temperatures (Durmaz and Gökmen, 2011). Increases in tocopherol contents with roasting were attributed to the increase in extractability of tocopherols by the thermal degradation of cellular structure (Kim *et al.*, 2002).

Colour values

The colour developments of the oils from the seeds roasted at different roasting temperatures are shown in Figure 3. There were no significant differences between the L* values of the oils, while soybean oils were slightly darker in terms of greenness (a* values) and yellowness (b* values). Flaxseed and soybean oils had higher green and yellow colour values for their both unroasted and roasted forms. Poppy and flax oils were the oils which were affected by roasting more than the other oils as their L* values decreased more than those of the other oils. After the oils were roasted at 90 and 150 °C flax and poppy oils were the darkest oils, at 210 °C the oils did not differ too much in terms of L* values.

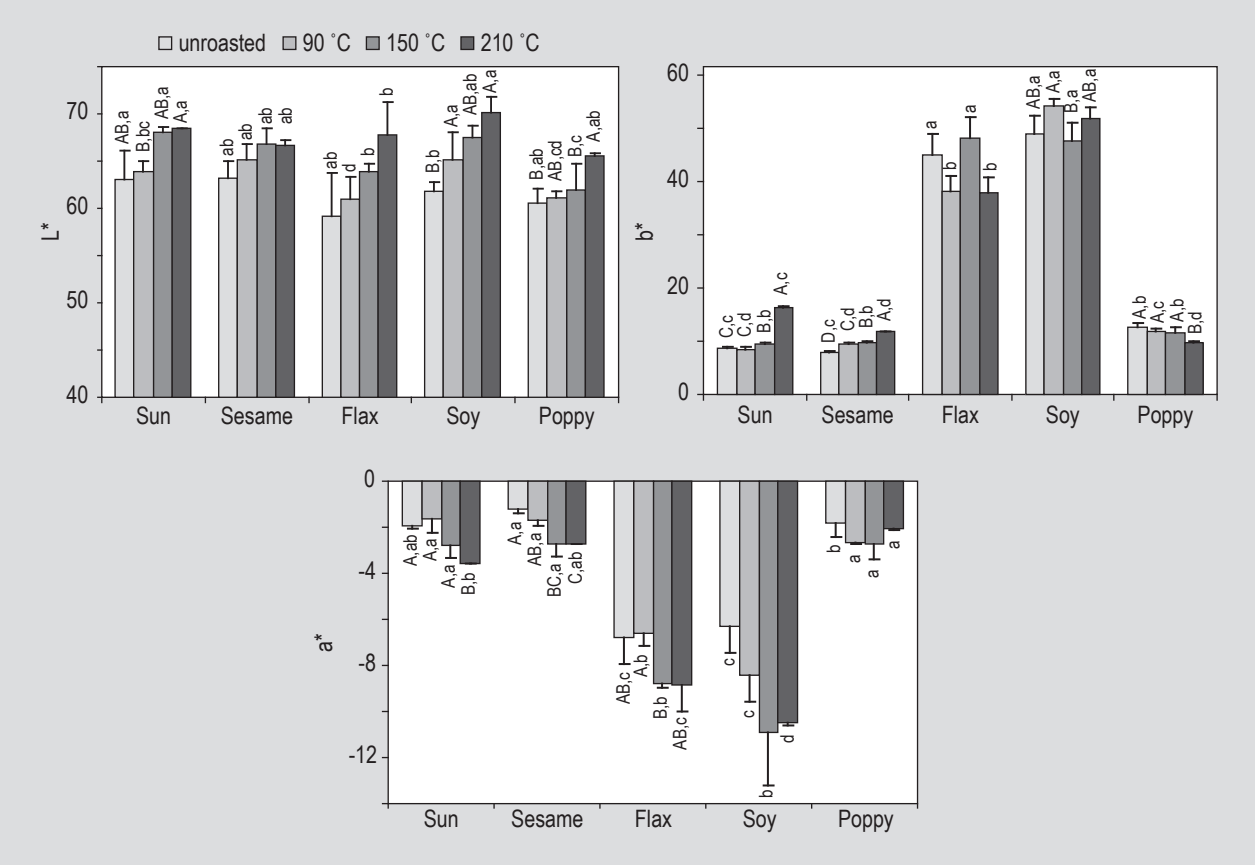

Figure 3. Colour development (L* = brightness; b* = yellow/blueness; a* = red/greenness) of oils prepared from the seeds, unroasted or roasted at different temperatures. For each temperature, significant differences between seed types are shown by different small letters (a-e) (*P*<0.05). For each lipid type, significant differences between roasting temperatures are shown by different capital letters (A-D) (*P*<0.05).

Roasting did not lead to significant changes in L* values of oils. Increasing roasting temperature afterward caused significant changes in a* and b* values of sunflower and sesame oils as the oils had higher colour values in terms of greenness and yellowness after roasting, while roasting did not change the a* values of other oils, with the of exception for poppy oil which exhibited a slight fading of yellowness after roasting at 210 °C.

The increase in colour intensity of oils due to roasting of seeds was also reported before (Durmaz and Gökmen, 2011; Kim *et al.*, 2002; Lee *et al.*, 2004; Shyu, 1986; Yen, 1990; Yoshida, 1994). Lee *et al.* (2004) reported that the higher the roasting temperature, the greater the formation of non-enzymatic reaction products such as Maillard reaction products, because of the interaction of proteins with reducing sugars.

4. Conclusions

The saturated fatty acid (palmitic and stearic acids) contents of oils showed different trends with roasting depending on the oilseed source, while the level of both of these fatty acids decreased in sunflower oil after roasting. α-tocopherol in sunflower oil diminished gradually with increasing roasting temperatures. There was no a significant decrease in α-tocopherol content of soybean oil with roasting. β-tocopherol was higher in the oils of roasted seeds. The amount of γ-tocopherol was noticeably reduced in the oils, except for soybean which did not exhibit any significant change with roasting. The content of δ-tocopherol was reduced in sesame and soybean oils, while it increased in flax and poppy oils with roasting. Oil viscosity increased generally as the roasting temperature was increased. Roasting did not lead to significant changes in the L* values of oils. Increasing roasting temperatures led to darker colour in terms of greenness and yellowness of sunflower and soybean oils. PVs of the flaxseed and poppy oils increased when the seeds were roasted, while soybean and sesame oils were not influenced by seed roasting in terms of PV. A higher roasting temperature such as 210 °C is not recommended as the results suggest that the oils had distinctly lower levels of total lipid yield and elevated levels of FFA content.

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