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ORIGINAL ARTICLE

Impact of roasting and extraction methods on chemical properties, oxidative stability and Maillard reaction products of peanut oils

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Abstract This study was designed to investigate the influence of dry air roasting (140, 160 and 180 °C for 5 and 10 min) and extraction methods (solvent and mechanical) on peanut oil quality characteristics. Oil yield, oxidative stability index (OSI), radical scavenging activity (RSA), and Maillard reaction products were increased while peroxide value (PV) and conjugated dienes were decreased in oil of peanuts roasted at 180 °C for 10 min. Oils extracted mechanically from roasted peanuts had lower PV while higher OSI and RSA than the solvent-extracted oils. The fatty acid composition of oils from roasted peanuts (at 160 and 180 °C for 10 min) changed slightly compared to unroasted peanuts. The level of 5-hydroxymethylfurfural and non-enzymatic browning index was significantly increased in oil from peanuts roasted at 180 °C for 10 min. FTIR spectra showed a slight change in peak intensities with no observed peak shift in oils extracted from peanuts roasted at 180 °C for 10 min. Based on the results obtained, mechanically extracted oil from peanuts roasted at 180 °C for 10 min improves oil quality characteristics and enhances oxidative stability.

Keywords Peanuts · Roasting · Extraction method · Oxidative stability · Fatty acid composition · MRPs

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Introduction

Peanut (*Arachis hypogaea* L.) is one of the most popular leguminous crops across the world known for its high nutritional value and multipurpose uses in food products (Akram et al. 2018). It is primarily cultivated in tropical, subtropical and warm agro-climates of Africa, Asia, Australia, and America as one of the major oil-seed crops for edible purposes. Peanut is grown on 26 million hectares area and is contributing approximately 5.77 million metric tons (MMT) of oil in total worldwide vegetable oils production (Nawade et al. 2018). China, India, Nigeria, and the USA are major peanut-producing countries in total annual worldwide production of 29–30 MMT (Wang 2018). In India, peanut production is significant for oil extraction and as an important ingredient in various snack foods due to its distinctive flavor and a rich source of bioactive components (Arya et al. 2016). Peanut is an important crop for industrial processing and edible oil production. Evaluation of new approaches in peanut processing and oil extraction is of significant importance for human health. Consumption of processed peanut or peanut oil is beneficial for decreasing the risk of cardiovascular diseases, diabetes and colorectal cancer (Akram et al. 2018; Arya et al. 2016; Dun et al. 2018).

Roasting, deep frying, blister frying, boiling, and microwave heating is generally used in peanut processing (Ali et al. 2017; Shi et al. 2017). The pre-treatment of oilseeds increases the levels of bioactive compounds, enhances aroma and improves oil yield (Wroniak et al. 2016). The quality of oil obtained from peanut depends mainly on processing methods as they significantly affect the concentration of major oil components (Dun et al. 2018). Roasting is commonly employed to prepare oilseeds for human intake. Evaluation of oils extracted from

roasted seeds for quality characteristics is extremely important (Shi et al. 2017). During roasting, melanoidins produced as a result of Maillard reaction products (MRPs) improves oxidative stability and impart typical color and flavor to oil (Zou et al. 2018). Earlier studies reported that the temperature, time duration and method of roasting affects quality characteristics of oils from different crops (Cai et al. 2013; Shi et al. 2017; Zou et al. 2018).

The extraction process is an important step in the production of oil from oilseeds. Mechanical expression (screw pressing) and organic solvent (using n-hexane) extraction are the two conventional oil recovery methods commonly followed in oil industries (Bogaert et al. 2018). Oilseeds after passing through continuous mechanical pressing are extracted with a solvent to recover residual oil (Koubaa et al. 2016). The extraction process is an important factor in the properties of oils obtained from oil-seeds (Mohammed et al. 2016). There is a growing demand from consumers, oil-extraction and production industries to study differences in the oil qualities obtained by the different extraction and processing methods (Koubaa et al. 2016; Petropoulos et al. 2018). The dry air roasting process and extraction method affect nutritional value and oxidative stability of oils and understanding of these aspects are of utmost importance. To the best of our knowledge, there is a lack of information available in the literature regarding the effect of dry roasting and extraction process on peanut oil characteristics. With this background, the present study was carried out to investigate the effect of dry roasting and extraction method on chemical properties, oxidative stability, FAC and MRPs formation in peanut oils.

Materials and methods

Materials

Peanuts of commercial variety were procured from the local market in Amritsar (Punjab), India and were stored at 4 °C for further treatments and analysis. Methanol, *n*-hexane, iso-octane, potassium hydroxide and p-anisidine were purchased from Merck (India). 2,2-Diphenyl-1-picrylhydrazyl (DPPH) and 5-hydroxymethylfurfural (HMF) were obtained from Sigma-Aldrich (St. Louis, MO, USA). Certified reference material of fatty acid methyl ester (FAME) 37 Mix from Supelco was purchased. All the chemicals and reagents were of analytical grade.

Dry air roasting and oil extraction

250 g of peanuts were roasted in an air fryer (Philips, India) at temperatures of 140, 160 and 180 °C for 5 and 10 min, respectively in the triplicate set. After roasting, peanuts were allowed to cool to room temperature and stored in polyethylene bags at 4 °C until further processed.

Solvent extraction

Oil was extracted from the 250 g of unroasted and roasted peanuts by following procedure mentioned elsewhere with slight modifications (Damirchi et al. 2005). Roasted peanuts were powdered using electric grinder mixer, treated with n-hexane (750 ml) and agitated at 200 rpm in an orbital shaker (Remi, India) for 2 h. The extraction process was repeated for two times with n-hexane. The mixture was filtered with Buchner funnel under vacuum and the solvent was evaporated with a rotary evaporator (IKA R-10, Germany) at 40 °C and the remaining oil was collected and stored at 4 °C for further analysis. The oil was weighed to calculate oil yield (%) and stored at 4 °C for further analysis.

Mechanical extraction

Oil was extracted from 250 g of unroasted and roasted peanuts by using screw expeller (Rajkumar Agro Engineers Pvt. Ltd. Nagpur, India) at a temperature below 50 °C. After extraction, oil was centrifuged at 12,000 rpm for 10 min to remove impurities, weighed to calculate oil yield (%) and stored at 4 °C for further analysis.

Chemical properties

Acid value (method Ca 5a-40) and peroxide value (method Cd 8b-90) were determined according to Official methods of AOCS (AOCS 1997). The conjugated dienes (CD) content was determined by the IUPAC II D.23 method (IUPAC 1987). 1% oil solution was prepared by dissolving in *n*-hexane and mixed thoroughly. The absorbance values were then measured at 233 nm.

Oxidative stability index (OSI)

OSI in terms of induction period (IP) was determined with 892 professional rancimat apparatus (Metrohm, Switzerland). The tests were carried out with 3 g of oil samples at a temperature of 120 ± 1.6 °C and an air flow of 20 l/h. IP was calculated automatically by apparatus software with the precision of 2 decimal places.

Radical scavenging activity (RSA)

Radical scavenging activity (RSA) of peanut oils was determined according to the procedure described by Kalantzakes et al. (2006). Briefly,1 ml of oil solution (10%

w/v) prepared in ethyl acetate was mixed with 4 ml of freshly prepared DPPH (0.1 mM) solution. Oil samples were shaken vigorously and incubated in dark for 30 min. The absorbance of the DPPH solution and samples were recorded before and after incubation at 515 nm using UV/VIS spectrophotometer (Cary-60, Agilent Technologies, Santa Clara, CA, USA). Ethyl acetate was used as blank and results were calculated as % DPPH inhibition and represented as RSA using the following equation

$$RSA = \left[1 - \frac{A_{30}}{A_c}\right] \times 100$$

where RSA is the percent radical scavenging capacity, A_{30} is the absorbance of the sample after 30 min incubation and A_c is absorbance of control DPPH solution.

Analysis of Maillard reaction products (MRPs)

5-Hydroxymethylfurfural (HMF) was extracted from peanut oil by liquid–liquid extraction procedure and determined by HPLC system as described by Durmaz and Gömen (2010). 0.5 g of oil was mixed with 1 ml of methanol (70%) in Eppendorf tube for analysis. The mixture was vortexed for 1 min and centrifuged at 10,000 rpm for 5 min. After centrifugation, the upper layer was separated from the mixture and extraction was repeated for three times. The combined mixture of upper layers was diluted to 5 ml by methanol (70%) and filtered through a 0.45 µm nylon syringe filter. HMF was detected using HPLC system (Agilent Infinity 1260, Agilent Technologies, Santa Clara, CA, USA) comprised of a diode array detector quaternary gradient pump and Agilent C18 column (250 × 4.6 mm, 5 µm, Agilent Technologies) at a wavelength of 285 nm. The quantification of HMF was done by comparing their retention time with standard and results were expressed as mg/kg. The non-enzymatic browning index (BI) of peanut oils was determined using the method described earlier (Zou et al. 2018). The solution of oil samples was obtained with oil to chloroform ratio of 1:20 (w/v). The BI of the solution was determined as absorbance at 420 nm using a UV/VIS spectrophotometer (Cary-60, Agilent Technologies, Santa Clara, CA, USA).

Fatty-acid composition

FAC of peanut oil samples was determined according to the American Oil Chemists' Society official method Ce-1 h-05 with slight modifications (AOCS 1997). Gas chromatograph (GC) instrument (Agilent 7820A, Agilent Technologies, USA) equipped with a flame ionization detector (GC-FID) and DB-WAX capillary column (30 m × 0.250 mm × 0.25 µm, Agilent J&W, USA) with temperature limits of 20–250 °C was used to perform the analysis. 2 µl of sample was injected using 10 µl manual syringe (Agilent Technologies, USA) and the injection mode was splitless. Nitrogen was used as a carrier gas with a flow rate of 1.0 ml/min. The initial column temperature of 80 °C was increased to a 150 °C at a rate of 6 °C/min and from 150 to 240 °C at a rate of 2 °C/min. The temperature was maintained at 240 °C for the subsequent 10 min. The injector and detector temperature were maintained at 260 °C. Individual fatty acids (FAs) were quantified by comparing retention times (RT) and a peak area of the unknown sample with FAME standard (FAME mix, Sigma-Aldrich, USA). The individual FAs were expressed as relative percentages (g/100 g) of total FAs. All the analyses were carried out in triplicate.

FTIR spectroscopy

The infrared spectra were acquired using Fourier Transform Infrared Spectroscopy (Vertex-70, Brucker optics instruments, Germany) equipped with Attenuated Total Reflection (ATR) assembly and connected to the OPUS software. IR spectra were recorded accumulating 32 scans/sample at a resolution of 4 cm^{-1} in the spectral range of 4000–650 cm^{-1}. Empty ZnSe crystal was used as a reference and the background spectrum of air was subtracted before scanning a sample. A drop of oil was dropped on the ATR crystal. Triplicate spectra were collected for each sample. The analysis of each spectrum was done by using Origin Pro 8 software.

Statistical analysis

Experiments were performed in triplicate and values were reported as mean values ± standard deviation. The data were subjected to two-way analysis of variance (ANOVA) using Minitab statistical software (version 14.12.0, Minitab, State College, Pa., U.S.A.).

Results and discussion

Oil yield

The oil yield of unroasted and roasted peanuts extracted by solvent and mechanical method is shown in Table 1. The oil yield was higher by solvent extraction as compared to mechanical extraction from unroasted peanuts (47.75 and 41.17%, respectively). The oil yield varied from 47.77 to 55.35% in solvent extracted oils while 41.18 to 46.28% in mechanically extracted oils from roasted peanuts. In both extraction methods, oils from peanuts roasted at 180 °C for 10 min showed the highest oil yield. Earlier studies also reported similar results for microwave roasting of apricot

Table 1 Effect of roasting and extraction methods on chemical properties, oxidative stability and radical scavenging activity of peanut oils

Extraction methods	Roasting conditions	Oil yield (%)	AV mg KOH/g	PV meq O_2/kg	CD value	OSI (h)	RSA
Solvent	Unroasted	47.75 ± 0.15^{a}	0.45 ± 0.02^{a}	3.69 ± 0.04^{a}	2.76 ± 0.03^{c}	4.82 ± 0.04^{c}	58.35 ± 0.65^{b}
	140 °C for 5 min	47.77 ± 0.16^{a}	0.47 ± 0.03^{a}	8.70 ± 0.03^{c}	2.91 ± 0.04^{c}	4.17 ± 0.05^{b}	55.23 ± 1.89^{a}
	140 °C for 10 min	48.41 ± 0.25^{b}	0.53 ± 0.04^{b}	10.63 ± 0.03^{d}	2.97 ± 0.05^{c}	3.99 ± 0.05^{a}	55.21 ± 1.17^{a}
	160 °C for 5 min	51.50 ± 0.32^{c}	0.54 ± 0.06^{b}	12.84 ± 0.03^{e}	3.08 ± 0.03^{d}	3.61 ± 0.03^{a}	54.65 ± 0.73^{a}
	160 °C for 10 min	51.63 ± 0.50^{c}	0.58 ± 0.03^{c}	4.82 ± 0.01^{b}	2.10 ± 0.05^{a}	6.04 ± 0.05^{d}	67.26 ± 1.20^{d}
	180 °C for 5 min	53.83 ± 0.15^{d}	0.59 ± 0.08^{c}	8.08 ± 0.03^{c}	2.64 ± 0.04^{b}	4.13 ± 0.03^{b}	60.48 ± 1.39^{c}
	180 °C for 10 min	55.35 ± 0.40^{e}	0.79 ± 0.09^{d}	2.57 ± 0.01^{a}	2.01 ± 0.04^{a}	8.10 ± 0.05^{e}	69.66 ± 0.56^{d}
Mechanical	Unroasted	41.17 ± 0.46^{a}	0.55 ± 0.07^{a}	6.75 ± 0.03^{d}	2.44 ± 0.05^{b}	4.25 ± 0.05^{a}	60.64 ± 1.49^{c}
	140 °C for 5 min	41.18 ± 0.53^{a}	1.50 ± 0.11^{b}	7.28 ± 0.03^{d}	2.56 ± 0.05^{c}	3.93 ± 0.05^{a}	59.52 ± 1.21^{b}
	140 °C for 10 min	41.97 ± 0.51^{a}	1.59 ± 0.12^{b}	9.56 ± 0.01^{e}	2.71 ± 0.05^{d}	4.35 ± 0.05^{a}	54.46 ± 1.20^{a}
	160 °C for 5 min	42.61 ± 0.34^{b}	1.67 ± 0.11^{b}	12.26 ± 0.01^{f}	2.88 ± 0.04^{e}	4.22 ± 0.05^{a}	54.30 ± 0.74^{a}
	160 °C for 10 min	43.09 ± 0.66^{c}	1.77 ± 0.12^{b}	4.63 ± 0.03^{b}	2.07 ± 0.05^{a}	8.26 ± 0.04^{c}	61.54 ± 1.02^{c}
	180 °C for 5 min	44.03 ± 0.68^{d}	2.13 ± 0.10^{c}	5.35 ± 0.02^{c}	2.54 ± 0.04^{b}	5.82 ± 0.04^{b}	58.29 ± 1.24^{b}
	180 °C for 10 min	46.28 ± 0.57^{e}	2.96 ± 0.10^{d}	2.03 ± 0.02^{a}	2.03 ± 0.03^{a}	10.08 ± 0.05^{d}	74.89 ± 0.41^{d}

Values (mean ± SD, n = 3) with similar superscripts (a–f) in a column do not differ significantly ($p < 0.05$)

AV acid value, *PV* peroxide value, *CD* conjugated dienes *OSI* oxidative stability index, *RSA* radical scavenging activity

kernel and black cumin seeds (Juhaimi et al. 2018; Bakhshabadi et al. 2017). The increase in oil yield of roasted peanut oils may be due to the generation of permanent pores in the cell walls and rupturing of cell walls. The changes in porosity allowed the movement of oil from cell walls and thus increases oil extraction efficiency (Azadmard-Damirchi et al. 2010). F values showed a significant effect of roasting temperature and time on oil yield of solvent and mechanically extracted peanut oils (Tables 2, 3).

Chemical properties

Acid value (AV)

Acid value (AV) of oils obtained by solvent and mechanical extraction from unroasted and roasted peanuts is shown in Table 1. AV of oils obtained by solvent and mechanical extraction from unroasted peanuts was 0.45 and 0.55 mg KOH/g, respectively. AV of solvent and mechanically extracted oils from roasted peanuts ranged between 0.47 to 0.79 mg KOH/g and 1.50 to 2.96 mg KOH/g, respectively. Oils from unroasted peanuts had lower AV than those of peanuts roasted at a higher temperature (160 and 180 °C). An earlier study on oil from roasted sesame seeds also reported similar results (Tenyang et al., 2017). As shown in Table 1, AV was less than 4 mg KOH/g for roasted peanut oils, the recommended value for crude oils (FAO/WHO 2009). Extraction method, roasting temperature and roasting time showed a significant effect on the AV of peanut oils. AV of solvent and mechanically extracted peanut oils varied significantly with roasting temperature and time (Tables 2, 3). Increase in AV may be due to the rapid hydrolysis of triglycerides at a higher temperature, leading to the accumulation of free FAs.

Peroxide value (PV)

The peroxide value (PV) of solvent and mechanically extracted oils from unroasted and roasted peanuts is shown

Table 2 *F* values from ANOVA analysis of the data (roasting temperature versus time) of solvent extracted oils shown in Table 1 and 4

	DF	Oil yield	PV	AV	CD	OSI	RSA	MUFA	PUFA	SFA
Roasting temperature	2	562.82**	36,419.13**	16.07**	407.24**	2559.95**	78.54**	353.20**	253.19**	392.57**
Roasting time	2	552.98**	151,741.96**	30.34**	727.09**	5901.71**	61.79**	577.35**	1075.11**	1339.27**
Interaction	4	145.55**	43,676.48**	6.66**	328.88**	2638.95**	81.62**	143.35**	69.10**	100.12**

DF degree of freedom, *PV* peroxide value, *AV* acid value, *CD* conjugated dienes, *OSI* oxidative stability index, *RSA* DPPH radical scavenging activity, *MUFAs* monounsaturated fatty acids, *PUFAs* polyunsaturated fatty acids, *SFAs* saturated fatty acids

**p <0.005

Table 3 F values from ANOVA analysis of the data (roasting temperature versus time) of mechanical extracted oils shown in Tables 1 and 4

	DF	Oil yield	PV	AV	CD	OSI	RSA	MUFA	PUFA	SFA
Roasting temperature	2	46.99**	40,952.69**	120.54**	591.79**	6660.95**	84.51**	299.30**	138.20**	365.78**
Roasting time	2	54.71**	25,615.65**	638.43**	1612.31**	13,435.63**	113.36**	436.92**	246.17**	1150.95**
Interaction	4	14.13**	39,124.57**	44.15**	1004.35**	3258.28**	48.75**	78.61**	35.11**	95.20**

DF degree of freedom, *PV* peroxide value, *AV* acid value, *p-AV* p-anisidine value, *CD* conjugated dienes, *OSI* oxidative stability index, *RSA* DPPH radical scavenging activity, *MUFAs* monounsaturated fatty acids, *PUFAs* polyunsaturated fatty acids, *SFAs* saturated fatty acids

$^{**}p < 0.005$

in Table 1. PV of oils obtained by solvent and mechanical extraction from unroasted peanuts was 3.69 and 6.75 meq O_2/kg, respectively. PV increased gradually in a solvent (8.70 to 12.84 meq O_2/Kg) and mechanical (7.28 to 12.26 meq O_2/Kg) extracted peanut oils upon increasing roasting conditions from 140 °C for 5 and 10 min to 160 °C for 5 min. However, further increase in roasting conditions from 160 °C for 10 min to 180 °C for 5 and 10 min caused a decrease in PV as shown in Table 1. PV was significantly lower than 10 meq O_2/kg (the recommended PV for oils, FAO/WHO 2009) for oils extracted by solvent (2.57 meq O_2/Kg) and mechanical (2.03 meq O_2/Kg) method from peanuts roasted at 180 °C for 10 min. The initial increase in PV may be due to the accumulation of hydro-peroxides as a result of the free radical attack on unsaturated FAs. Afterward, the level of these peroxides decreases at higher roasting temperature due to their unstable nature. Recent study also reported that PV increased initially till roasting at 160 °C and then decreased on extending the roasting temperature to 180 °C in sesame seed oils (Ji et al. 2019). F values showed a significant effect of roasting temperature and time on PV of solvent and mechanically extracted peanut oils (Tables 2, 3). An earlier study on pecan nut oil indicated a strong relationship between OSI and PV of the oil and reported that the decrease in PV improves OSI of pecan oil (do Prado et al. 2013).

Conjugated dienes (CD)

The conjugated dienes (CD) determines the degree of oxidation in oils. The CD of oils extracted by solvent and mechanical method from unroasted peanuts was 2.76 and 2.44, respectively. CD increased gradually till the roasting temperature of 160 °C for 5 min (3.08 and 2.88) and then decreased at 180 °C for 10 min (2.01 and 2.03) for both solvent and mechanical extracted oils, respectively (Table 1). The decrease in CD value at higher (180 °C) roasting temperature indicates an accelerated degradation of hydro-peroxide like structures. An earlier study reported that CD showed no initial increase with roasting while decreased at a higher roasting temperature in coffee seed oils (Budryn et al. 2012). F values showed a significant effect of roasting temperature and time on CD of peanut oils extracted by solvent and mechanical method (Tables 2, 3).

Oxidative stability index (OSI)

The OSI of oils obtained by solvent and mechanical extraction from unroasted and roasted peanuts is shown in Table 1. OSI mainly measures the formation of primary or secondary oxidation products and it depends on the amount of antioxidants present in oils (Pereira et al. 2019). OSI of solvent and mechanically extracted oils from unroasted peanuts was 4.82 and 4.25 h, respectively. Highest OSI of 8.10 and 10.08 h was observed for solvent and mechanically extracted oils from peanuts roasted at 180 °C for 10 min. OSI decreased with increase in roasting temperature from 140 to 160 °C for 5 min and increased at 180 °C for 10 min. The initial decrease in OSI of oils till roasting at 160 °C for 5 min may be the result of an increase in oil oxidation products. These products start degrading at a higher roasting temperature which may increase the oxidative stability of peanut oil. OSI was significantly increased with increase in roasting time at high temperature (180 °C for 10 min). MRPs are more likely to be extracted from seeds roasted at high temperature and this may be the possible reason behind the improved OSI of oils (Shrestha et al. 2013). The statistical analysis revealed a significant effect of roasting temperature and time on OSI of peanut oils extracted by solvent and mechanical method (Tables 2, 3).

Radical scavenging activity (RSA)

The RSA of solvent and mechanically extracted oils from unroasted peanuts is 58.35 and 60.64%, respectively (Table 1). The highest RSA was observed in oils extracted by solvent (69.66%) and mechanical (74.89%) method from peanuts roasted at 180 °C for 10 min. Probably the greater RSA of peanut oils obtained at a higher temperature may be due to the formation of non-enzymatic reaction products. The increased antioxidant activity can be

attributed to the release of phenolics or Maillard reaction products (MRPs) such as HMF into the oil-phase after roasting at a higher temperature (Jogihalli et al. 2017). These compounds are known to have strong antioxidant properties (Zou et al. 2018). F values showed a significant impact of roasting temperature and time on RSA of oils extracted by solvent and mechanical method (Tables 2, 3).

Effect of roasting on Maillard reaction products (MRPs)

The non-enzymatic browning index (BI) and 5-Hydroxymethylfurfural (HMF) content of solvent and mechanical extracted oils from unroasted and roasted peanuts are illustrated in Fig. 1. HMF was not detected in oils extracted from unroasted peanuts and those roasted at 140 and 160 °C for 5 min. At higher roasting temperature (180 °C), the level of HMF was increased from 1.44 to 3.07 mg/kg in a solvent extracted oils and from 1.79 to 9.74 mg/kg in mechanical extracted oils with an increase in roasting time from 5 to 10 min. Oils obtained from unroasted peanuts and those roasted at 140 °C (for 5 and 10 min) and 160 °C for 5 min exhibited similar non-enzymatic BI in both extraction methods. However, higher BI was observed in oils extracted from peanut roasted at 180 °C for 10 min (Fig. 1). The HPLC analyses of peanut oils indicated that HMF increases at a higher roasting temperature in a time-dependent manner. MRPs (HMF and furfural derivatives) formed during roasting are responsible for the browning of oils (Cai et al. 2013). The BI of peanut oils also increased significantly with the increase of roasting time at higher temperature (180 °C for 10 min). Similar phenomena were observed for oil extracted from roasted wheat germ and pine nuts (Zou et al. 2018; Cai et al. 2013). During roasting, the interaction of reducing sugars with free amino acids or lipid oxidation products results into the formation of Maillard reaction products (Zou et al. 2018).

Fatty acid composition (FAC)

Effect of roasting on fatty acid composition (FAC) of solvent and mechanically extracted oils from unroasted and roasted peanuts is shown in Table 4. Eight FAs detected in peanut oil were palmitic (C16:0), stearic (C18:0), arachidic (C20:0), behenic (C22:0), lignoceric (C24:0), oleic (C18:1n9c), eicosaenoic (C20:1n9c) and linoleic (C18:2n6c) acid. A high proportion of unsaturated fatty acids (MUFAs and PUFAs) and a low proportion of saturated fatty acids were present in peanut oil. Oleic and linoleic acid were detected as the dominant unsaturated FAs in peanut oil. Results are comparable to data published previously (Ali et al. 2017). SFAs, MUFAs and PUFAs content in oil from unroasted peanuts extracted chemically were 19.53, 40.96 and 39.29% and those extracted mechanically were 19.99, 39.82, 39.08%, respectively (Tables 2, 3). FAC of peanut oils varied slightly with the roasting temperature and time duration. SFAs content increased while no significant difference in PUFAs and MUFAs content were observed in peanut oils after roasting (Tables 2, 3). The oils extracted using solvent and mechanical method from the peanuts roasted at 180 °C for 10 min contains the higher level of SFAs (palmitic, stearic, arachidic, behenic and lignoceric acids) compared to unroasted peanuts. The level of oleic, linoleic and eicosaenoic acid was slightly reduced in peanut oil after roasting at 180 °C for 10 min. The slight reduction may be due to the degradation of unsaturated fatty acids in the oils at a higher temperature. Similar results were reported for oil extracted from roasted poppy and sesame seeds (Ghafoor et al. 2019; Ji et al. 2019). F values showed a

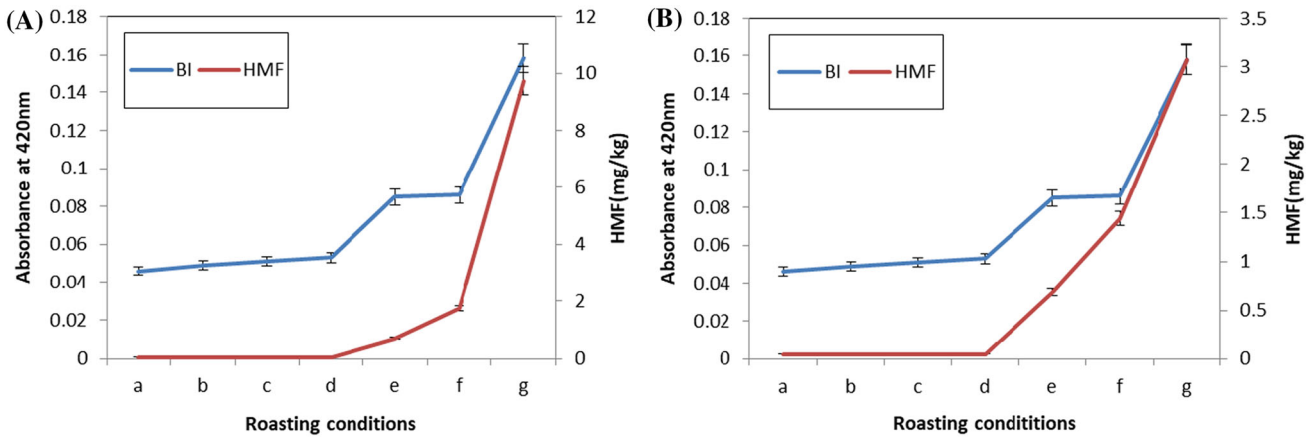

Fig. 1 Effect of roasting conditions on browning index (BI) and 5-hydroxymethylfurfural (HMF) content in **A** mechanically and **B** solvent extracted oils from roasted peanuts (a: unroasted; b: 140 °C for 5 min c: 140 °C for 10 min; d: 160 °C for 5 min; e: 160 °C for 10 min; f: 180 °C for 5 min; g: 180 °C for 10 min)

Table 4 Effect of roasting and extraction methods on fatty acid composition (%) of peanut oils

Extraction methods	Roasting conditions	C16:0 (Palmitic)	C18:0 (Stearic)	C20:0 (Arachidic)	C22:0 (Behenic)	C24:0 (Lignoceric)	C18:1n9c (Oleic)	C20:1n9c (Eicosenoic)	C18:2n6c (Linoleic)	SFAs	MUFAs	PUFAs
Solvent	Unroasted	11.74 ± 0.04^{a}	3.20 ± 0.02^{a}	1.28 ± 0.02^{a}	2.37 ± 0.04^{a}	0.94 ± 0.03^{a}	39.64 ± 0.03^{c}	1.32 ± 0.02^{e}	39.29 ± 0.02^{d}	19.53 ± 0.09^{a}	40.96 ± 0.05^{d}	39.29 ± 0.02^{e}
	140 °C for 5 min	11.77 ± 0.04^{a}	3.48 ± 0.05^{b}	1.29 ± 0.03^{a}	2.72 ± 0.02^{b}	1.07 ± 0.02^{b}	39.60 ± 0.03^{c}	1.11 ± 0.03^{d}	39.08 ± 0.04^{d}	20.33 ± 0.02^{b}	40.71 ± 0.05^{d}	39.08 ± 0.04^{d}
	140 °C for 10 min	11.91 ± 0.03^{b}	3.55 ± 0.04^{b}	1.35 ± 0.01^{b}	2.82 ± 0.02^{c}	1.12 ± 0.03^{bc}	39.59 ± 0.07^{c}	1.10 ± 0.02^{cd}	38.86 ± 0.05^{c}	20.75 ± 0.06^{b}	40.69 ± 0.05^{d}	38.86 ± 0.05^{c}
	160 °C for 5 min	12.01 ± 0.04^{c}	3.59 ± 0.04^{b}	1.39 ± 0.04^{b}	2.98 ± 0.02^{c}	1.18 ± 0.02^{c}	39.14 ± 0.04^{b}	1.08 ± 0.04^{c}	38.64 ± 0.04^{a}	21.15 ± 0.04^{c}	40.22 ± 0.00^{c}	38.64 ± 0.04^{b}
	160 °C for 10 min	12.09 ± 0.02^{c}	3.62 ± 0.03^{c}	1.41 ± 0.03^{c}	3.03 ± 0.04^{d}	1.20 ± 0.02^{d}	38.97 ± 0.03^{a}	0.99 ± 0.02^{b}	38.61 ± 0.04^{a}	21.35 ± 0.02^{c}	39.95 ± 0.04^{b}	38.61 ± 0.04^{b}
	180 °C for 5 min	12.31 ± 0.03^{d}	3.80 ± 0.02^{d}	1.43 ± 0.04^{c}	3.26 ± 0.02^{e}	1.23 ± 0.02^{d}	38.82 ± 0.02^{a}	0.97 ± 0.03^{b}	38.53 ± 0.01^{a}	22.04 ± 0.10^{d}	39.79 ± 0.05^{b}	38.53 ± 0.01^{a}
	180 °C for 10 min	12.36 ± 0.04^{d}	3.96 ± 0.04^{d}	1.50 ± 0.03^{d}	3.43 ± 0.02^{e}	1.24 ± 0.04^{d}	38.69 ± 0.05^{a}	0.89 ± 0.05^{a}	38.40 ± 0.05^{a}	22.48 ± 0.15^{e}	39.32 ± 0.07^{a}	38.40 ± 0.05^{a}
Mechanical	Unroasted	11.65 ± 0.03^{a}	3.35 ± 0.03^{a}	1.28 ± 0.05^{a}	2.82 ± 0.03^{a}	0.89 ± 0.03^{a}	38.65 ± 0.04^{d}	1.17 ± 0.01^{e}	39.08 ± 0.04^{d}	19.99 ± 0.10^{a}	39.82 ± 0.03^{e}	39.08 ± 0.04^{d}
	140 °C for 5 min	11.99 ± 0.02^{b}	3.60 ± 0.05^{b}	1.36 ± 0.04^{b}	2.86 ± 0.02^{a}	0.97 ± 0.02^{b}	38.62 ± 0.03^{c}	1.09 ± 0.02^{e}	39.04 ± 0.04^{d}	20.78 ± 0.06^{b}	39.71 ± 0.05^{d}	39.04 ± 0.04^{d}
	140 °C for 10 min	12.14 ± 0.02^{c}	3.68 ± 0.03^{c}	1.40 ± 0.02^{bc}	2.91 ± 0.03^{b}	1.01 ± 0.04^{b}	38.60 ± 0.03^{c}	1.04 ± 0.05^{d}	38.96 ± 0.02^{c}	21.15 ± 0.08^{c}	39.64 ± 0.02^{d}	38.96 ± 0.02^{c}
	160 °C for 5 min	12.23 ± 0.03^{d}	3.75 ± 0.03^{d}	1.46 ± 0.02^{c}	2.96 ± 0.04^{b}	1.04 ± 0.02^{b}	38.54 ± 0.04^{c}	0.98 ± 0.04^{d}	38.82 ± 0.05^{c}	21.44 ± 0.10^{c}	39.52 ± 0.05^{d}	38.82 ± 0.05^{c}
	160 °C for 10 min	12.29 ± 0.04^{d}	3.76 ± 0.04^{d}	1.53 ± 0.05^{d}	3.12 ± 0.03^{c}	1.20 ± 0.03^{c}	38.32 ± 0.04^{b}	0.96 ± 0.02^{c}	38.70 ± 0.05^{bc}	21.90 ± 0.03^{d}	39.28 ± 0.06^{c}	38.70 ± 0.05^{bc}
	180 °C for 5 min	12.36 ± 0.04^{d}	3.79 ± 0.03^{d}	1.61 ± 0.03^{e}	3.24 ± 0.04^{d}	1.39 ± 0.02^{d}	38.31 ± 0.05^{b}	0.76 ± 0.04^{b}	38.67 ± 0.04^{b}	22.39 ± 0.02^{d}	39.07 ± 0.09^{b}	38.67 ± 0.04^{b}
	180 °C for 10 min	12.56 ± 0.04^{e}	3.84 ± 0.02^{e}	1.71 ± 0.05^{f}	3.56 ± 0.04^{e}	1.50 ± 0.05^{d}	38.22 ± 0.04^{a}	0.62 ± 0.03^{a}	38.52 ± 0.02^{a}	23.16 ± 0.18^{e}	38.84 ± 0.02^{a}	38.52 ± 0.02^{a}

Values (mean ± SD, n = 3) with similar superscripts (a–f) in a column do not differ significantly ($p < 0.05$)

SFAs saturated fatty acids, *MUFAs* monounsaturated fatty acids, *PUFAs* polyunsaturated fatty acids

significant influence of roasting temperature and time on PUFAs, MUFAs and SFAs content of peanut oils extracted by solvent and mechanical method (Tables 2, 3).

FTIR spectroscopy

FTIR information of solvent and mechanically extracted oils from unroasted and roasted peanut oils was determined in the spectral region of 4000–650 cm^{-1}. As shown in Fig. 2, the FTIR spectra showed absorption bands at different wavenumbers, as follows: shoulder peak at 3008 cm^{-1} (associated with C–H stretching symmetric vibration of cis-olefinic double-bonds,=CH), sharp peak at 2929 cm^{-1} (assigned to asymmetric stretching vibration of C–H bonds of aliphatic CH_2 groups of triglycerides), sharp shoulder peak at 2854 cm^{-1} (attributed to symmetric stretching vibration of C–H bonds of aliphatic CH_2 functional groups of triglycerides), sharp peak at 1745 cm^{-1} (represents stretching vibration of ester carbonyl (C=O) functional groups of the triglycerides), peak at 1463 cm^{-1} (bending vibration of C–H bonds of CH_2 aliphatic groups of triglycerides), small peak of weak intensity at 1377 cm^{-1} (bending symmetric vibration of C–H bonds of CH_2 groups of triglycerides) and sharp peak at 1161 cm^{-1} (stretching vibration of C–O ester groups of the triglycerides). Earlier studies reported similar spectral information in different edible oils (Ozulku et al. 2017; Poiana et al. 2015).

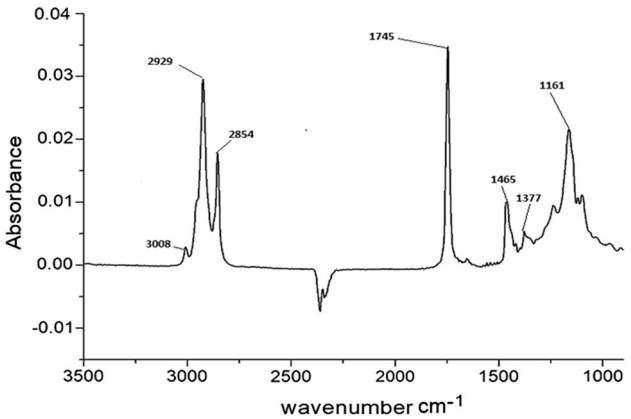

Fig. 2 FTIR spectrum of peanut oil at room temperature (25 °C)

Visual examination of FTIR spectra does not show any marked difference in spectral features apart from slight changes in the intensities of some peaks (Fig. 3). No significant difference in peak intensities was observed in oils extracted by solvent and mechanical method (Fig. 3A, B). All the peaks were observed at designated wave numbers and no shift in peaks was observed in oils extracted from peanuts roasted at high temperature. Upon closer examination, a slight increase or decrease in the peak intensities was observed in certain spectral regions of oil extracted from roasted and unroasted peanuts (Fig. 3). The intensity of the peak at 3008 cm^{-1} depends on unsaturated FAC of oils. A slight decrease in intensity of shoulder peak at 3008 cm^{-1} indicating the disappearance of cis double bonds was observed in oil from peanut roasted at 180 °C for 10 min compared to oil of unroasted peanuts (Fig. 3). FAC of oils also showed a slight decrease in the level of unsaturated FAs (oleic, ecosenoic and linoleic acid) as a consequence of the roasting process (Table 4). An earlier study also reported a similar trend at wavenumber 3008 cm^{-1} in safflower oil after roasting (Mariod et al. 2012). The intensities of the peak at 2929 cm^{-1} and shoulder peak at 2854 cm^{-1} were slightly increased in oil extracted from peanuts roasted at 180 °C for 10 min. These peaks are associated with a slight increase in the level of saturated

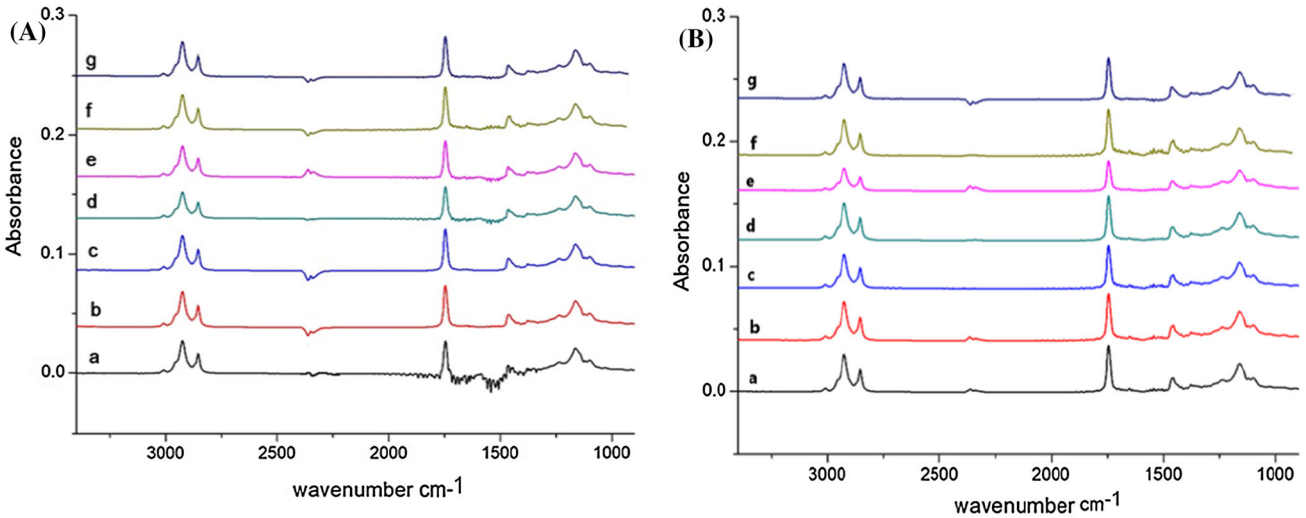

Fig. 3 FTIR spectra of unroasted and roasted peanut oils extracted by **A** solvent and **B** mechanical method (a: unroasted; b: 140 °C for 5 min c: 140 °C for 10 min; d: 160 °C for 5 min; e: 160 °C for 10 min; f: 180 °C for 5 min; g: 180 °C for 10 min)

FAs (palmitic, stearic, arachidic, behenic and lignoceric acid) in peanut oils after roasting (Table 4, Fig. 3). Earlier studies had correlated levels of unsaturated and saturated FAs with peak intensities observed at 3008, 2929 and 2854 cm^{-1} wavenumber regions of edible oils (Ozulku et al. 2017; Poiana et al. 2015; Sim and Ting 2012). The oil extracted from peanuts roasted at 180 °C for 10 min showed no significant change in peak intensity at 1745 cm^{-1} compared to unroasted and roasted at 180 °C for 5 min. This indicates that secondary oxidation products responsible for the off-flavor were not formed in oils of roasted peanuts. In comparison with oil from unroasted peanuts, higher or equal peak intensities at 1465, 1377 and 1161 were observed for oil from peanuts roasted at 180 °C for 10 min. The FTIR spectra justify that slight change in peak intensities at certain wave number regions in the IR spectra were due to a slight change in FAC of oils obtained from roasted in comparison to unroasted peanuts.

Conclusion

Dry air roasting is an excellent way to improve the oil yield and oxidative stability of peanut oils. Roasting and extraction methods have significantly affected the quality parameters of oils such as PV, AV, CD, OSI and RSA of oils with minor changes in FAC. MRPs (HMF and browning index) were increased by roasting of peanuts at 180 °C for 10 min. Mechanically extracted oils had lower PV and higher OSI and RSA. The FTIR spectra confirmed no peak shifting in oil from peanuts roasted at 180 °C for 10 min. Mechanically extracted oils from peanuts roasted at 180 °C for 10 min can be used for blending with oils having lower oxidative stability. Incorporation or consumption of roasted peanut oils has a wide range of possible applications in the prevention of oil oxidation and extending the shelf life of oils or food products.

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Compliance with ethical standards

Conflict of interest The authors declared that they have no conflict of interest.

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