Effect of superheated-steam roasting on physicochemical properties of peanut (*Arachis hypogaea*) oil

N. F. M. Idrus¹ · W. Zzaman^{1,2} · T. A. Yang¹ · A. M. Easa¹ · M. S. Sharifudin³ ·
B. W. Noorakmar³ · M. H. A. Jahurul³

Received: 31 December 2016 / Revised: 5 April 2017 / Accepted: 10 April 2017 / Published online: 27 July 2017
© The Korean Society of Food Science and Technology and Springer Science+Business Media B.V. 2017

Abstract Peanut (*Arachis hypogaea*) is an important source of protein and lipid globally. The effect of superheated-steam roasting on quality of peanut oil was evaluated based on physicochemical quality parameters. Three roasting temperatures (150, 200, and 250 °C) were used for different periods of roasting time and the obtained results were compared with those of conventional roasting. At 250 °C, superheated-steam roasted peanuts yielded more oil (26.84%) than conventionally roasted peanuts (24.85%). Compared with conventional roasting, superheated-steam roasting resulted in lower oil color, peroxide, p-anisidine, free fatty acid, conjugated diene and triene, and acid values and higher viscosity and iodine values in the roasted peanut oil. These values were significantly different from each other ($p < 0.05$). The fatty acids in roasted peanut oils were affected by roasting temperature and time for both the roasting modes. The superheated steam technique can be used to roast peanuts while maintaining their favorable characteristics.

Keywords Peanut oil · Superheated steam · Conventional roasting · Physicochemical properties · GC

Introduction

Peanut oil is one of the important vegetable oils in human diet in many countries. The major compositions of peanut are protein (27–29%) and oil (40–50%) [1]. Mechanical pressing and solvent extractions are the two most commonly used methods for peanut oil extraction. Among these two methods, mechanical pressing is less efficient owing to its low ability to recover oil, which is in the range of 40–60%. On the other hand, solvent extraction could yield 90–98% of oil recovery. However, solvent extraction has several disadvantages (when compared with mechanical pressing): (1) lower-quality protein in oil cake produced, (2) high required investment, and (3) high energy requirement [2]. Oil color and viscosity are essential physical parameters to evaluate edible oil quality which is directed to the marketplace. Furthermore, these parameters have been monitored throughout the processes based on the commercial standard fixed to maintain consistent oil quality. There have been several studies on the determined color and viscosity of edible oils such as almond, canola, corn, grape seed, hazelnut, olive, sunflower, sesame, soybean, and walnut oils [3, 4].

Like all vegetable oils, triglycerides are the major component of peanut oil and they contain glycerol and fatty acids such as palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2), arachidic (C20:0), eicosenoic (C20:1), behenic (C22:0), and lignoceric (C24:0) acids. Among these fatty acids, oleic and linoleic acids are the major factors towards the peanut oil nutritional quality. Moreover, these two fatty acids constituted 80% of the total fatty acids of peanut oil, which has a significant effect on the stability of the oil [5]. A past study concluded that the oleic to linoleic acid ratio contributes highly to the stability of peanut oil, where a high ratio indicates more

✉ M. H. A. Jahurul
jahurul@ums.edu.my; jahurulhaque@yahoo.com

¹ Food Technology Division, School of Industrial Technology, Universiti Sains Malaysia, 11800 Minden, Pulau Pinang, Malaysia

² Department of Food Engineering and Tea Technology, Shahjalal University of Science and Technology, Sylhet 3114, Bangladesh

³ Faculty of Food Science and Nutrition, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia

stable oil [6]. This ratio varies among peanut variety and could be affected during peanut processing steps [7]. A major concern with roasted peanut and peanut products is lipid oxidation and production of off flavors during the roasting process. Lipid oxidation is a major concern in the peanut roasting industry as oil constitutes 50% of peanuts.

The normal convection roasting method is commonly used for roasting cocoa beans at different temperatures (120–250 °C) and for different durations (60–120 min). This method has certain disadvantages because of traditional ways of heating and energy transfer. Zzaman and Yang [8] reported that convection roasting induces burn flavor, undesirable color, acrylamides, and loss of antioxidant properties of cocoa beans due to prolonged heating. Superheated steam cooking involves introduction to food of superheated steam vapor that is generated from water heated at a temperature above the saturation temperature under the given pressure. The advantages of superheated steam cooking include an increase of heat transfer, which enhances thermal degradation; provision of an oxygen-free environment in which food oxidation is prevented; an accelerated drying rate, which relates to energy efficiency [8, 9]. In this study, the effect of superheated steam and conventional roasting at three different temperatures to certain quality attributes of peanut oil were determined based on physicochemical properties such as total oil yield; oil color; oil viscosity; and peroxide, iodine, free fatty acid, acid, p-anisidine, conjugated dienes and trienes values, and fatty acids.

Materials and methods

Sample preparation

Runner-type raw peanuts (average length: $1.85 \text{ cm} \pm 0.16$; moisture content: $5.05 \pm 0.23\%$ /weight) obtained from Georgetown, Penang, stored in a chiller (7 °C), and allowed to equilibrate at room temperature before roasting. The peanuts (100 g) were placed in a single-layer plate and roasted using a superheated steam oven (Healsio, AX-1500 V, SHARP) under the superheated steam and conventional modes (normal without steam). Each roasting was conducted at 150, 200, and 250 °C for different roasting times. All procedures were conducted in triplicates.

Oil extraction

All raw peanuts and peanuts roasted using superheated steam and conventional roasting at three different temperatures for each roasting time were pressed using the hydraulic pressing technique. In cocoa-based industries,

roasting is one of the important unit operations in cocoa processing. Roasting has significant impact on the quality of cocoa products. The roasting temperature and times were selected in this study based on our previous studies [8, 9]. A manually operated hydraulic press was used to obtain peanut oil via pressing. Around 300 g of samples were weighed and placed into a mould before being pressed using a hydraulic presser. The pressure of presser was maintained at 100 kPa.

Physicochemical properties

It's the peroxide, p-anisidine, iodine, free fatty acid, acid, and conjugated dienes and trienes values were obtained according to the AOAC [10] method for both raw and roasted peanuts at each roasting temperature and time. All samples for physicochemical analysis were prepared in triplicates.

Color determination

Oil color for raw and roasted peanuts for each roasting mode, temperature, and time were measured using a Minolta CM-3500D colorimeter (light source, pulsed xenon arc lamp; reflectance, d/8; measurement time, 2.5 s) after calibration against white and black glass standards. Colors were expressed as CIELAB color values (L^* , a^* , b^*), where the L^* value represents the lightness to darkness gradation, the a^* value represents the greenness to redness spectrum, and the b^* value represents the blueness to yellowness spectrum. All samples were measured in triplicates.

Viscosity analysis

Viscosity of raw and roasted peanut oils for each roasting mode, temperature, and time were measured using a viscometer. Around 30 ml of oil was placed into cube glass, which was then placed onto a viscometer. Viscosity of the oil was expressed in mPa s. All samples were measured in triplicates.

Fatty acid determination

The fatty acids in peanut oil were determined using gas chromatography with a flame ionization detector (GC 2010 Plus, Shimadzu with AOC 5000, Shimadzu, Osaka, Japan). The BPX70 (70% Cyanopropyl polysilphenylene-siloxane, 30-m length, with a $0.25 \mu\text{m}$ film coating, 0.25 mm ID, SGE France) capillary column was used to determine the fatty acids. The detailed procedure for fatty acid analysis is discussed in our previous study [11].

Statistical analysis

Data analysis was performed using the general liner model (GLM) and post hoc analysis was conducted using Tukey Honestly Significant difference (HSD) in the Statistical package for social science (SPSS) software version 17.0 (IBM Corporation, Armonk, New York, USA). The statistical analyses were performed at a 5% significance level.

Results and discussion

Total oil yield

Raw peanuts yielded 15.94% of oil, while peanuts roasted using superheated steam and conventional roasting at 150 °C for 5 min yielded 16.25 and 19.96%. The total oil yield increased with roasting time in both roasting modes (Table 1). At low temperature of 150 °C, peanuts roasted using superheated steam yielded lower amounts of oil compared with conventionally roasted peanuts. However, opposite trends were observed at higher temperature (250 °C), where peanuts roasted using superheated steam yielded more oil in comparison with conventionally roasted peanuts. For example, 25.51% oil was obtained in peanuts roasted with superheated steam at 250 °C, while 22.85% oil was obtained for

conventionally roasted peanuts. According to Li et al. [12], the peanut oil yield increases slightly with temperature from 130 to 150 °C and decreases the total protein content from 84.33 to 51.40%. The maximum peanut oil yield was attained for roasting at 150 °C for 20 min via conventional microwave heating, and the quality of oil was affected if higher temperature was applied during the roasting process. Approximately 40% oil has been extracted from peanuts via a typically followed series of steps including cracking into small pieces, cooking, and mechanical pressing extraction. The remaining oil is extracted using organic solvents (hexane), which is obtained via an evaporation–condensation system. The reduction of oil yield observed in this study could be attributed to the extraction method as well as extraction times (5–40 min only). Furthermore, it may vary because of the moisture content of peanuts before pressing, applied pressure, displacement or compression speed of the piston, cake thickness expressed as a function of mass of seeds per pressing unit area (kg/cm²), and pressing duration. The oil degradation process has been established as a free radical mechanism that yields hydroperoxides, also known as primary oxidation products, which are then degraded into aldehydes, ketones, lactones, alcohols, acids, and so on generally known as secondary oxidation products [13].

Table 1 Extracted oil yield (%) from raw and roasted peanuts subjected to superheated-steam and conventional roasting at various temperatures and times

Roasting modes	Temperature (°C)	Time (min)	Oil yield (%)
Raw			15.94 ± 0.05 ^a
Superheated steam	150	5	16.25 ± 0.03 ^b
		20	16.60 ± 0.02 ^c
		40	17.30 ± 0.01 ^d
	200	5	22.85 ± 0.02 ^g
		10	23.80 ± 0.40 ⁱ
		20	24.16 ± 0.05 ^j
	250	2	23.09 ± 0.03 ^h
		5	25.51 ± 0.02 ^l
		10	26.84 ± 0.04 ^m
Conventional	150	5	19.96 ± 0.07 ^e
		25	24.29 ± 0.01 ^j
		45	25.53 ± 0.06 ^l
	200	5	22.37 ± 0.03 ^f
		15	23.06 ± 0.03 ^h
		25	23.68 ± 0.07 ⁱ
	250	5	22.84 ± 0.06 ^g
		10	24.85 ± 0.06 ^k
		15	26.69 ± 0.21 ^m

Mean ± standard deviation

Different letter indicates significant difference between values ($p < 0.05$)

Physicochemical properties

Oil color

The lightness values of raw, superheated-steam-roasted, and conventional roasting (150 °C for 5 min) oils were found to be 93.96, 96.50, and 96.18, respectively. Superheated-steam-roasted peanut oil demonstrated a higher lightness value than raw and conventionally roasted peanut oil. Lightness values decreased with increasing roasting time and temperature in both roasting modes (Table 2). For superheated-steam roasting at 200 °C, lightness value of roasted peanut oil at the initial roasting time (5 min) was 95.19 and decreased to 93.77 at the final roasting time (20 min). The reasons of lightening of peanuts during roasting could be attributed to the reduced moisture content, denaturation of proteins, and the concentrated amount of oil particles embedded in the protein matrix, which may impart whiteness to peanuts by scattering light [14].

Redness values of raw peanut oil was found to be -1.19 , while it was -3.24 and -3.11 for superheated-steam-roasted oil and conventional roasting peanut oils roasted at 150 °C for 5 min. Superheated-steam-roasted peanut oil showed lower redness values than conventional roasting

oil. The redness values of peanut oils increased with roasting time in both roasting modes. The redness value obtained at the initial roasting time (5 min), -3.12 , increased to -1.61 at the final roasting time (20 min) for the superheated-steam-roasted peanut oil at 200 °C. Similar trends were observed for conventional roasting at the same temperature (200 °C), where the redness value obtained at the initial roasting time (5 min), -2.44 , increased to -1.54 at the final roasting time (25 min). These increased redness values for both roasting modes were significantly different from each other, as indicated by different letter in Table 2 ($p < 0.05$).

Raw peanut oil had a yellowness value of 15.04, while roasted peanut oils obtained via both roasting modes at 150 °C for 5 min were 16.35 and 16.67, respectively. Yellowness values increased with the roasting times and temperatures for both the roasting modes. Superheated-steam-roasted peanut oil roasted at 250 °C showed a yellowness value of 17.33 at the initial roasting time (2 min), which increased to 19.91 at the final roasting time (10 min). A more intense color of oil can be obtained with longer roasting time. Browning substances in roasted peanut oil occurred due to the Maillard reaction, caramelization, and phospholipid degradation, which increased with

Table 2 Lightness (L^*), redness (a^*), yellowness (b^*) values and oil viscosity of peanut oils obtained via superheated-steam and conventional roasting at three different temperatures (150, 200, and 250 °C) and roasting times

Roasting modes	Temperature (°C)	Time (min)	Lightness (L^*)	Redness (a^*)	Yellowness (b^*)	Oil viscosity (mPa s)
Raw			93.95 ± 0.00^{bcde}	-1.19 ± 0.01^j	15.03 ± 0.05^a	53.60 ± 0.2645^a
Superheated steam	150	5	96.49 ± 0.00^i	-3.24 ± 0.03^a	16.34 ± 0.02^b	61.33 ± 0.92^{bcdefg}
		20	96.32 ± 0.01^i	-2.60 ± 0.04^{cd}	18.04 ± 0.00^{cd}	65.20 ± 0.10^{fg}
		40	92.87 ± 0.00^{ab}	-1.54 ± 0.02^{ghi}	21.60 ± 0.00^{hi}	65.83 ± 2.88^g
	200	5	95.18 ± 0.54^{efghi}	-3.12 ± 0.01^{ab}	17.47 ± 0.01^{bc}	60.60 ± 0.90^{bcdef}
		10	94.73 ± 0.00^{defg}	-2.48 ± 0.02^d	19.26 ± 0.01^{def}	61.46 ± 1.62^{bcdefg}
		20	93.72 ± 0.01^{bcde}	-1.61 ± 0.02^{fgh}	21.26 ± 0.05^{hi}	63.33 ± 0.70^{defg}
	250	2	93.71 ± 0.00^i	-2.83 ± 0.02^{bc}	17.33 ± 0.00^{bc}	59.16 ± 0.63^{bcd}
		5	93.77 ± 0.00^{ghi}	-2.45 ± 0.01^d	18.46 ± 0.37^{cde}	61.56 ± 0.75^{bcdefg}
		10	95.73 ± 0.04^{fghi}	-1.96 ± 0.06^e	19.90 ± 1.12^{fg}	62.30 ± 1.47^{cdefg}
	Conventional	5	96.17 ± 0.00^{hi}	-3.11 ± 0.01^{ab}	16.66 ± 0.01^b	58.26 ± 3.49^{abc}
		25	95.87 ± 0.02^{ghi}	-1.99 ± 0.01^e	19.55 ± 0.03^{ef}	62.36 ± 1.62^{cdefg}
		45	93.40 ± 0.17^{bcd}	-1.44 ± 0.05^{hij}	25.35 ± 1.24^k	65.30 ± 0.17^{fg}
	200	5	94.77 ± 0.00^{defgh}	-2.44 ± 0.01^d	19.02 ± 0.01^{def}	60.16 ± 2.51^{bcde}
		15	94.61 ± 0.05^{cdefg}	-1.88 ± 0.05^{ef}	20.93 ± 0.02^{gh}	62.73 ± 1.91^{cdefg}
		25	91.75 ± 0.03^a	-1.53 ± 0.01^{ghi}	22.51 ± 0.04^{ij}	64.03 ± 0.98^{efg}
	250	5	94.30 ± 0.00^{bcdef}	-2.10 ± 0.06^e	19.94 ± 0.02^{fg}	57.43 ± 0.57^{ab}
		10	94.08 ± 0.01^{bcde}	-1.81 ± 0.40^{efg}	21.94 ± 0.03^{hi}	59.03 ± 0.41^{bcd}
		15	93.08 ± 2.07^{abc}	-1.28 ± 0.01^{ij}	23.49 ± 0.37^j	62.36 ± 1.62^{cdefg}

Mean $\pm$ standard deviation

Different letter indicates significant difference between values ($p < 0.05$)

roasting time and temperature [15]. Several studies have reported a significant increase in oil color with increasing roasting time and temperature in samples such as rice germ and sesame seeds [16]. Megahad [17] reported a gradual darkening and increase of Lovibond color indices in peanut oil extracted after roasting with times. Triglycerides of peanut oil are slightly degraded during the roasting process and produced free fatty acids. Hassanein et al. [18] reported an increase in oil color intensity with the formation of browning compounds, which is caused by phospholipid degradation during the roasting process.

Oil viscosity

The viscosities of raw and superheated-steam-roasted (150 °C for 5 min) peanut oils were respectively 53.60 and 61.33 mPa s (Table 2). The viscosity of roasted peanut oils for both the roasting modes increased with roasting time. For example, for superheated-steam roasting at 250 °C, the oil viscosity was found to be 59.17 mPa s at the initial roasting time (2 min), which increased to 62.30 mPa s at the final roasting time (10 min). For conventional roasting at the same roasting temperature (250 °C), the oil viscosity was 57.43 mPa s at the initial roasting time (5 min), which increased to 62.37 mPa s at the final roasting time (15 min). These increased values were significantly different from each other ($p < 0.05$).

Our results were found to be in the range of most vegetable oil viscosities (50–100 mPa s as) as reported by Besbes et al. [19]. Roasted peanut oil viscosity could be affected by the content of monounsaturated and polyunsaturated fatty acids. Oil viscosity increases owing to formation and polymerization of high molecular weight compounds including carbon–carbon and carbon–oxygen–carbon bonds between fatty acids [20].

Peroxide and p-anisidine values

The peroxide value of raw peanut oil was 1.05 meq/kg, while those of roasted peanut oils obtained via superheated-steam and conventional roasting at 150 °C for 5 min were 1.12 and 1.16 meq/kg, respectively. The highest peroxide value (4.72 meq/kg) was obtained in conventional roasting oil after roasting at 150 °C for 45 min. The lowest peroxide value (1.12 meq/kg) was obtained in roasted peanut oil obtained via superheated-steam roasting at 150 °C for 5 min. Peroxide values increased with roasting time in both roasting modes. The low peroxide value found in samples indicates slow oxidation of these oils [21]. According to Demian [22], the peroxide formation is slow at first induction period, which may vary from a few weeks to several months depending on the oil and roasting temperature. In addition, the results

showed that roasted peanut oil had a higher peroxide value because roasting of peanuts initiates lipid oxidation, which occurs during storage and increases the peroxide value of roasted peanuts [21].

Raw peanut oil showed lower p-anisidine value (1.26) as compared to roasted peanut oils obtained via both roasting modes. For superheated-steam roasting at 200 °C for 5 min, the p-anisidine value was 1.79, while it was 2.44 for conventional roasting under the same roasting conditions. However, no significant difference was noted between these two values, as indicated by same letter in Table 3 ($p > 0.05$). The highest p-anisidine value (4.59) was found in roasted peanut oil obtained via superheated-steam roasting at 150 °C for 40 min, whereas the lowest p-anisidine value (1.66) was found in roasted peanut oil obtained via superheated-steam roasting at 150 °C for 5 min. The p-anisidine values of roasted peanut oil increased with roasting time for both roasting modes.

Peroxide value acts as an indicator for the formation of the primary oxidation product in peanut oil, while p-anisidine value indicates the level of secondary oxidation product formation [23]. The peroxide and p-anisidine values in peanut oil and sesame seed oil increased with roasting times and temperatures [24]. Formation of hydroperoxide during the roasting process caused an increased in the peroxide value with roasting time. The roasting process could promote development of undesirable and bad compounds such as oxidation products and pigments. This has a significant effect on oxidative stability based on peroxide values in refined canola and soybean oils [25].

Iodine value

Iodine value of raw peanut oil was found to be 94.94, while it was 94.18 for roasted peanut oil obtained via superheated-steam roasting at 150 °C for 5 min. Superheated-steam-roasted peanut oil showed a higher iodine value (94.18) than conventional roasted peanut oil (88.05). Iodine values decreased with increasing roasting times and temperatures for both roasting modes. For example, for superheated-steam roasting at 250 °C, the iodine value was 91.16 at the initial roasting time (2 min) and decreased to 89.14 at the final roasting time (10 min). For conventional roasting at the same roasting temperature (250 °C), the iodine value was 89.15 at the initial roasting time (5 min) and decreased to 88.22 at the final roasting time (15 min). These decreased values for both the roasting modes were significantly different from each other, as indicated by a different letter in Table 3 ($p < 0.05$).

Iodine value was observed to decrease with increasing roasting time, which could be attributed to reduction of unsaturated fatty acids because of oxidation,

Table 3 Peroxide, p-anisidine, iodine, free fatty acid, acid, and conjugated diene and triene values of peanut oils obtained via superheated-steam and conventional roasting at three different temperatures (150, 200, and 250 °C) for different roasting times

Roasting modes	Temperature (°C)	Time (min)	Peroxide value (meq/kg)	p-anisidine value	Iodine value	Free fatty acid value (%)	Acid value (%)	Conjugated diene (K ₂₃₂)	Conjugated triene (K ₂₇₀)
Raw Superheated steam	150	5	1.05 ± 0.03 ^a 1.12 ± 0.02 ^{ab}	1.26 ± 0.04 ^a 1.66 ± 0.05 ^g	94.95 ± 0.04 ^o 94.18 ± 0.03 ⁿ	1.83 ± 0.06 ^a 2.03 ± 0.06 ^b	3.53 ± 0.07 ^a 3.90 ± 0.09 ^{ab}	1.43 ± 0.05 ⁱ 0.38 ± 0.01 ^a	0.17 ± 0.06 ^k 0.04 ± 0.01 ^a
		20	2.02 ± 0.02 ^f	2.83 ± 0.21 ^{jk}	92.85 ± 0.02 ^l	2.23 ± 0.06 ^{cd}	4.32 ± 0.17 ^{bc}	0.39 ± 0.01 ^a	0.05 ± 0.01 ^b
	200	40	3.78 ± 0.02 ^l	4.59 ± 0.13 ^o	90.05 ± 0.03 ^{fg}	2.43 ± 0.06 ^{efg}	4.79 ± 0.01 ^{cde}	0.41 ± 0.01 ^{ab}	0.07 ± 0.01 ^{gh}
		5	1.55 ± 0.02 ^d	1.79 ± 0.23 ^c	93.45 ± 0.01 ^m	2.17 ± 0.06 ^{bc}	4.63 ± 0.47 ^{cd}	0.41 ± 0.01 ^{ab}	0.06 ± 0.01 ^c
		10	2.23 ± 0.05 ^g	2.14 ± 0.32 ^h	91.42 ± 0.02 ^k	2.57 ± 0.06 ^{fgh}	5.27 ± 0.26 ^{def}	0.45 ± 0.01 ^{bc}	0.07 ± 0.01 ^{def}
		20	3.46 ± 0.03 ^k	3.55 ± 0.25 ^{ij}	90.87 ± 0.04 ⁱ	2.77 ± 0.05 ^{ij}	5.46 ± 0.25 ^{ef}	0.60 ± 0.01 ^{gh}	0.07 ± 0.01 ^h
	250	2	1.37 ± 0.03 ^c	2.02 ± 0.29 ^b	91.16 ± 0.01 ^j	1.83 ± 0.06 ^a	3.53 ± 0.05 ^a	0.39 ± 0.00 ^a	0.06 ± 0.01 ^{de}
		5	2.05 ± 0.01 ^f	2.19 ± 0.29 ^d	90.11 ± 0.03 ^g	2.37 ± 0.06 ^{de}	4.83 ± 0.11 ^{cde}	0.46 ± 0.01 ^{cd}	
	0.07 ± 0.00 ^{efg}								
	Conventional	150	10	3.94 ± 0.04 ^m	3.86 ± 0.27 ⁱ	89.14 ± 0.03 ^e	2.77 ± 0.06 ^{ij}	5.55 ± 0.05 ^f	0.51 ± 0.01 ^{de}
5			1.16 ± 0.02 ^b	1.88 ± 0.27 ^f	90.92 ± 0.03 ⁱ	2.03 ± 0.05 ^b	3.93 ± 0.10 ^{ab}	0.41 ± 0.01 ^{ab}	0.04 ± 0.01 ^{ab}
25			2.55 ± 0.02 ^h	2.45 ± 0.15 ^l	90.32 ± 0.03 ^h	2.43 ± 0.06 ^{efg}	4.78 ± 0.04 ^{cde}	0.43 ± 0.01 ^{abc}	0.04 ± 0.00 ^b
45			4.72 ± 0.04 ^o	3.44 ± 0.15 ⁿ	89.15 ± 0.02 ^e	2.77 ± 0.06 ^{ij}	5.15 ± 0.67 ^{def}	0.43 ± 0.01 ^{abc}	0.07 ± 0.01 ^{def}
200		5	1.73 ± 0.04 ^e	2.44 ± 0.11 ^c	89.97 ± 0.03 ^f	2.40 ± 0.01 ^{def}	4.78 ± 0.06 ^{cde}	0.41 ± 0.01 ^{ab}	0.06 ± 0.01 ^d
		15	2.79 ± 0.01 ⁱ	2.59 ± 0.33 ^h	88.91 ± 0.02 ^d	2.57 ± 0.06 ^{fgh}	5.17 ± 0.03 ^{def}	0.42 ± 0.00 ^{abc}	0.07 ± 0.06 ^{def}
250		25	4.33 ± 0.02 ⁿ	3.53 ± 0.38 ^k	88.05 ± 0.04 ^a	2.83 ± 0.55 ^j	5.57 ± 0.02 ^f	0.57 ± 0.01 ^{fg}	0.08 ± 0.01 ⁱ
		5	2.77 ± 0.02 ⁱ	2.89 ± 0.12 ^e	89.15 ± 0.03 ^e	2.60 ± 0.01 ^{ghi}	5.23 ± 0.08 ^{def}	0.51 ± 0.01 ^e	0.07 ± 0.99 ^{def}
		10	3.25 ± 0.04 ^j	3.58 ± 0.18 ⁱ	88.46 ± 0.04 ^c	2.63 ± 0.06 ^{hi}	5.37 ± 0.18 ^{ef}	0.55 ± 0.01 ^{ef}	0.07 ± 0.02 ^{fgh}
		15	3.88 ± 0.02 ^m	4.02 ± 0.31 ^m	88.22 ± 0.03 ^b	2.83 ± 0.06 ^j	5.53 ± 0.01 ^f	0.63 ± 0.01 ^h	0.12 ± 0.00 ^j

Mean ± standard deviation

Different letter indicates significant different between values ($p < 0.05$)

polymerization, and breakage of long chain fatty acid [26]. Yoshida et al. [27, 28] reported a significant decrease in iodine value with a decrease of molecular species containing more than four double bonds as increase of roasting time for sunflower seed and peanut oil.

Free fatty acid and acid values

Free fatty acid of raw peanut oil was 1.83%, which is lower compared with the value for roasted peanut oil obtained via superheated-steam roasting at 150 °C for 5 min (2.03%). The highest free fatty acid (2.83%) was determined in roasted peanut oil obtained via conventional roasting at 200 °C for 25 min, whereas the lowest free fatty acid (1.83%) was determined in roasted peanut oil obtained using superheated steam at 250 °C for 2 min. Free fatty acids increased with roasting time for both roasting modes. Raw peanut oil demonstrated an acid value of 3.53%, while roasted peanut oil obtained via superheated-steam and conventional roasting at 150 °C for 5 min demonstrated respective values of 3.90 and 3.94%. Raw peanut oil demonstrated lower acid values than roasted peanut oils. Superheated-steam roasting resulted in a lower acid value than conventional roasting. The highest acid value (5.57%) was obtained in roasted peanut oil obtained via conventional roasting at 200 °C for 25 min, whereas the lowest acid value (3.90%) was obtained in peanut oil obtained via superheated-steam roasting at 150 °C for 5 min.

Acid values measures free fatty acid content in oil samples and is commonly used as one of the main indicators of peanut oil quality during the roasting process [29]. An increase in free fatty acids and acid values in the roasted peanut oil could be attributed to hydrolysis of triglycerides during the roasting process and the production of free fatty acids with diglycerides. Several studies have proved the occurrence of this reaction during roasting of olive oil, peanut oil, and sesame seed oil [30, 31].

Conjugated diene and triene values

Raw peanut oil demonstrated conjugated diene and triene values of 1.43 and 0.17, respectively. Moreover, it showed higher values for both conjugated diene and triene in comparison with roasted peanut oil. Superheated-steam-roasted peanut oil showed lower conjugated diene and triene values as compared with conventional roasted peanut oil. Peanut oil obtained via superheated-steam roasting at 200 °C for 5 min demonstrated conjugated diene and triene values of 0.41 and 0.06, respectively. Peanut oil obtained via conventional roasting under the same conditions (200 °C, 5 min) demonstrated conjugated diene and triene values of 0.41 and 0.06. Both conjugated diene and triene values for roasted peanut oils obtained via both roasting

modes increased with roasting temperature. Conjugated diene and triene values of roasted peanut oil determined at 232 nm and 270 nm indicates the oxidative deterioration and purity of oil [23]. An increased in roasting time could increase the formation of conjugated diene and triene present in triglyceride molecules [17, 27]. Conjugated diene and triene values in corn oil increased with roasting time [25].

Fatty acid compositions

Table 4 shows seven kinds of saturated fatty acids identified in roasted peanut oils. Major fatty acids found in all roasted peanut oils were C12:0 and C16:0 acids, followed by C18:0, C4:0, and C8:0 acids. The fatty acids can influence the quality and flavor of edible peanuts and peanut products. Even though eight major fatty acids are present in peanuts, C16:0, C18:0, C18:1, and C18:2 acids constitute approximately 90% of total peanut triglycerides. The high oleic to linoleic acid ratio characteristic could provide a significant health benefit to the consumer and has the potential to increase the marketability of peanuts [32, 33]. The highest C12:0 (14.89%) was identified in roasted peanut oil obtained via conventional roasting at 250 °C for 10 min, whereas the lowest C12:0 (7.15%) was obtained in roasted peanut oil obtained via conventional roasting at 200 °C for 25 min. Superheated-steam roasting resulted in higher content of C16:0 than conventional roasting. The highest percentage of stearic acid (4.13%) was identified in roasted peanut oil obtained via conventional roasting at 150 °C for 25 min, whereas the lowest percentage of stearic acid (2.76%) was identified in roasted peanut oil obtained via superheated-steam roasting at 150 °C for 40 min. Arachidic acid was only identified in roasted peanut oils obtained via superheated-steam roasting at 150 °C for 40 min.

Table 5 shows five kinds of unsaturated fatty acids identified in roasted peanut oil obtained via superheated-steam and conventional roasting at three different temperatures: oleic, linoleic, α -linolenic, cis-11,14,17-eicosatrienoic, and erucic acids. Oleic acid had the highest percentage, followed by linoleic, cis-11,14,17-eicosatrienoic, and erucic acids. Raw peanut oil contained 28.78% of oleic acid, while roasted peanut oil obtained via superheated-steam and conventional roasting at 150 °C for 5 min respectively contained 29.84 and 27.69%. The highest percentage of oleic acid found was 32.68% in roasted peanut oil obtained via conventional roasting at 150 °C for 45 min, whereas the lowest percentage of oleic acid (26.10%) was found in roasted peanut oil obtained via superheated-steam roasting at 150 °C for 40 min. According to Li et al. [12], the technique of extraction used affects the total oil yields and the fatty acid constituents to

Table 4 Saturated fatty acids of peanut oils obtained via superheated-steam and conventional roasting at various temperatures and for roasting times

Modes	Tempt (°C)	Time (min)	Butyric (C4)	Caprylic (C8)	Capric (C10)	Lauric (C12)	Palmitic (C16)	Stearic (C18)
Raw			2.32 ± 0.08 ^{cdef}	0.37 ± 0.15 ^{abc}	ND	10.03 ± 0.54 ^{ab}	11.76 ± 1.46 ^{abcd}	3.56 ± 0.10 ^{de}
SHS	150	5	1.57 ± 0.02 ^{ab}	0.31 ± 0.10 ^{abc}	0.17 ± 0.02 ^{bcd}	8.28 ± 1.34 ^a	14.10 ± 0.13 ^d	3.54 ± 0.23 ^{de}
		20	1.60 ± 0.05 ^b	0.43 ± 0.05 ^{bc}	0.14 ± 0.01 ^b	8.14 ± 0.96 ^a	12.33 ± 1.62 ^{abcd}	3.45 ± 0.36 ^{de}
		40	2.44 ± 0.09 ^{efg}	0.26 ± 0.07 ^{abc}	0.15 ± 0.08 ^{bc}	9.83 ± 0.07 ^{ab}	11.46 ± 1.13 ^{abcd}	2.76 ± 0.04 ^b
	200	5	2.62 ± 0.10 ^{fg}	0.30 ± 0.01 ^{abc}	0.29 ± 0.02 ^{de}	10.97 ± 1.23 ^{abc}	11.50 ± 0.67 ^{abcd}	3.24 ± 0.17 ^{bcd}
		10	1.60 ± 0.09 ^b	0.14 ± 0.11 ^{ab}	ND	7.63 ± 1.04 ^a	9.60 ± 1.16 ^{ab}	2.92 ± 0.26 ^{bc}
		20	1.10 ± 0.04 ^a	0.20 ± 0.12 ^{abc}	0.15 ± 0.10 ^{bc}	10.05 ± 0.75 ^{abc}	11.81 ± 0.61 ^{abcd}	3.25 ± 0.05 ^{bcd}
	250	2	2.23 ± 0.26 ^{cdef}	0.61 ± 0.08 ^c	0.28 ± 0.02 ^{cde}	13.86 ± 4.49 ^{bc}	9.88 ± 2.63 ^{abc}	ND
		5	2.25 ± 0.08 ^{cdef}	0.55 ± 0.02 ^{bc}	0.24 ± 0.01 ^{bcd}	10.71 ± 0.61 ^{abc}	12.97 ± 0.15 ^{bcd}	3.36 ± 0.01 ^{cde}
		10	2.25 ± 0.07 ^{cdef}	0.36 ± 0.07 ^{abc}	0.20 ± 0.01 ^{bcd}	8.63 ± 0.70 ^a	13.68 ± 0.38 ^d	3.49 ± 0.05 ^{de}
Conv	150	5	2.85 ± 0.09 ^g	0.35 ± 0.16 ^{abc}	0.17 ± 0.05 ^{bcd}	9.56 ± 0.31 ^{ab}	11.08 ± 0.89 ^{abcd}	3.45 ± 0.19 ^{de}
		25	1.93 ± 0.31 ^{bcd}	0.43 ± 0.25 ^{bc}	0.24 ± 0.07 ^{bcd}	6.84 ± 2.37 ^a	12.16 ± 0.72 ^{abcd}	4.13 ± 0.29 ^f
		45	2.35 ± 0.11 ^{def}	0.45 ± 0.12 ^{bc}	0.21 ± 0.02 ^{bcd}	7.66 ± 0.59 ^a	12.81 ± 0.93 ^{bcd}	3.49 ± 0.18 ^{de}
	200	5	2.68 ± 0.18 ^{fg}	0.39 ± 0.06 ^{abc}	0.35 ± 0.02 ^e	8.53 ± 0.33 ^a	11.62 ± 0.62 ^{abcd}	3.31 ± 0.18 ^{cd}
		15	2.51 ± 0.27 ^{efg}	0.59 ± 0.14 ^c	0.28 ± 0.07 ^{cde}	11.44 ± 0.95 ^{abc}	12.52 ± 1.25 ^{bcd}	3.58 ± 0.15 ^{de}
		25	2.11 ± 0.17 ^{cde}	ND	ND	7.15 ± 1.21 ^a	11.94 ± 0.74 ^{abcd}	3.50 ± 0.08 ^{de}
	250	5	2.42 ± 0.06 ^{efg}	0.20 ± 0.03 ^{abc}	ND	8.61 ± 0.64 ^a	12.52 ± 0.38 ^{bcd}	3.88 ± 0.06 ^{ef}
		10	1.85 ± 0.22 ^{bc}	0.55 ± 0.33 ^{bc}	ND	14.89 ± 3.12 ^c	8.79 ± 2.6273 ^a	ND
		15	2.40 ± 0.20 ^{defg}	0.37 ± 0.04 ^{abc}	ND	10.31 ± 0.99 ^{abc}	13.38 ± 0.58 ^{cd}	3.62 ± 0.08 ^{def}

Mean ± standard deviation

Different letter indicates significant difference between values ($p < 0.05$)

ND non-detectable, SHS superheated steam, Conv conventional

a large extent. In this study, the least oleic acid was obtained via the pressing technique. This indicates that the extraction was incomplete. In another study, Zaidul et al. [34] reported that the short-chain fatty acids (low molecular weight) were extracted faster than the long chain fatty acids (high molecular weight).

Linoleic acid contents in raw peanut oil, roasted peanut oil obtained via superheated-steam and conventional roasting at 200 °C for 5 min were found to be 20.01, 19.41, and 18.60% respectively. Superheated-steam roasting afforded more linoleic acid than conventional roasting. The highest linoleic acid (21.45%) was found in roasted peanut oil obtained via superheated-steam roasting at 150 °C for 5 min. α -linolenic acid was found to be 0.46% in raw peanut oil and 0.38% in roasted peanut oil obtained via superheated-steam roasting at 250 °C for 5 min. Superheated-steam roasting afforded a lower percentage of α -linolenic acid than conventional roasting.

Decrease in polyunsaturated fatty acids in soybean oil as subjected to roasting process reported by Hassanein et al. [18]. In roasted soyabean oil, saturated fatty acid content was more than the unsaturated fatty acids content. The roasting process could affect the compositional and nutritional quality of the fatty acids fraction in oil. The content

of unsaturated fatty acids decreased as oil as the roasting process continued; however, saturated fatty acids did not affect much [18]. There are significant differences in fatty acid patterns of sesame seed oil during roasting. In another study, Nederal et al. observed an increasing and decreasing trend of fatty acids with roasting temperatures in pumpkin seed oil [35].

Oil extracted from roasted peanuts via superheated-steam and conventional roasting at three different temperatures (150, 200, and 250 °C) for each roasting time were evaluated based on physicochemical properties. Superheated-steam roasting resulted in a higher percentage of oil than conventional roasting at higher temperature (250 °C). Oil color was found to be lower with superheated steam. Free fatty acid, peroxide, and p-anisidine, conjugated diene and triene values of roasted peanut oil obtained via superheated-steam roasting were found to be significantly lower than those via conventional roasting. Roasted peanut oil obtained via superheated-steam roasting showed higher iodine value and oil viscosity than roasted peanut oil obtained via conventional roasting. The major fatty acids identified in roasted peanut oils obtained via both roasting modes were oleic acid, followed by linoleic, palmitic, lauric, erucic, and stearic acids. Each fatty acid constituting

Table 5 Unsaturated fatty acids of peanut oils obtained via superheated-steam and conventional roasting at three different temperatures (150, 200, and 250 °C) and for different roasting times

Modes	Tempt. (°C)	Time (min)	Unsaturated fatty acids (%)				
			Oleic (C18:1)	Linoleic (C18:2)	α -linolenic (C18:3)	cis-11,14,17-eicosatrienoic (C20:3)	Erucic (C22:1)
Raw			28.78 $\pm$ 1.20 ^{abcdef}	20.01 $\pm$ 0.93 ^{bcd}	0.45 $\pm$ 0.03 ^{bc}	1.66 $\pm$ 0.11 ^{de}	4.24 $\pm$ 0.59 ^c
SHS	150	5	29.84 $\pm$ 2.50 ^{bcddefg}	21.45 $\pm$ 1.80 ^d	0.49 $\pm$ 0.13 ^{bc}	1.21 $\pm$ 0.07 ^{bc}	ND
		25	27.84 $\pm$ 0.34 ^{abcd}	19.23 $\pm$ 0.28 ^{abcd}	ND	1.37 $\pm$ 0.09 ^{bcd}	4.01 $\pm$ 2.30 ^c
		40	26.10 $\pm$ 0.76 ^{ab}	18.70 $\pm$ 0.29 ^{abcd}	0.97 $\pm$ 0.14 ^{de}	1.13 $\pm$ 0.09 ^{bc}	4.93 $\pm$ 1.42 ^c
	200	5	27.85 $\pm$ 1.35 ^{abcd}	19.40 $\pm$ 0.55 ^{abcd}	0.67 $\pm$ 0.15 ^{bcdde}	1.25 $\pm$ 0.14 ^{bc}	ND
		10	25.03 $\pm$ 0.96 ^a	17.59 $\pm$ 1.06 ^{ab}	0.55 $\pm$ 0.14 ^{bcd}	1.11 $\pm$ 0.06 ^b	2.87 $\pm$ 0.46 ^{bc}
		20	28.61 $\pm$ 0.81 ^{abcde}	19.62 $\pm$ 1.06 ^{abcd}	0.67 $\pm$ 0.18 ^{bcdde}	1.31 $\pm$ 0.05 ^{bc}	0.57 $\pm$ 0.45 ^{ab}
	250	2	27.66 $\pm$ 0.81 ^{abcd}	17.15 $\pm$ 0.82 ^{ab}	ND	ND	4.15 $\pm$ 1.29 ^c
		5	26.80 $\pm$ 0.45 ^{abc}	18.24 $\pm$ 1.16 ^{abc}	0.38 $\pm$ 0.08 ^{ab}	1.15 $\pm$ 0.09 ^{bc}	4.59 $\pm$ 0.57 ^c
		10	30.87 $\pm$ 0.13 ^{defg}	19.72 $\pm$ 0.45 ^{abcd}	0.80 $\pm$ 0.21 ^{bcdde}	ND	ND
		15	27.68 $\pm$ 1.13 ^{abcd}	19.18 $\pm$ 0.60 ^{abcd}	0.82 $\pm$ 0.10 ^{cde}	1.32 $\pm$ 0.09 ^{bc}	4.37 $\pm$ 0.45 ^c
Conv.	150	25	32.54 $\pm$ 2.60 ^{fg}	16.80 $\pm$ 0.81 ^a	0.84 $\pm$ 0.12 ^{cde}	1.78 $\pm$ 0.31 ^e	ND
		45	32.67 $\pm$ 2.08 ^g	20.78 $\pm$ 0.67 ^{cd}	1.01 $\pm$ 0.23 ^e	1.15 $\pm$ 0.11 ^{bc}	4.79 $\pm$ 0.77 ^c
	200	5	28.20 $\pm$ 0.91 ^{abcd}	18.57 $\pm$ 0.56 ^{abcd}	0.94 $\pm$ 0.24 ^{de}	1.45 $\pm$ 0.09 ^{bcdde}	4.23 $\pm$ 0.28 ^c
		15	28.13 $\pm$ 0.49 ^{abcd}	19.28 $\pm$ 0.82 ^{abcd}	ND	1.33 $\pm$ 0.06 ^{bcd}	4.54 $\pm$ 1.13 ^c
		25	28.33 $\pm$ 1.12 ^{abcd}	19.25 $\pm$ 0.98 ^{abcd}	0.74 $\pm$ 0.07 ^{bcdde}	1.46 $\pm$ 0.12 ^{cde}	3.04 $\pm$ 1.15 ^{bc}
	250	5	32.40 $\pm$ 1.01 ^{efg}	20.66 $\pm$ 0.82 ^{cd}	0.93 $\pm$ 0.19 ^{de}	1.39 $\pm$ 0.06 ^{bcd}	ND
		10	30.24 $\pm$ 0.44 ^{cdefg}	18.63 $\pm$ 1.67 ^{abcd}	ND	ND	4.36 $\pm$ 1.33 ^c
		15	31.28 $\pm$ 0.96 ^{defg}	20.60 $\pm$ 1.29 ^{cd}	0.814 $\pm$ 0.10 ^{cde}	ND	ND

Mean $\pm$ standard deviationDifferent letter indicates significant difference between values ($p < 0.05$)

ND non-detectable, SHS superheated steam, Conv conventional

the roasted peanut oils obtained via both roasting modes was affected by roasting time and temperature. These physicochemical properties were significantly different with each other ($p < 0.05$). Based on the results obtained in this study, the superheated steam technique can be used to roast peanuts while maintaining its favorable characteristics.

Acknowledgements Great appreciations go to the Fellowship Scheme of the Institute of Postgraduate Studies, Universiti Sains Malaysia.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

References

- Yoshida H, Hirakawa Y, Tomiyama Y, Mizushima Y. Effects of microwave treatment on the oxidative stability of peanut (*Arachis hypogaea*) oils and the molecular species of their triacylglycerols. *Europ. J. Lipid Sci. Technol.* 105: 351–358 (2003).
- Gandhi AP, Jha K, Khare SK, Ali N. Status of soymeal production and its utilization for human food in India. (Indore, India) (1992).
- Rodenbush CM, Hsieh FH, Viswanath DS. Density and viscosity of vegetable oils. *J. Am. Oil Chem. Soc.* 76: 1415–1419 (1999).
- Fasina OO, Hallman H, Craig-Schmidt M, Clements C. Predicting temperature dependence viscosity of vegetable oils from fatty acid composition. *J. Am. Oil Chem. Soc.* 83: 899–903 (2006).
- Zambiasi RC, Przybylski R, Zambiasi MW, Mendonca CB. Fatty acid composition of vegetable oils and fats. *B. CEPPA Curitiba.* 25(1): 111–120 (2007).
- Davis JP, Sweigart DS, Price KM, Dean LL, Sanders TH. Refractive index and density measurements of peanut oil for determining oleic and linoleic acid contents. *J. Am. Oil Chem. Soc.* 90(2): 199–206 (2013).
- Sanders TH. Fatty acid composition of lipid classes in oils from peanuts differing in variety and maturity. *J. Am. Oil Chem. Soc.* 57: 12–15 (1980).
- Zzaman W, Yang TA. Effect of superheated steam and convection roasting on changes in physical properties of cocoa bean (*Theobroma cacao*). *Food Sci. Technol. Res.* 19: 181–186 (2013).
- Zzaman W, Yang TA. Moisture, color and texture changes in cocoa beans during superheated steam roasting. *J. Food Process. Preserv.* 38(3): 1364–1370 (2014).
- AOAC (2000). Official Methods of Analysis of AOAC International, (17th Edition).

11. Jahurul MHA, Zaidul ISM, Norulaini NNA, Sahena F, Jaffri JM, Omar AKM. Supercritical carbon dioxide (SC-CO₂) extraction and studies of mango seed kernel for cocoa butter analogy fats. *Cyta-Journal Food*. 12(1): 97–103 (2014).
12. Li P, Gasmalla MAA, Zhang W, Liu J, Bing R, Yang R. Effects of roasting temperatures and grinding type on the yields of oil and protein obtained by aqueous extraction processing. *J. Food Eng.* 173: 15–24 (2016).
13. Tan CP, Che Man YB, Jinap S, Yusoff MSA. Effects of microwave heating on changes in chemical and thermal properties of vegetable oils. *J. Am. Oil Chem. Soc.* 78: 1227–1232 (2001).
14. Kahyaoglu T, Kaya S. Modeling of moisture, color and texture changes in sesame seeds during the conventional roasting. *J. Food Eng.* 75: 167–177 (2005).
15. Craft BD, Kosinska A, Amarowicz R, Pegg RB. Antioxidant properties of extracts obtained from raw, dry-roasted, and oil-roasted US peanuts of commercial importance. *Plant Food. Human Nutr.* 65: 311–318 (2010).
16. Kim IH, Kim CJ, You MJ, Lee KW, Kim CT, Chung SH, Tae BS. Effect of roasting temperature and time on the chemical composition of rice germ oil. *J. Am. Oil Chem. Soc.* 79: 413–418 (2002).
17. Megahad MG. Microwave roasting of peanuts: effects on oil characteristics and composition. *Nahrung*. 45: 255–257 (2001).
18. Hassanein MM, El-Shami SM, Al-Mallah MH. Changes occurring in vegetable oils composition due to microwave heating. *Grasas Aceites*. 54: 343–349 (2003).
19. Besbes S, Blecker C, Deroanne C, Lognay G, Drira N-E, Attia H. Heating effects on some quality characteristics of date seed oil. *Food Chem.* 91: 469–476 (2005).
20. Guillen MD, Ruiz A. Formation of hydroperoxy- and hydrox-yalkenals during thermal oxidative degradation of sesame oil monitored by proton NMR. *J. Lipid Sci. Technol.* 106: 680–687 (2004).
21. Akubugwo IE, Ugbo AE. Physicochemical studies on oils from five selected Nigerian plant seeds. *Pakistan J. Nutr.* 6: 75–78 (2007).
22. Demian MJ. *Principles of Food Chemistry*. (2nd ed.) pp. 37–38. Van Nostrand Reinhold International Company Limited, London, England, (1990).
23. Anwar F, Anwar T, Mehmood Z. Methodical characterization of rice bran oil from pakistan. *Grasas Aceites*. 56: 126–127 (2005).
24. Yoshida H, Takagi S, Mitsuhashi S. Tocopherol distribution and oxidative stability of oils prepared from the hypocotyl of soybeans roasted in a microwave oven. *J. Am. Oil Chem. Soc.* 76: 915–920 (1999).
25. Vieira TMFS, Regitano D'Arce MAB. Stability of oils heated by microwave: uv spectrophotometric evaluation. *Ciência Tecnológica Alimentos*. 18: 433–437 (1998).
26. Anjum F, Anwar F, Jamil A, Iqbal M. Microwave roasting effects on the physico-chemical composition and oxidative stability of sunflower seed oil. *J Am Oil Chem Soc.* 83: 777–783 (2006).
27. Yoshida H, Abe S, Hirakawa Y, Takagi S. Roasting effects on fatty acid distributions of triacylglycerols and phospholipids in sesame (*Sesamum indicum*) seeds. *J. Sci. Food Agric.* 81: 620–626 (2001).
28. Yoshida H, Hirakawa Y, Tomiyama Y, Miz Y. Effect of microwave treatment on the oxidative stability of peanut (*Arachis hypogaeae*) oils and the molecular species of their triacylglycerols. *Europ. J. Lipid Sci. Technol.* 105: 351–358(2002).
29. Rao Y, Xiang B, Zhou X, Wang Z, Xie S, Xu J. Quantitative and qualitative determination of acid value of peanut oil using near-infrared spectrometry. *J. Food Eng.* 93: 249–252 (2009).
30. Cossignani L, Simontti MS, Neri A, Damiani P. Changes in olive oil composition due to microwave heating. *J. Am. Oil Chem. Soc.* 75: 931–937 (1998).
31. Yoshida H, Hirakawa Y, Abe S. Roasting influence on molecular species of triacylglycerols in sunflower seeds (*Helianthus annuus* L.). *Food Res. Int.* 34: 613–619 (2001).
32. Ó'Brien RD. *Fats and oils. Formulating and processing for applications*, CRC press, Boca Raton, USA (2004).
33. Rodrigues AC, Ströher GL, Freitas AR, Visentainer JV, Oliveira CC, de Souza NE. The effect of genotype and roasting on the fatty acid composition of peanuts, *Food Res. Int.* 44(1): 187–192 (2011).
34. Zaidul ISM, Norulaini NN, Omar AM, Sato Y, Smith RL. Separation of palm kernel oil from palm kernel with supercritical carbon dioxide using pressure swing technique. *J. Food Eng.* 81(2): 419–428 (2007).
35. Nederal S, Skevin D, KraljicMarko K, Papesa O, Bataljaku A. Chemical composition and oxidative stability of roasted and cold pressed pumpkin seed oils. *J. Am. Oil Chem. Soc.* 89: 1763–1770 (2012).