Journal of Food and Nutrition Research, 2017, Vol. 5, No. 9, 659-667
Available online at http://pubs.sciepub.com/jfnr/5/9/5

DOI:10.12691/jfnr-5-9-5

Effects of Microwave Roasting Process and Time on Chemical Composition and Oxidative Stability of Sunflower Oil

Khalid Mohammed, Marwa Koko, Mohammed Obadi, Kekgabile Shathani Letsididi, Peirang Cao, Y. Liu*

State Key Laboratory of Food Science and Technology, School of Food Science and Technology, Jiangnan University, Lihu Avenue, Wuxi, P. R. China
*Corresponding author: foodscilyf@163.com

Abstract **Purpose:** In this study, sunflower seeds (*Helianthus annuus*) were treated with an industrial microwave oven under 700 W for 8, 12, 16 and 20 min and oil was extracted using mechanical press technique. A suitable roasting treatment (20 min) is advantageous to oil extraction yield and tocopherol contents. The extracted oil results showed no variations in the contents of fiber, ash, and protein that were attributable to the roasting. However, the color, FFA, *p*-anisidine, saponification and density values of oils were increased significantly as the roasting time increased. The iodine values of the oils were noticeably decreased. The oxidative stability revealed that, as the roasting time increased, the oxidative stability of sunflower oil decreased. Tocopherol contents were identified, namely, α- and β- tocopherols, whereas no δ-tocopherol was detected. The main tocopherol found in sunflower oil was α-tocopherol. The content of α-tocopherol in sunflower oil at 15 min of roasting gradually increased from 895.1 to 1108.83 mg/kg as roasting time increased. The fatty acid compositions of sunflower oil did not change with the roasting time. The major fatty acid was linoleic acid.

Keywords: *microwave roasting, oxidative oil index, sunflower seeds, tocopherol*

Cite This Article: Khalid Mohammed, Marwa Koko, Mohammed Obadi, Kekgabile Shathani Letsididi, Peirang Cao, and Y. Liu, "Effects of Microwave Roasting Process and Time on Chemical Composition and Oxidative Stability of Sunflower Oil." *Journal of Food and Nutrition Research*, vol. 5, no. 9 (2017): 659-667. doi: 10.12691/jfnr-5-9-5.

1. Introduction

One of the most famous techniques of food preparation today is Microwave heating because of its suitability, rapidity and low cost [1]. Recently, the design of the Microwave is improving, and then the cost of electricity should stimulate new development trends and models of microwave heating and food properties as the reason for demonstrating work in research. Microwave heating system has been utilized in the food industry for normal heating, boiling, cooking, drying, pasteurization, sterilization and thawing various foodstuffs [2,3]. George and others showed the application of Microwave heating in food processing that identified benefits and restrictions for an extensive variety of food manufacturing processes [4].

The mechanism of food substance warming in a microwave oven is resulted by interaction of electromagnetic field and the chemical constituents of food. The electromagnetic interactions instantaneously create heat regeneration due to molecular friction and excitation [5,6]. The effect of microwaves on food ingredients have been conducted on numerous studies [7], and the influence of microwave and conventional heating on the nutrients, flavors and colors in foods have also been studied [8].

The effect of microwave heating on various animal and vegetable lipid constituents was well studied and confirmed [9,10]. The level of value of quality deterioration such as oxidative degradation was influenced by the measure of polyunsaturated fatty acids amount in the oil [11]. The change in the chemical composition and levels of minor components affected the functional and nutritional properties of oils [12]. Several studies reported that; the maintenance of supplements and nutrients such as vitamins in food samples during microwave heating is enhanced when the roasting time is reduced.

On the other side, further reports demonstrated that the nutrients retention during microwave treatment was not much better than that of exposure to conventional heating [13].

Amount of tocopherol homologs (α-, β-, γ-, and δ-) in food acts as free radical scavengers during oil oxidation. The unsaturated fatty acids (FA) contents determines their amount in vegetable oils [14]. Up to 1 g/kg^{-1} of extra of tocopherols can be found in unsaturated oils, although most saturated oils contain nearly none. The determination of tocopherol homologs in sunflower oil is important because of its antioxidant effects and positive healthful physiological effects in human metabolism. Microwave roasting has been displayed to effect the thermal oxidation of tocopherols [12,15].

Sunflower oil is characterized to contain high amount of tocopherols (up to 935 ppm) higher than those of other oils such as soybean and peanut. It is considered as an oil with high stability due to its great content of natural antioxidants [16,17], although sunflower oil is sensitive and it can be easily oxidized during frying and roasting.

The objectives of this research were to determine the effects of microwave radiation on the chemical composition of sunflower seeds oil and to extend our understanding in regards to the changes in the distribution of fatty acids (FA) and tocopherols of oil, and to evaluate the relationship between oxidative oil index and minor components contents in extracted sunflower oil by various microwave roasting times

2. Materials and Methods

2.1. Sunflower Seeds

In this study Sunflower seeds samples were obtained from Shandong Lu hua Group LTD (Shandong, China). 300-500 g of the seed was regularly obtained. The crude oil of sunflower was extracted by mechanical method and kept away from the light, high temperature and oxygen in order to avoid auto-oxidation. Duplicates of seeds samples were collected.

Standards of tocopherols [DL-α-tocopherol, (+)-δ-tocopherol, and (+)-γ-tocopherol] and FAME were purchased from Roche Vitamins Inc –Parsippany, New Jersey, 07054-USA. All other chemicals and solvents used were of analytical grade.

2.2. Microwave Roasting of Sunflower Seeds

Each sample (500 g) was placed in a turn vessel and then was roasted in an industrial microwave oven (Nanjing Jiequan Microwave Development Co, Ltd) at a frequency of 700 MHz (oven capable of generating 130°C) for 8, 12, 16 and 20 min. After roasting, sunflower seeds were permitted to cool to ambient temperature and blended before grinding and oil extraction.

Moisture content of raw and roasted samples were determined after each exposure time and considered as obvious moisture, and then were calculated by dividing the weight of moisture loss by the weight of the sample before roasting.

2.3. Oil Extraction after Roasting

The microwaved batch (500g) of sunflower seeds were quickly subjected to the mechanical press (Korea Hydraulic Oil Press) and pressed at 600 kg/cm for 20 min to obtain the sunflower oil. The unroasted sunflower oil was prepared by the same process as described above. The extracted sunflower oil was filtered with filter bag under vacuum to eliminate impurities.

2.4. Protein Contents

Protein content was determined according to the AOAC VA, Method 28.110 [22] using a micro-Kjeldhal apparatus. Each meal sample (2 g) was digested for about an hour with 2 g of digestion mixture (Cu, Fe, and K sulfates in the ratio of 9:1:90 by wt.) and 10 mL of concentrated H_2SO_4. When the digestion was completed, the solution became clear and was then made up to 100.0 mL in a volumetric flask with distilled water.

For the nitrogen determination, 5 mL of 2% boric acid solution was first taken in a beaker with a few drops of methyl red as indicator. Then 10 mL of the digested mixture, 10 mL of 40% NaOH solution, and 10 mL of distilled water were transferred to the distillation chamber. Ammonia was liberated, and it combined with NaOH to form NH_4OH, which was then received into the boric acid solution to form ammonium borate (from pink color to yellow). Distillate (ammonium borate) was then titrated with 0.1 N H_2SO_4. The volume of acid that had been added at the point when the color of the distillate changed from yellow to pink was recorded. Protein was calculated according to the following formula: %protein = %N ×6.25.

2.5. Fiber Contents

Fiber contents were determined according to the standard International Standard Organization procedure, Standard No. 5983 [23]. Two grams of finely ground defatted meal were weighed and then boiled with 250 mL of 0.1275 N H_2SO_4, followed by the separation and washing of insoluble residues. The residues were then boiled with 250 mL of 0.313 92 N NaOH followed by the separation, washing, and drying of residues. The dried residues were weighed and ashed in a muffle furnace (Shanghai Instruments Co., Ltd) at 600°C, and the loss of mass was determined gravimetrically.

2.6. Ash Contents

Ash contents were determined by the standard ISO method, Standard No. 749 [24]. Two grams of meal were carbonized by heating on a gas flame and then ashed in an electric muffle furnace at 600°C until a constant mass was achieved.

2.7. Physical and Chemical Parameters of Oils

Determination of density, refractive index, FFA, PV, iodine value, saponification value, and *p*-anisidine value of the extracted oil was carried out according to the standard IUPAC, Method 2.301 [21]. Color was determined in duplicate, using Lovibond PFX880 Tintometer according to the official AOCS method. The optical path length of the glass cell was '1'.

2.8. Oxidative Oil Index Determination

A Rancimat model 743 (Metrohm–Swiss) was used to determine the oxidative oil index. The tests were done with 3 g oil samples at temperatures of 120°C and an airflow rate of 20 L/h [19].

2.9. Tocopherols Content Determination

A chromatographic system consisting of a Waters 1525 binary pump (Waters, Milford, USA), 40µL injection loop and photodiode array detector (Waters, USA) was used to

determine tocopherols content (VE). Lichrospher Si-60 column (25092.0, 5μm, Hanbon Science and Technology, China) was used for separation. The mobile phase used was a mixture of n-hexane–isopropanol (98.5:1.5 v/v) at a flow rate of 0.15 mL/min.

The signal was measured at wavelength 295 nm [20]. Mixed tocopherols (α-, β-, γ-, and δ-) were used as standard to measure the retention time of each of these compounds. The standard was prepared using n-hexane at a concentration of 0.01 g mL^{-1} .One gram of each sample was weighed into a 10-mL n-hexane actinic glass volumetric flask. The samples were brought to volume with n-hexane before injection of 20μL onto HPLC column. By the end of each analysis, isopropanol was pumped through the HPLC column for 30 min and n-hexane also for 30 min and this removed the more polar oil components on the column during the detection. Afterwards this washing step, the mobile phase was pumped through the column to get equilibration before injection of samples.

2.10. Fatty Acid Composition

FAME were prepared by IUPAC standard, Method 2.301 [21] and analyzed on a Shimadzu gas chromatograph model 2010PLUS equipped with a TR-FAME 260M154P (Thermo Scientific) methyl lignocerate-coated (film thickness 0.25 μm) polar capillary column (60 m ×0.25 mm) and an FID. The carrier gas was nitrogen, and the total gas flow rate was 25 mL/min. Other conditions were as follows: initial oven temperature, 60°C; ramp rate, 5°C/min; final temperature, 220°C; injector temperature 250°C; detector temperature, 250°C. FAME were identified by comparing their relative and absolute retention times with those of authentic standards. Quantification was done by a Chromatography Station for Windows (CSW32) data-handling program (Data APEX Ltd., Prague, The Czech Republic). The FA composition was reported as a relative percentage of the total peak area. The internal standard was nonadecanoic acid.

2.11. Statistical Analysis

Each reported value is the mean of determinations for triplicate samples prepared from each roasting condition, and the data were analyzed by ANOVA and Duncan's multiple range test (Duncan's test). Statistical significance was accepted at a level of $P < 0.05$ using SPSS 16.0 for Windows (SPSS Inc., Chicago, USA).

3. Results and Discussion

3.1. Proximate Analysis

The proximate analysis results of the unroasted (control sample) and roasted sunflower seeds were shown in Table 1, the petroleum ether-extracted oil contents of unroasted seeds was 37.93%. In roasting seeds at interval times 8, 12, 16 and 20 min, the oil content increased significantly by time ($P < 0.05$).

The moisture content of the unroasted sunflower seeds oil was 5.69 %. Contents of protein, fiber, and ash were 24.20, 00, and 2.43%, respectively.

Microwave roasting of seeds did not influence the fiber, ash, and protein contents significantly ($P > 0.05$). The loss in the weight of seeds after roasting process at interval times 8, 12, 16 and 20 min amounted to 1.71, 0.68, 0.69, and 0.41, %, respectively. With increasing roasting time, the loss in weight of the seeds was clearly higher. [5,26] reported that an increasing in the roasting time of sunflower seeds resulted in significant increasing in weight loss, which is reliable with our results. This loss in weight might reveal total volatile compounds, however it was considered to be mostly due to the loss in moisture content. In the present investigation, the loss in weight of sunflower seeds oil was found to be larger if compared with those results reported by Yoshida [5], which might be attributable to deviations in the genetic manipulation and the original moisture contents of the types of sunflower seeds oil inspected. Some authors reported that after roasting for frequent times, the weight variations of peanut and sesame seeds might have occurred due to the existence of moisture and volatile constituents [15,26]. In contrast, previous investigation studied showed no significant differences in the weight loss between different cultivars of soybeans at different times of roasting [15]. Oomah & Mazza, reported that microwave oven drying might be used as a rapid method for moisture determination in seeds oil such as flax, canola, and mustard. Statistical analysis presented weight loss increasing significantly according to increasing in roasting time [15].

Table 1. Proximate Analysis of Roasted/Unroasted Sunflower Oilseeds

Contents (%)	Control	Roasted			
		8 min	12 min	16 min	20 min
Moisture	5.69±0.113[a]	1.71±0.368[b]	0.68±0.375[c]	0.69±0.002[cd]	0.41±0.002[d]
Oil	37.93±0.488[a]	39.46±0.460[ab]	41.36±0.071[c]	44.32±0.071[d]	41.01±1.025[bc]
Protein	24.2±0.289[a]	24.79±1.66[a]	24.02±1.27[a]	22.67±1.35[a]	24.53±1.73[a]
Fiber	9.15±0.212[a]	9.25±0.212[a]	9.00±0.848[a]	9.36±0.367[a]	9.06±0.021[a]
Ash	2.43±0.091[a]	2.47±0.014[a]	2.49±0.007[a]	2.43±0.007[a]	2.49±0.050[a]

[a]Values are presented as mean ± SD of duplicate samples analyzed individually in triplicate. The control is oil extracted from unroasted sunflower oilseeds.

Table 2. Microwave roasting effects on physical and chemical parameters of sunflower oils

Contents	Control	Roasted			
		8 min	12 min	16 min	20 min
Refractive index at (40°C)	1.4675±0[a]	1.4674±0[a]	1.4675±0[a]	1.4674±0[a]	1.4674±0[a]
Density (24°C) (mg◊mL-1)	0.9081±0.001[a]	0.9029±0.004[b]	0.9224±0.001[c]	0.9054±0.007[d]	0.9162±0[a]
Color (red units)	0.4±0[a]	1.0±0[b]	1.1±0[c]	1.25±0.070[d]	1.6±0[a]
Color (yellow units)	1.1±0[a]	4.3±0[b]	4.6±0[c]	4.8±0[b]	5.8±0[a]
Saponification value (mg of KOH/g of oil)	173.02±0.332[d]	169.47±1.65[c]	156.93±1.11[b]	154.8±0.721[b]	147.3±0.806[a]
FFA (% as oleic acid)	0.07±0.007[a]	0.11±0.008[b]	0.12±0.003[b]	0.13±0.005[c]	0.16±0.002[d]
Iodine value (g of I/100 g	122±0.283[a]	119.73±0.326[d]	107.4±0.328[c]	101.15±0.557[b]	93.62±0.820[a]

[a]Values are presented as mean ± SD of duplicate samples analyzed individually in triplicate. The control is oil extracted from unroasted sunflower oilseeds.

3.2. Microwave Roasting Effects on Physical and Chemical Parameters of Sunflower Oils

Physical and chemical parameters of the sunflower seed oils before and after microwave treatment were summarized in Table 2, the refractive index of the control oil from raw sunflower seeds was 1.4675. As predictable, no significant differences in refractive index between raw and roasted sunflower seeds at different roasting times (8–20 min) were recorded in this study.

The density of the control oils was 0.9081 mg·mL^{-1}. The densities of the oils gradually increased as roasting time increased. After 20 min of roasting, the densities increased beyond the original value. This increase in values might be due to the occurrence of polymerization, which makes the oil denser.

The color progress of sunflower oil which was extracted at different roasting times, changed gradually from light yellow to yellow and then to a brown color (16 and 20 min of roasting). Therefore, with an increase in the roasting time, browning substances were significantly increased. Browning substances were very polar because of active radicals. The longer the microwave treatment time, the larger the strengthening of the color. The formation of browning substances in numerous thermally processed foods resulted from Maillard-non-enzymatic reactions type, caramelization and phospholipids degradation increased with the increasing roasting time [30]. Previous studies have reported that the positive change in the roasting time and temperature of seeds such as rice germ and sesame seeds resulted in a significant increase in the oil's color [26,31,32]. Megahed reported that oil extracted from peanuts revealed gradual darkening and higher Lovibond color changed with increasing of heating time [33]. Hafez proved that TAG were slightly hydrolyzed by microwaves to produce FFA; and an increase in microwave roasting time was accompanied by an increase in the browning substances and phospholipids degradation, which might be attributed to the increase of polar lipids [34]. Phospholipids were demonstrated to cause browning of the oil during roasting treatment. Subsequently, increase in browning substances might be attributable to the increase in contents of other lipids, such as glyceroglycolipids in the oil. A previous study reported that color intensity increases with the formation of browning substances, as a result of phospholipid degradation during microwave heating, which was in range with our results [36].

Saponification value of the control sunflower oil sample was 173.02 mg·g^{-1}. After 20 min of microwave heating of sunflower seeds, the saponification values of the extracted oils were lower than the original values. The more the roasting time, the lesser the saponification value. Saponification value significantly decreased ($P < 0.05$), after 8, 12, 16 and 20 min of microwaved sunflower oil.

The free fatty acids (FFA) tests evidently revealed that, as the roasting time increased, the FFA contents of sunflower oil increased significantly ($P < 0.05$), these findings are in agreement with Yoshida, who reported that FFA in sunflower seed oil increased with increasing of roasting time [37]. The increase in FFA of the oil might be attributed to hydrolysis of TAG by microwaves to produce FFA and DAG, as reported for olive oil, peanuts and sesame seeds [6,12,27]. Fukuda reported that heated sesame oil contained high FFA than other refined vegetable oils [39].

Iodine value of control oil was 122 g of I/100 g of oil. The iodine values of the extracted oils were decreased after roasting. Anjum reported that the decrease in iodine value of the oil might be attributed to the reduction in the number of unsaturation sites due to oxidation, polymerization, or breakage of the long-chain FA [40]. Nevertheless, Jung reported that the iodine values of red pepper seeds oils did not change by roasting time [41]. Some authors found that for sunflower seeds and peanut oils, roasting caused a significant decrease ($P < 0.05$) in molecular species containing more than four double bonds [25,42].

Iodine value is frequently utilized as measurement of stability of oil after roasting. Most of unsaturated oils are unstable to thermal oxidation. More exact, the amounts of PUFA such as linoleic and linolenic acids act as indication of stability, which have more than one double bond in the molecule structure. Linoleic and linolenic oxidize faster than oleic acid, which has one double bond. Therefore, if there are two oils with the same iodine value, the oil with the higher linoleic acid content will oxidize more rapidly than the oil with the higher oleic acid content. The roasting influenced the iodine values of sunflower oils significantly ($P < 0.05$).

3.3. Effects of Roasting Process on Sunflower Oil Stability

Figure 1 elucidates the oil oxidation stability index of the oils obtained from control and roasted sunflower seeds samples. OSI tests evidently showed that as the roasting time increased, the oxidative stability of sunflower oil was improved. The OSI of control sunflower oil was higher than the microwaved oil, because it contains high amounts of VE, anti-oxidative phenolic compounds and might be attributable to its fatty acids composition being more resistant to oxidation. The OSI was significantly decreased after roasting.

Figure 2 shows the peroxide and *p*-anisidine values, PV considered as indicator for the extent of formation of initial oxidation factors in oils while the *p*-anisidine value reflects the degree of secondary oxidation compounds development [28]. There was noticeable increase in PV and *p*-anisidine values after 12 min of roasting, and more clearly differences ($P < 0.05$) were detected after 20 min of roasting. Yoshida demonstrated that a slight enhancement in PV and *p*-anisidine value in peanut seed oil after 30 min of roasting, and a progressive increase with longer roasting time in sesame seed oil [12,26,27]. Commonly, PV does not elucidate the entire state of oxidation of oil because hydro-peroxide was unstable during heating; this resulted in rapid transformation to secondary products. On the other hand, the release of secondary oxidation compounds during microwave roasting was obviously low. The most sensitive parameters that are responsible for changing the chemical properties of refined fats that are heated in a microwave oven is *p*-anisidine value [40]. Lee proposed that an increase in the roasting time, PV of safflower oil was developed. Some of the undesirable and unsafe compounds such as oxidation products and pigments can be produced during microwave roasting of peanuts [30].

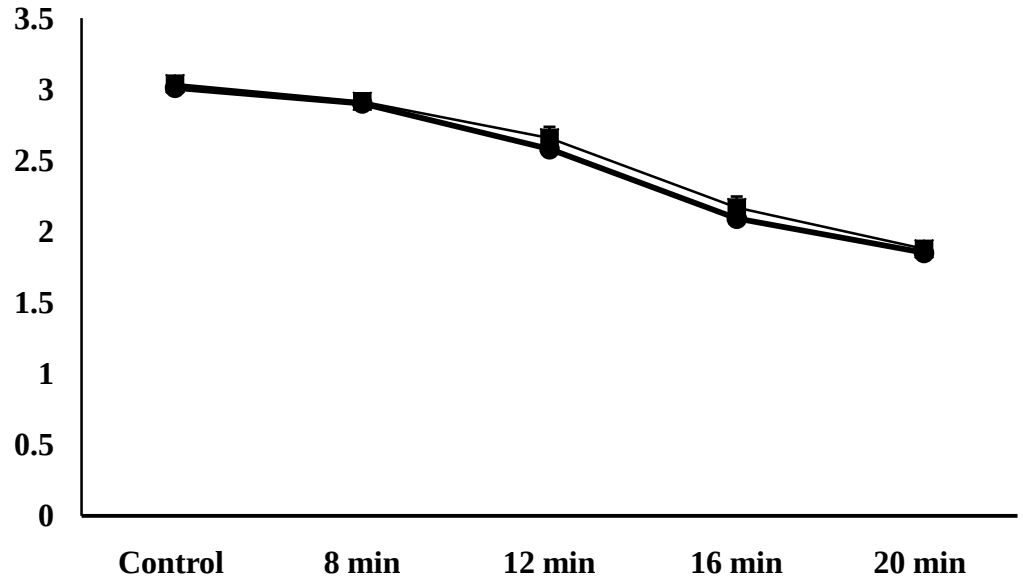

Figure 1. Effects of roasting process on sunflower oil stability (OSI)

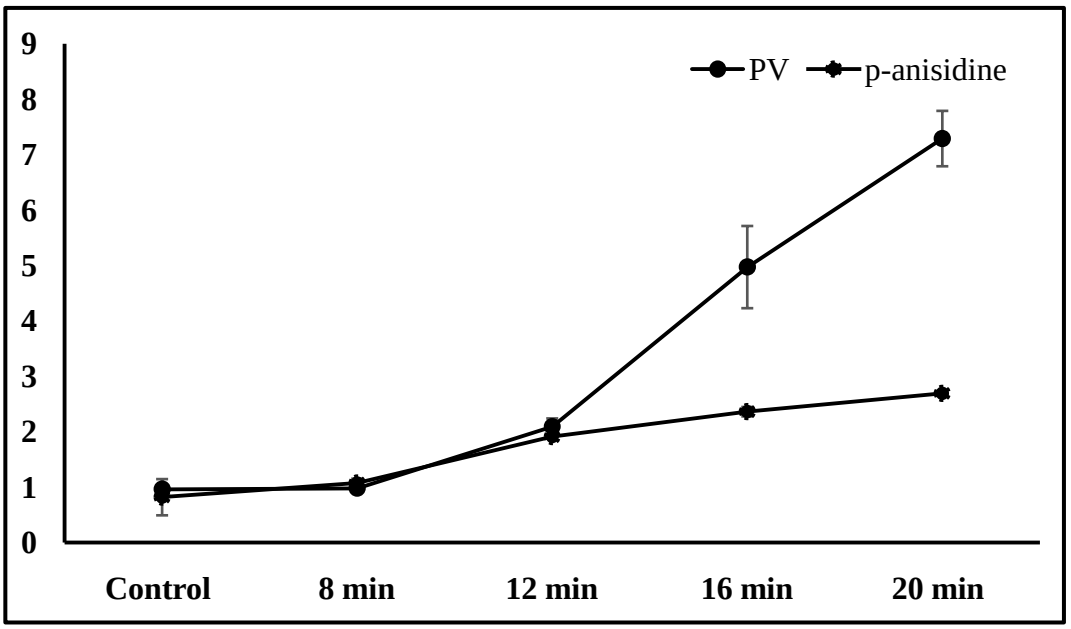

Figure 2. Peroxide (PV) & *P*- anisidine Values

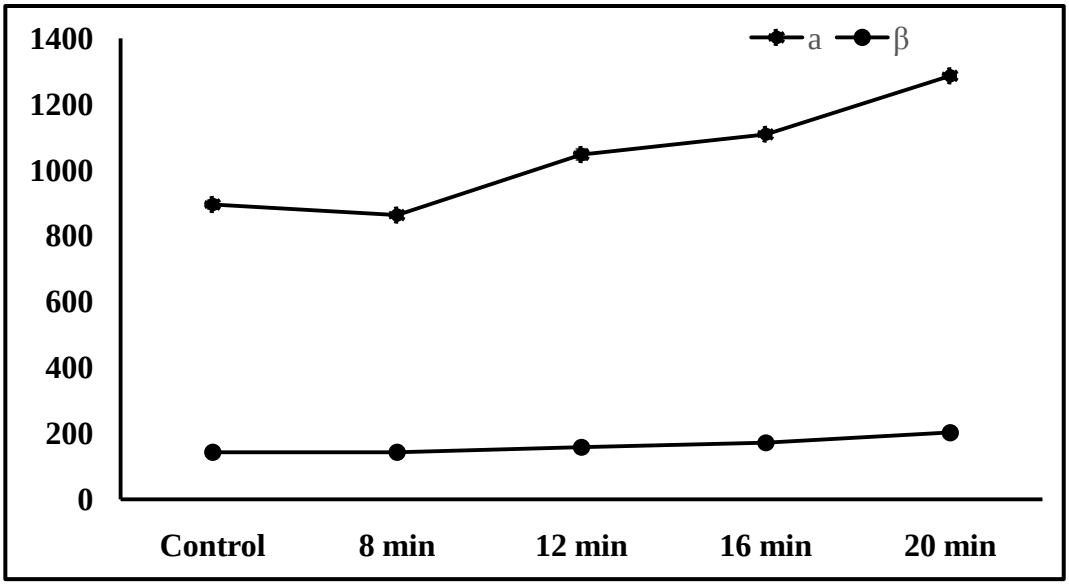

Figure 3. Total tocopherols (VE)

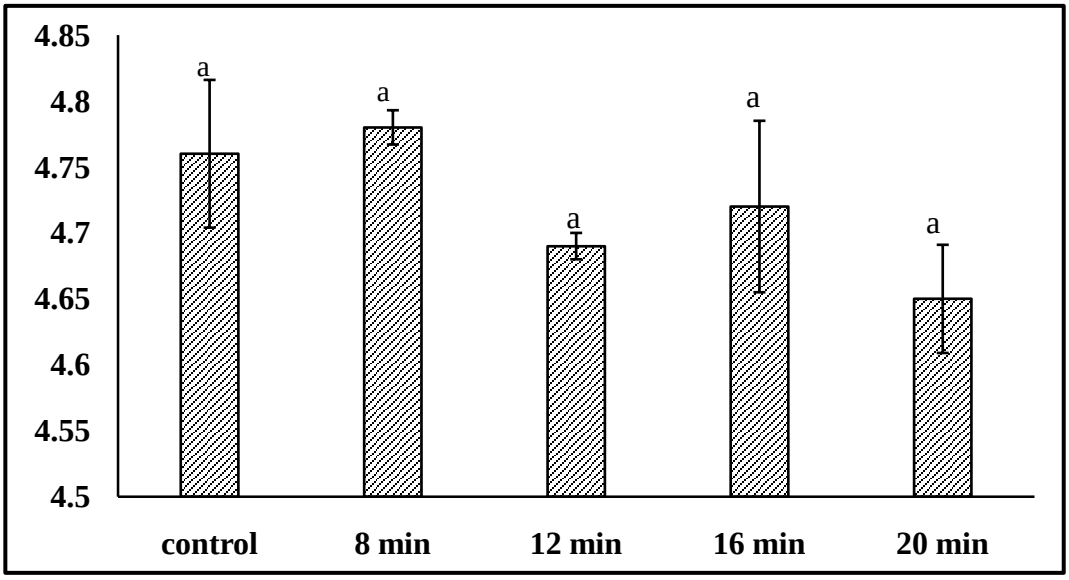

Figure 4. Palmitic

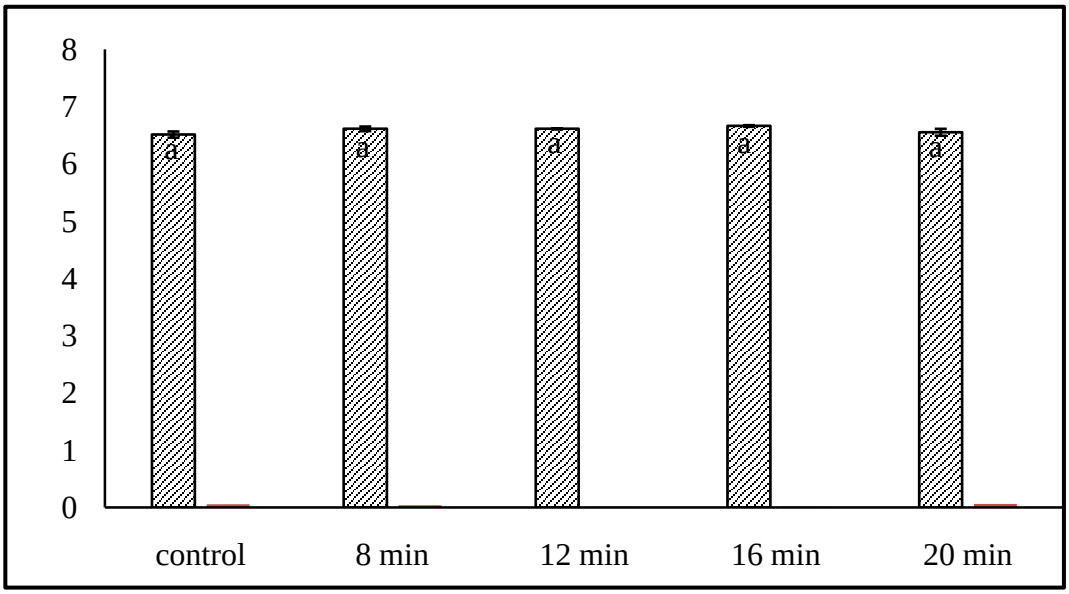

Figure 5. Stearic

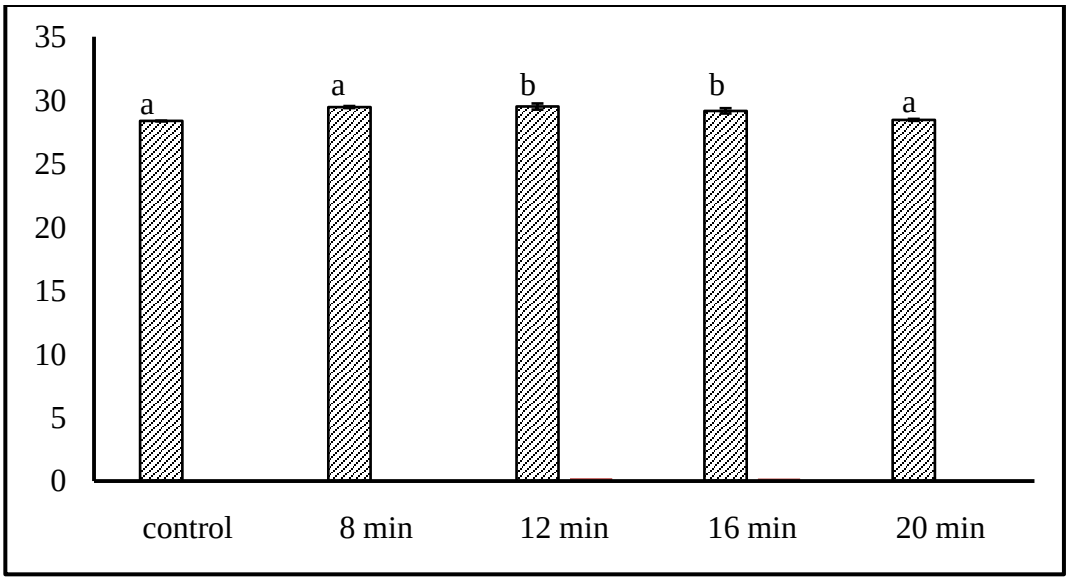

Figure 6. Oleic

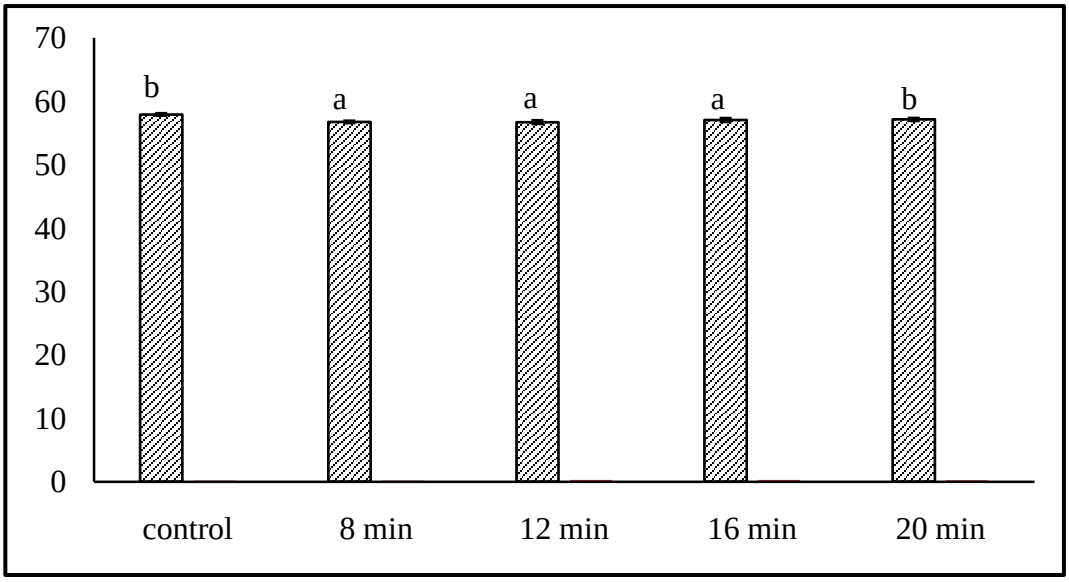

Figure 7. Linoleic

3.4. Total Tocopherols (VE)

The contents of the individual tocopherols in oils are arranged at different roasting times that were included in Figure 3, the major tocopherol that was found in sunflower oil was α-tocopherol, but no presence of δ tocopherols was detected. The content of α-tocopherol in sunflower oil gradually ($P < 0.05$) increased as roasting time amplified. For example, the contents of α-tocopherol in sunflower oils which was roasted at 8, 12, 16 and 20 min were 863.04 ±3.72, 1047.4±15.84, and 1108.83±1.14 and 1286.83±5.71 mg/kg respectively. Comparable trends were detected in β-, and γ-tocopherols. Yoshida reported that the content of tocopherol in sesame oil that was prepared by microwave oven heating decayed during the time [12]. Yen reported that the level of tocopherol in sesame oils prepared by electric oven and heating increased by roasting at temperatures up to 200°C [31]. Kim also reported that the content of α-tocopherol in rice germ oil increased as roasting temperature and time increased. These results propose that the tissues damage occurred due to the heating, and this caused rapid release of tocopherols [32].

3.5. Fatty Acid (FA) Composition

The oil stability, physical properties, and nutritional quality can be determined through FA composition. There were almost no differences in FA structure of microwaved sunflower oils (Figure 4, Figure 5, Figure 6 and Figure 7). Sunflower oil (control) contained was 4.76% palmitic, 6.51% stearic, 28.36% oleic and 57.91% linoleic. Sunflower oil from roasted seeds for 20 min contained 4.65% palmitic, 6.55% stearic, 28.45% oleic and 57.12% linoleic. Previous studies have revealed that there was no differences in FA compositions of rice germ and sesame seed oils which were prepared at different roasting temperatures with time interval [31,32,45]. Our results of the FA analysis exhibited no formation of any *trans* FA during microwave roasting.

4. Conclusion

The chemical composition and oxidative stability of sunflower oil obtained from the roasted seeds at different roasting times (8, 12, 16 and 20 min) were assessed and compared with that of unroasted sunflower oil. Color, FFA, *p*-anisidine and tocopherols contents of oils were varied through the roasting time. Nevertheless, fatty acids composition of sunflower oils did not change with microwave heating. Commercial sunflower with 37.93% oil content is consider one of the important types of sunflower grown in China. The oil stability index showed that, as the roasting time increased, the oil stability index of sunflower oil increased.

Acknowledgements

This work was supported by the Natural Science Foundation of China (31671786), the Research Fund of National 13th Five-Year Plan of China (2016YFD0401404), Northern Jiangsu province science and technology projects (BN2016137), and the Fundamental Research Funds for the Central Universities (JUSRP51501).

References

[1] Yoshida, H., & Sachiko, T. (1997). Microwave roasting and positional distribution of fatty acids of phospholipids in soybeans (Glycine max L.). *Journal of the American Oil Chemists' Society*, 74.8, 915-921.

[2] Rosenberg, U., & Bogl, W. (1987). Microwave thawing, drying, and baking in the food industry. *Food Technology*.

[3] Rosenberg, U., & Bogl, W. (1987). Microwave pasteurization, sterilization, blanching, and pest control in the food industry. *Food Technology (USA)*.

[4] George, M. (1997). Industrial microwave food processing. *Food Review-Cape Town*, 24, 11-15.

[5] Yoshida, H., Hirakawa, Y., & Abe, S. (2001). Influence of microwave roasting on positional distribution of fatty acids of triacylglycerols and phospholipids in sunflower seeds (*Helianthus annuus L.*). *European Journal of Lipid Science and Technology*, 103, 201-207.

[6] Yoshida, H., Abe, S., Hirakawa, Y., & Takagi, S. (2001). Roasting effects on fatty acid distributions of triacylglycerols and phospholipids in sesame (*Sesamum indicum*) seeds. *Journal of the Science of Food and Agriculture*, 81, 620-626.

[7] Finot, P. A. (1995). Nutritional values and safety of microwave-heated food. Mitteilungen Aus Dem Gebiete der Lebensmi Eluntersuchung and Hygiene, 86, 128-128.

[8] Mudgett, R. E. (1982). Electrical-properties of foods in microwave processing. *Food technology*, 36, 109-115.

[9] Yoshida, H., Kondo, I., & Kajimoto, G. (1992). Effects of microwave energy on the relative stability of vitamin E in animal fats. *Journal of the Science of Food and Agriculture*, 58, 531-534.

[10] Farag, R. S. (1994). Influence of microwave and conventional heating on the quality of lipids in model and food systems. *Fett*, 96, 215-222.

[11] Yoshida, H., Hirooka, N., & Kajimoto, G. (1990). Microwave energy effects on quality of some seed oils. *Journal of Food Science*, 55, 1412-1416.

[12] Yoshida, H., Shigezaki, J., Takagi, S., & Kajimoto, G. (1995). Variations in the composition of various acyl lipids, tocopherols and lignans in sesame seed oils roasted in a microwave oven. *Journal of the Science of Food and Agriculture*, 68, 407-415.

[13] Takagi, S., Ienaga, H., Tsuchiya, C., & Yoshida, H. (1999). Microwave roasting effects on the composition of tocopherols and acyl lipids within each structural part and section of a soya bean. *Journal of the Science of Food and Agriculture*, 79, 1155-1162.

[14] Ahmad, S., & Hassan, F. U. (2000). Oil yield and fatty acid composition of spring sunflower. *Pak. J. Biol. Sci*, 3, 2063-2064.

[15] Yoshida, H., Matsuda, K., Hirakawa, Y., & Mizushina, Y. (2003). Roasting effects on the distribution of tocopherols and phospholipids within each structural part and section of soybeans. *Journal of the American Oil Chemists' Society*, 80, 665-674.

[16] Bramley, P. M., Elmadfa, I., Kafatos, A.et al. (2000). Vitamin E. Journal of The Science of Food and Agriculture, 80, 913-938.

[17] Shahidi, F. (2005). Bailey's industrial oil and fat products, six volume set. In: Sunflower Oil (edited by F. Shahidi & M.A. Grompone). 6th edn, Pp. 655-730, Canada: Wiley online library.

[18] ISO, Oilseeds Residues, Determination of Total Ash, ISO, Geneva. (1977). Standard No. 749

[19] Farhoosh, R. (2007). The effect of operational parameters of the Rancimat method on the determination of the oxidative stability measures and shelf-life prediction of soybean oil. Journal of the American Oil Chemists' Society, 84, 205-209.

[20] Sánchez-Machado, D. I., Lopez-Hernandez, J., & Paseiro-Losada, P. (2002). High-performance liquid chromatographic determination of α-tocopherol in macroalgae. *Journal of Chromatography A*, 976, 277-284.

[21] International Union of Pure and Applied Chemistry (IUPAC). (1987). Standard Methods for the Analysis of Oils and Fats and Derivatives,7th revised and enlarged edn., edited by C. Paquot and A. Hautfenne, Blackwell Scientific, London, Method 2. 301.

[22] AOAC, Official Methods of the Association of Official Analytical Chemists. (1984). 14th edn, AOAC, Arlington, VA, Method 28. 110.

[23] ISO, Animal Feeding Stuff. (1981). Determination of Nitrogen and Calculation of Crude Protein Contents, ISO, Geneva, Standard No. 5983.

[24] ISO, Oilseeds Residues. (1977). Determination of Total Ash, ISO, Geneva, Standard No. 749.

[25] Yoshida, H., Hirakawa, Y., & Abe, S. (2001). Roasting influences on molecular species of triacylglycerols in sunflower seeds (*Helianthus annuus L.*). *Food research international*, 34, 613-619.

[26] Yoshida, H., & Kajimoto, G. (1994). Microwave heating affects composition and oxidative stability of sesame (*Sesamum indicum*) oil. *Journal of Food Science*, 59, 613-616.

[27] Yoshida, H., Hirakawa, Y., Tomiyamaa, Y., & Mizushina, Y. (2003). Effects of microwave treatment on the oxidative stability of peanut (*Arachis hypogaea*) oils and the molecular species of their triacylglycerols. *European Journal of Lipid Science and Technology*, 105, 351-358.

[28] Anwar, F., Anwer, T., & Mahmood, Z. (2005). Methodical characterization of rice (*Oryza sativa*) bran oil from Pakistan. Grasas y Aceites, 56, 125-134.

[29] Oomah, B. D., & Mazza, G. (1992). Microwave oven drying for moisture determination in flax, canola and yellow mustard seeds. *Food Science and Technology-Zurich-*, 25, 523-523.

[30] Lee, Y. C., Kim, I. H., Chang, J., Rhee, Y. K., Oh, H. I., & Park, H. K. (2004). Chemical composition and oxidative stability of safflower oil prepared with expeller from safflower seeds roasted at different temperatures. *Journal of Food Science*, 69(1).

[31] Yen, G. C. (1990). Influence of seed roasting process on the changes in composition and quality of sesame (*Sesame indicum*) oil. *Journal of the Science of Food and Agriculture*, 50, 563-570.

[32] Kim, I. H., Kim, C. J., You, J. M., Lee, K. W., Kim, C. T., Chung, S. H., & Tae, B. S. (2002). Effect of roasting temperature and time on the chemical composition of rice germ oil. *Journal of the American Oil Chemists' Society*, 79, 413-418.

[33] Megahed, M. G. (2001). Microwave roasting of peanuts: Effects on oil characteristics and composition. *Molecular Nutrition & Food Research*, 45, 255-257.

[34] Hafez, Y. S., Singh, G., Mclellan, M. E., & Monroe-Lord, L. (1983). Effects of microwave heating on nutritional quality of soybeans. *Nutrition reports international*, 28, 413-421.

[35] Husain, S. Rafat, J. Terao, and S. Matsushita. (1986). Effect of browning reaction products of phospholipids on autoxidation of methyl linoleate. *Journal of the American Oil Chemists' Society*, 63, 1457-1460.

[36] Hassanein, M. M., El-Shami, S. M., & El-Mallah, M. H. (2003). Changes occurring in vegetable oils composition due to microwave heating. *Grasas y aceites*, 54, 343-349.

[37] Yoshida, H., Hirakawa, Y., Abe, S., & Mizushina, Y. (2002). The content of tocopherols and oxidative quality of oils prepared from sunflower (*Helianthus annuus L.*) seeds roasted in a microwave

oven. *European Journal of Lipid Science and Technology*, 104, 116-122.

[38] Cossignani, L., Simonetti, M. S., Neri, A., & Damiani, P. (1998). Changes in olive oil composition due to microwave heating. *Journal of the American Oil Chemists' Society*, 75, 931-937.

[39] Fukuda, Y. (1990). Food chemical studies on the antioxidants in sesame seed. *Nippon Shokuhin Kogyo Gakkaishi*, 37, 484-492.

[40] Anjum, F., Anwar, F., Jamil, A., & Iqbal, M. (2006). Microwave roasting effects on the physico-chemical composition and oxidative stability of sunflower seed oil. Journal of the American Oil Chemists' Society, 83, 777-784.

[41] Jung, M. Y., Bock, J. Y., Baik, S. O., Lee, J. H., & Lee, T. K. (1999). Effects of roasting on pyrazine contents and oxidative stability of red pepper seed oil prior to its extraction. *Journal of Agricultural and Food Chemistry*, 47, 1700-1704.

[42] Yoshida, H., Takagi, S., & Hirakawa, Y. (2000). Molecular species of triacylglycerols in the seed coats of soybeans (glycine max L.) following microwave treatment. Food Chemistry, 70, 63-69.

[43] Farhoosh, R., Einafshar, S. & Sharayei, P. (2009). The effect of commercial refining steps on the rancidity measures of soybean and canola oils. Journal of Food Chemistry, 115, 933-938.

[44] Gray, J. I. (1978). Measurement of lipid oxidation: a review. *Journal of the American Oil Chemists' Society*, 55, 539-546.

[45] Yoshida, H. (1994). Composition and quality characteristics of sesame seed (*Sesamum indicum*) oil roasted at different temperatures in an electric oven. *Journal of the Science of Food and Agriculture*, 65, 331-336.