Effect of Microwave Treatment on Oil Contents, Fatty Acid Compositions and Mineral Contents of Hazelnut Varieties

Elfadil E. Babiker1, Ibrahim A. Almusallam1, Nurhan Uslu2, Fahad Y. Al-Juhaimi1, Mehmet Musa Özcan2*, Kashif Ghafoor1, and Isam A. Mohamed Ahmed1

1 Department of Food Science & Nutrition, College of Food and Agricultural Sciences, King Saud University, P. O. Box 2460, Riyadh 11451, SAUDI ARABIA
2 Food Engineering Department, Faculty of Agriculture, Selçuk University, 42079 Konya, TURKEY

Abstract: The oil content of both ‘raw’ and hazelnut kernels was significantly ($p < 0.05$) reduced as the microwave power increased from 180 W to 360 W. The contents of fatty acids fluctuated for all varieties with microwave power, with a significant ($p < 0.05$) increment observed for ‘Sivri’ hazelnut at 180 and 720 W. The maximum linoleic acid contents for ‘Raw’, ‘Sivri’ and ‘Tombul’ hazelnuts were found as 11.87%, 12.61% and 17.68% for nuts roasted at 540 W, unroasted and those roasted at 720 W, respectively. It was observed that K (9735.1 mg/kg) and Mg (2343.7 mg/kg) contents of the investigated samples were found at the maximum levels in unroasted ‘Tombul’ hazelnut, while the highest P (2845.0 mg/kg) and S (1795.3 mg/kg) contents are determined for hazelnut roasted at 720 W ($p < 0.05$). The highest Ca content in hazelnut kernel was also observed at 360 W with 2400.9 mg/kg. However, roasting process did not dramatically affect the mineral contents of samples.

Key words: hazelnut, microwave roasting, moisture, oil, fatty acid, mineral, GC, ICP-AES

1 Introduction

Hazelnut (Corylus avellana L.) is a good source of major nutrient (protein, oil, vitamin and mineral) required for human health. In Turkey, the coast of the Black Sea, is the major producer of such nut and contributing about 70.3% of the world production1). The hazelnut contains 54.6-69.0% of fat which plays as a major role in human nutrition as a source of fatty acid mainly oleic acid2,3, about 12% protein1, minerals (Ca, Mg, P, K), vitamins E and B complex, sterols and several bioactive polyphenols, so it can reduce oxidative stress and cancer risk4). The quality of oil and fatty acid content of hazelnut can be affected by environmental conditions, cultivar, location and agricultural practices5). Roasting of the nuts leads to different physico-chemical changes such as crispy texture, characteristic flavour because of pyrazine compounds and colour that developed after roasting6). The application of microwave heating can replace the conventional process because is faster and safe energy cost7,8). Moreover, microwave heating of hazelnut reduce the level of contamination by aflatoxin9). Microwave and conventional heating are now used in many food processing steps such as cooking, drying, tempering, baking, pasteurization and sterilization. Thermal reaction of long chain fatty acids esters that requires long time of heating or stirring at room temperature, can be reduced by using microwave oven9,10). Microwave treatment had many advantages compared to conventional processes such as speed of operation, energy savings, precise process control, faster start up and shut-down times10,11).

In the present study we would like to investigate the effect of roasting process using microwave oven on oil yield, mineral content and fatty acid composition of Turkish hazelnut varieties.

2 Material and Methods

2.1 Material

Hazelnuts were obtained from Giresun province (‘Tirebolu’) in Turkey and dried at 70°C to moisture level of <12%. Thereafter, the nuts were put in coloured glass bottles. The
hazelnuts were deforested and dehulled before analyses. All reagents and solvents were standard and purchased from Sigma-Aldrich Co. (St. Louis, MO, USA).

2.2 Method

2.2.1 Microwave heating

Microwave treatment was performed at the Arçelik ARMD 580 (İstanbul, Turkey) factory, using an ARÇELİK microwave device with a microwave frequency of 2450 MHz, with 900 W of microwave power, provided with a special fans to obtain regular heat distribution. The microwave equipment consisted of metal structure and an inner metal surface that direct microwaves into the cell. The dimensions of the microwave cavity were 34.5 cm × 34.0 cm × 22.5 cm. Hazelnut samples for each treatment were placed into a glass plate with 50 mL capacity and placed at same distances of the microwave. Thereafter, they heated with 50 mL capacitation under nitrogen in microwave at 2450 MHz for 5 min and cooled at room temperature.

2.2.2 Oil extraction and determination

The oil of the ground hazelnut was extracted using petroleum benzene in Soxhlet apparatus for 5 h and the residual solvent was evaporated by a rotary vacuum evaporator at 50°C. The oil content of nuts was estimated by AOAC method.

2.2.3 Determination of fatty acid content

Hazelnut oils were esterificated as reported by ISO-5509 method. The methyl esters of fatty acid of nuts were estimated by gas chromatography (Shimadzu GC-2010) equipped with flame-ionization detector (FID) and capillary column (Tecnocroma TR-CN100, 60 m × 0.25 mm, film thickness: 0.20 µm). The injection block and detector temperature was 260°C and the mobile phase of the system was nitrogen with 1.51 mL/min flow rate. Total flow rate was 80 mL/min and split rate was 1/40. The temperature of the column was programmed to be 120°C every 5 minutes and increased to 240°C with 4°C/min and held 25 minutes at 240°C. Fatty acid methyl ester mixture (Sigma Chemical Co.) standard was used to identify the samples peaks. Commercial mixtures of fatty acid methyl esters were used as reference data for the relative retention times as reported in AOAC method.

2.2.4 Mineral content determination

A ground sample of hazelnut (0.2 g) was mixed with 15 mL of pure NH₄OH and 2 mL H₂O₂ (% 30 w/v). The mixture was digested in a MARS 5 microwave oven at 210°C. Thereafter, filtrated using whatman No 42. The filtrate was put in a 50 mL flask and analysed using ICP-AES. Minerals contents were estimated using standard curve of known mineral concentrations.

Instrument
- ICP-AES (Varian-Vista)
- RF Power
  - 0.7-1.5 kW (1.2-1.3 kW for Axial)
- Plasma gas flow rate (Ar)
  - 10.5-15 L/min. (radial) 15° (axial)
- Auxiliary gas flow rate (Ar)
  - 1.5°
- Viewing height
  - 5-12 mm
- Copy and reading time
  - 1-5 s (max. 60 s)
- Copy time
  - 3 s (max. 100 s)

2.3 Statistical analysis

For statistical analysis, a complete randomized split plot block design was applied and the variance analysis (ANOVA) was done by using JMP version 9.0 (SAS Inst. Inc., Cary, N.C.U.S.A). All analyses were done in triplicates and the results are indicated as mean ± SD (MSTAT C) of independent hazelnut samples.

| Varieties       | Oil content          |
|-----------------|----------------------|
| 'Raw' hazelnut  | 63.78 ± 1.27 *c       |
| 'Raw' hazelnut (720 W) | 71.70 ± 2.13 **a       |
| 'Raw' hazelnut (540 W) | 71.00 ± 1.46 a       |
| 'Raw' hazelnut (360 W) | 64.28 ± 1.68 c       |
| 'Raw' hazelnut (180 W) | 67.20 ± 0.93 b       |
| 'Sivri' hazelnut | 59.74 ± 0.77 c       |
| 'Sivri' hazelnut (720 W) | 65.84 ± 0.91 a       |
| 'Sivri' hazelnut (540 W) | 65.81 ± 1.09 a       |
| 'Sivri' hazelnut (360 W) | 61.69 ± 1.13 b       |
| 'Sivri' hazelnut (180 W) | 65.11 ± 1.38 a       |
| 'Tombul' hazelnut | 52.67 ± 0.89 d       |
| 'Tombul' hazelnut (720 W) | 62.67 ± 1.32 b       |
| 'Tombul' hazelnut (540 W) | 63.42 ± 1.56 a       |
| 'Tombul' hazelnut (360 W) | 61.73 ± 1.43 c       |
| 'Tombul' hazelnut (180 W) | 61.30 ± 1.39 c       |

* mean ± standard deviation (n:3)
** Values within each row followed by different letters are significantly different (p < 0.05)
3 Results and Discussion

3.1 Oil and fatty acids contents of roasted hazelnut varieties

The oil content of roasted and unroasted hazelnut varieties is shown in Table 1. The oil content of the kernels of roasted nut was significantly (p<0.05) higher than that of unroasted. It was observed that the oil content of hazelnut varieties increased with increase in microwave power (watt). However, oil content of 'Raw' hazelnut kernels was significantly (p<0.05) reduced from 67.20% to 64.28%. In addition, the oil content of 'Sivri' hazelnut kernels also significantly (p<0.05) reduced from 65.11% to 61.69% when the microwave power increased from 180 W to 360 W (Table 1). Generally, oil contents of 'Raw', 'Sivri' and 'Tombul' hazelnut varieties were varied between 63.78% and 71.70%, 59.74% and 65.84% and 52.67% and 63.42%, respectively (Table 1). With respect to varieties, the maximum oil content was obtained from 'Raw' hazelnut. The results showed that the varieties are positively affected by roasting process at both 540 W and 720 W. Significant differences (p<0.05) among oil contents of hazelnut kernels were observed depending on microwave roasting power. According to the results obtained in this study, microwave roasting is a powerful technique to improve oil content of hazelnut. It has been reported that roasting of poppy seeds increased the oil contents while it reduced the moisture contents\(^{(17)}\). A study conducted on black cumin\(^{(18)}\)and rape seeds\(^{(19)}\) showed that changes in the microwave power and time was directly related to the efficiency of the oil extraction. Further they reported that as the microwave power and time were increased leads to increase in the efficiency of oil extraction. The increment in oil extraction could be due to the fact that, microwave lead to water loss in the plant cells and enhanced the pressure in the internal environment leading to decomposition of the cell material, membrane disruption as well as increment in the extraction efficiency of oil. Also, Al Juhaimi et al.\(^{(19)}\) reported similar results on apricot kernel oil roasted in

| Fatty acids         | Control  | 720 | 540 | 360 | 180 |
|---------------------|----------|-----|-----|-----|-----|
| Myristic            | 0.10 ± 0.03\(^{a}\) | 0.05 ± 0.01\(^{b}\) | 0.04 ± 0.01\(^{bc}\) | 0.03 ± 0.01\(^{b}\) | 0.04 ± 0.01\(^{bc}\) |
| Palmitic            | 5.92 ± 0.12\(^{a}\) | 5.79 ± 0.21\(^{a}\) | 5.89 ± 0.34\(^{a}\) | 5.60 ± 0.28\(^{b}\) | 5.94 ± 0.34\(^{a}\) |
| Palmitoleic         | 0.14 ± 0.03\(^{b}\) | 0.22 ± 0.05\(^{b}\) | 0.16 ± 0.09\(^{b}\) | 0.12 ± 0.07\(^{b}\) | 0.25 ± 0.09\(^{b}\) |
| Heptadecanoic       | ND       | 0.04 ± 0.01\(^{b}\) | 0.04 ± 0.01\(^{b}\) | 0.05 ± 0.03\(^{b}\) | 0.05 ± 0.02\(^{b}\) |
| Heptadecenoic       | ND       | 0.06 ± 0.02\(^{bc}\) | 0.08 ± 0.01\(^{b}\) | 0.09 ± 0.03\(^{b}\) | 0.08 ± 0.05\(^{b}\) |
| Stearic             | 3.06 ± 0.16\(^{a}\) | 3.08 ± 0.21\(^{a}\) | 2.86 ± 0.37\(^{b}\) | 3.19 ± 0.71\(^{a}\) | 3.36 ± 0.48\(^{b}\) |
| Oleic               | 79.92 ± 1.17\(^{b}\) | 80.27 ± 1.56\(^{b}\) | 78.64 ± 1.32\(^{d}\) | 81.11 ± 1.77\(^{b}\) | 80.35 ± 1.89\(^{b}\) |
| Linoleic            | 10.36 ± 0.59\(^{b}\) | 10.07 ± 0.98\(^{b}\) | 11.87 ± 0.71\(^{a}\) | 9.38 ± 0.49\(^{b}\) | 9.53 ± 0.69\(^{b}\) |
| Linolenic           | 0.08 ± 0.03\(^{a}\) | 0.08 ± 0.05\(^{a}\) | 0.07 ± 0.01\(^{b}\) | 0.08 ± 0.03\(^{b}\) | 0.07 ± 0.01\(^{b}\) |
| Arachidic           | 0.18 ± 0.09\(^{a}\) | 0.09 ± 0.03\(^{a}\) | 0.14 ± 0.07\(^{b}\) | 0.15 ± 0.03\(^{b}\) | 0.11 ± 0.05\(^{c}\) |
| Eicosenoic          | 0.17 ± 0.05\(^{a}\) | 0.17 ± 0.03\(^{a}\) | 0.14 ± 0.07\(^{b}\) | 0.13 ± 0.03\(^{ab}\) | 0.15 ± 0.07\(^{b}\) |
| Behenic             | 0.05 ± 0.01\(^{a}\) | ND     | 0.03 ± 0.01\(^{b}\) | ND     | 0.03 ± 0.01\(^{b}\) |
| Docosadienoic       | 0.02 ± 0.01\(^{ab}\) | 0.08 ± 0.03\(^{a}\) | 0.03 ± 0.01\(^{b}\) | 0.07 ± 0.03\(^{ab}\) | 0.04 ± 0.01\(^{b}\) |
| TOTAL               | 100.00   | 100.00 | 99.99 | 100.00 | 100.00 |
| Ω 3                 | 0.08     | 0.08   | 0.07   | 0.08   | 0.07   |
| Ω 6                 | 10.36    | 10.07  | 11.87  | 9.38   | 9.53   |
| Ω 9                 | 79.92    | 80.27  | 78.64  | 81.11  | 80.35  |
| ΣSAFA               | 9.31     | 9.05   | 9.00   | 9.02   | 9.53   |
| ΣMUFA               | 80.23    | 80.72  | 79.02  | 81.45  | 80.83  |
| ΣPUFA               | 10.46    | 10.23  | 11.97  | 9.53   | 9.64   |
| ΣUFA                | 90.69    | 90.95  | 90.99  | 90.98  | 90.47  |
| ΣUFA/ΣSAFA          | 9.74     | 10.05  | 10.11  | 10.08  | 9.49   |

SAFA; total saturated fatty acids, MUFA; total monounsaturated fatty acids, PUFA; total polyunsaturated fatty acids, UFA; total unsaturated fatty acids, ND: not detected. Figures are average ± SD (n:3). Figures for each row followed by different superscript are differed significantly at \(p<0.05\).
microwave oven.

Fatty acid compositions of oils extracted from roasted and unroasted three hazelnut varieties is presented in Tables 2-4. Microwave treatment was observed to cause minor changes in fatty acid content of hazelnut oil. The major fatty acids of hazelnut varieties oil were oleic acid followed by linoleic acid and palmitic acid. The content of other fatty acids was low or can not be detected. The dominant fatty acids of oil extracted from unroasted and roasted ‘raw’ hazelnut using different microwave powers (180, 360, 540 and 720 W) were oleic acid followed by linoleic and palmitic acid (Table 2).

Oleic acid content of the oil of ‘raw’ hazelnut roasted at 180, 360, 540 and 720 W was significantly ($p < 0.05$) influenced byroasting and when ‘raw’ hazelnut roasted at 180, 360 and 720 W. Oleic acid was significantly ($p < 0.05$) increased to 80.35, 81.11 and 80.27% compared to the control or unroasted nut (79.92%) but at 540 W it was significantly ($p < 0.05$) decreased to 78.64%. However, linoleic acid content was significantly ($p < 0.05$) increased to 11.87% at 540 W compared to the control or unroasted nut (10.36%) but at 180, 360 and 720 W it was significantly ($p < 0.05$) decreased.

Palmitic acid and other fatty acids contents were slightly affected by microwave power. The results obtained in this study indicated that microwave roasting at different power had affected fatty acid content of ‘raw’ hazelnut oils. The effect of microwave roasting at different power on fatty acids content of ‘sivri’ (Table 3) and ‘tombul’ (Table 4) hazelnuts oil was similar to that reported for ‘raw’ hazelnut oil (Table 2).

Hojjati et al.\textsuperscript{20} reported that the fatty acid content of roasted pistachios was significantly ($p < 0.05$) influenced by the roasting process, compared to unroasted seeds and they found that oleic acid, linoleic acid and palmitic acid are the major acids of roasted seeds. Further they reported that microwave roasting preserved healthy unsaturated fatty acid contents compared to hot-air roasting. However,

### Table 3: Effect of roasting on fatty acid compositions (%) of oils extracted from ‘Sivri’ hazelnut.

| Fatty acids     | Control   | 720       | 540       | 360       | 180       |
|-----------------|-----------|-----------|-----------|-----------|-----------|
| Myristic        | 0.02 ± 0.01\textsuperscript{b} | 0.03 ± 0.01\textsuperscript{a} | ND        | ND        | ND        |
| Palmitic        | 5.70 ± 0.71\textsuperscript{b} | 5.76 ± 0.23\textsuperscript{b} | 5.12 ± 0.36\textsuperscript{b} | 5.24 ± 0.52\textsuperscript{c} | 5.38 ± 0.46\textsuperscript{b} |
| Palmitoleic     | 0.17 ± 0.05\textsuperscript{b} | 0.17 ± 0.03\textsuperscript{b} | 0.48 ± 0.09\textsuperscript{b} | 0.16 ± 0.03\textsuperscript{b} | 0.16 ± 0.05\textsuperscript{b} |
| Heptadecanoic   | ND        | ND        | ND        | ND        | ND        |
| Heptadecenoic   | 0.09 ± 0.01\textsuperscript{d} | 0.15 ± 0.03\textsuperscript{e} | 0.19 ± 0.09\textsuperscript{b} | 0.22 ± 0.07\textsuperscript{a} | 0.19 ± 0.03\textsuperscript{b} |
| Searic          | 2.11 ± 0.28\textsuperscript{a} | 3.19 ± 0.49\textsuperscript{a} | 5.18 ± 0.35\textsuperscript{s} | 2.25 ± 0.17\textsuperscript{c} | 2.84 ± 0.19\textsuperscript{g} |
| Oleic           | 78.27 ± 1.12\textsuperscript{b} | 81.20 ± 0.98\textsuperscript{b} | 75.29 ± 0.78\textsuperscript{b} | 80.66 ± 1.48\textsuperscript{b} | 81.74 ± 1.79\textsuperscript{b} |
| Linoleic        | 12.61 ± 0.79\textsuperscript{c} | 9.13 ± 0.46\textsuperscript{c} | 9.92 ± 0.48\textsuperscript{c} | 11.06 ± 0.43\textsuperscript{b} | 9.44 ± 0.57\textsuperscript{c} |
| Linolenic       | 0.11 ± 0.03\textsuperscript{b} | 0.11 ± 0.05\textsuperscript{b} | 0.26 ± 0.09\textsuperscript{b} | 0.10 ± 0.03\textsuperscript{b} | 0.09 ± 0.01\textsuperscript{c} |
| Arachidic       | 0.11 ± 0.03\textsuperscript{c} | 0.12 ± 0.05\textsuperscript{b} | 0.25 ± 0.07\textsuperscript{b} | 0.11 ± 0.03\textsuperscript{b} | 0.10 ± 0.03\textsuperscript{e} |
| Eicosenoic      | 0.18 ± 0.05\textsuperscript{c} | 0.15 ± 0.07\textsuperscript{d} | 0.26 ± 0.09\textsuperscript{b} | 0.19 ± 0.03\textsuperscript{b} | 0.16 ± 0.03\textsuperscript{c} |
| Eicosadienoic   | 1.21 ± 0.22\textsuperscript{c} | 1.57 ± 0.13\textsuperscript{a} | 2.96 ± 0.32\textsuperscript{a} | ND        | ND        |
| Lignoceric      | 0.73 ± 0.11\textsuperscript{a} | 0.38 ± 0.07\textsuperscript{c} | 0.28 ± 0.09\textsuperscript{b} | ND        | ND        |
| TOTAL           | 99.99      | 99.98      | 100.00    | 99.99      | 100.00    |
| Ω 3             | 0.11       | 0.11       | 0.26      | 0.10       | 0.09      |
| Ω 6             | 12.61      | 9.13       | 9.92      | 11.06      | 9.44      |
| Ω 9             | 78.27      | 81.20      | 75.29     | 80.66      | 81.74     |
| ΣSAFA           | 8.65       | 9.07       | 10.83     | 7.60       | 8.41      |
| ΣMUFA           | 78.62      | 81.67      | 76.03     | 81.23      | 82.06     |
| ΣPUFA           | 12.72      | 9.24       | 13.14     | 11.16      | 9.53      |
| ΣUFA            | 91.34      | 90.91      | 89.17     | 92.39      | 91.59     |
| ΣUFA/ΣSAFA      | 10.55      | 10.02      | 8.23      | 12.15      | 10.89     |

SAFA; total saturated fatty acids, MUFA; total monounsaturated fatty acids, PUFA; total polyunsaturated fatty acids, UFA; total unsaturated fatty acids, ND: not detected. Values are mean ± SD (n:3). Figures are average ± SD (n:3). Figures for each row followed by different superscript are differed significantly at $p < 0.05$. 

\textsuperscript{20}Hojjati et al.
Effect of Heating on Oil Properties of Hazelnut Varieties

Table 4  Effect of roasting on fatty acid compositions(%) of oils extracted from ‘Tombul’ hazelnut.

| Fatty acids    | Control | 720 | 540 | 360 | 180 |
|----------------|---------|-----|-----|-----|-----|
| Myristic       | 0.08 ± 0.02<sup>a</sup> | 0.03 ± 0.01<sup>b</sup> | 0.02 ± 0.01<sup>ab</sup> | 0.06 ± 0.03<sup>b</sup> | 0.05 ± 0.03<sup>b</sup> |
| Palmitic       | 5.29 ± 0.45<sup>c</sup> | 5.26 ± 0.37<sup>c</sup> | 5.10 ± 0.32<sup>c</sup> | 5.22 ± 0.19<sup>c</sup> | 5.20 ± 0.26<sup>c</sup> |
| Palmitoleic    | 0.25 ± 0.09<sup>c</sup> | 0.16 ± 0.03<sup>bc</sup> | 0.12 ± 0.05<sup>b</sup> | 0.17 ± 0.09<sup>b</sup> | 0.16 ± 0.07<sup>b</sup> |
| Heptadecanoic  | 0.08 ± 0.03<sup>d</sup> | 0.04 ± 0.01<sup>d</sup> | 0.14 ± 0.05<sup>b</sup> | 0.16 ± 0.07<sup>b</sup> | 0.19 ± 0.03<sup>d</sup> |
| Heptadecenoic  | 0.09 ± 0.03<sup>b</sup> | 0.13 ± 0.05<sup>a</sup> | 0.08 ± 0.01<sup>e</sup> | 0.09 ± 0.03<sup>b</sup> | 0.08 ± 0.03<sup>e</sup> |
| Stearic        | 1.85 ± 0.11<sup>b</sup> | 1.55 ± 0.13<sup>b</sup> | 1.66 ± 0.21<sup>b</sup> | 2.02 ± 0.19<sup>b</sup> | 1.85 ± 0.31<sup>b</sup> |
| Oleic          | 75.66 ± 1.59<sup>a</sup> | 74.70 ± 1.68<sup>a</sup> | 76.73 ± 1.49<sup>a</sup> | 74.55 ± 1.48<sup>b</sup> | 73.83 ± 1.58<sup>b</sup> |
| Linoleic       | 16.31 ± 0.68<sup>b</sup> | 17.68 ± 0.82<sup>a</sup> | 15.58 ± 0.93<sup>c</sup> | 17.35 ± 0.91<sup>d</sup> | 17.53 ± 0.71<sup>e</sup> |
| Linolenic      | 0.08 ± 0.03<sup>d</sup> | 0.07 ± 0.03<sup>de</sup> | 0.17 ± 0.09<sup>f</sup> | 0.13 ± 0.05<sup>b</sup> | 0.11 ± 0.03<sup>c</sup> |
| Arachidic      | 0.14 ± 0.07<sup>c</sup> | 0.08 ± 0.01<sup>c</sup> | 0.08 ± 0.01<sup>c</sup> | 0.10 ± 0.03<sup>b</sup> | 0.10 ± 0.03<sup>b</sup> |
| Eicosenoic     | 0.12 ± 0.05<sup>e</sup> | 0.19 ± 0.03<sup>b</sup> | 0.16 ± 0.03<sup>b</sup> | 0.19 ± 0.07<sup>b</sup> | 0.18 ± 0.05<sup>b</sup> |
| Eicosadienoic  | 0.21 ± 0.05<sup>d</sup> | 0.58 ± 0.09<sup>e</sup> | 0.97 ± 0.11<sup>c</sup> | 0.63 ± 0.07<sup>b</sup> | 0.56 ± 0.09<sup>d</sup> |
| Behenic        | 0.03 ± 0.01<sup>b</sup> | 0.02 ± 0.01<sup>b</sup> | 0.11 ± 0.03<sup>b</sup> | 0.04 ± 0.01<sup>b</sup> | 0.03 ± 0.01<sup>b</sup> |
| Docosadienoic  | 0.04 ± 0.01<sup>bc</sup> | 0.09 ± 0.03<sup>c</sup> | 0.05 ± 0.02<sup>b</sup> | 0.04 ± 0.01<sup>b</sup> | 0.03 ± 0.01<sup>c</sup> |
| Lignoceric     | 0.91 ± 0.17<sup>c</sup> | 0.88 ± 0.13<sup>c</sup> | 0.67 ± 0.15<sup>c</sup> | 0.04 ± 0.01<sup>d</sup> | 0.86 ± 0.21<sup>bc</sup> |
| Nervonic       | ND       | ND   | ND   | 0.03 ± 0.01<sup>e</sup> | 0.05 ± 0.01<sup>bc</sup> | 0.10 ± 0.03<sup>e</sup> |
| TOTAL          | 100.00   | 100.00 | 100.00 | 100.00 | 100.00 |
| Ω 3            | 0.08     | 0.07 | 0.17 | 0.13 | 0.11 |
| Ω 6            | 16.31    | 17.68 | 15.58 | 17.35 | 17.53 |
| Ω 9            | 75.66    | 74.70 | 76.73 | 74.56 | 73.83 |
| ΣSAFA          | 7.45     | 6.98 | 7.11 | 7.48 | 8.01 |
| ΣMUFA          | 76.12    | 75.18 | 77.09 | 75.00 | 74.35 |
| ΣPUFA          | 16.43    | 17.84 | 15.80 | 17.52 | 17.64 |
| ΣUFA           | 92.55    | 93.02 | 92.89 | 92.52 | 91.99 |
| ΣUFA/ΣSAFA     | 12.42    | 13.32 | 13.06 | 12.37 | 11.48 |

SAFA: total saturated fatty acids, MUFA: total monounsaturated fatty acids, PUFA: total polyunsaturated fatty acids, UFA: total unsaturated fatty acids, ND: not detected. Values are mean ± standard deviation (n=3). Figures are average ± SD (n=3). Figures for each row followed by different superscript are differed significantly at p < 0.05.

Vaidya and Eun<sup>21</sup> did not observe significant differences in fatty acid content of roasted and unroasted walnut oils. Ogungbenle and Afolayan<sup>(2015)</sup> reported that the dominant fatty acids of cashew nut roasted in an oven at 150-200°C were oleic (58.7%), linoleic (18.9%) and palmitic (12.1%) acids. Koksal et al.<sup>26</sup> determined 4.72% to 5.87% palmitic, 0.86% to 2.49% stearic, 74.2% to 82.8% oleic and 9.82% to 18.7% linoleic acids in several hazelnut (Corylus avellana L.) varieties. Özdemir et al.<sup>25</sup> observed 6.6-8.3% palmitic, 1.8-3.8% stearic, 75.7-80.7% oleic and 10.1-13.8% linoleic acids in commercial and hybrid of hazelnut kernel oils. Also Allani<sup>27</sup> observed 6.91% palmitic, 79.85% oleic, 10.56% linoleic and 2.60% stearic acid in hazelnut oil. High ratio of unsaturated/saturated fatty acids in hazelnut, make it a good additive to improve the quality of processed food. Moreover, Parcerisa<sup>et al. 25</sup> stated that the dominant in hazelnut oil was oleic acid.

3.2 Effect of roasting on mineral compositions

Table 5 shows the content of some major and trace minerals of hazelnut varieties subjected to microwave roasting at different powers (180, 360, 540 and 720 W). According to the results obtained hazelnut varieties are rich sources of minerals. The most dominant minerals in hazelnut varieties were potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg) and sulfur (S). Other minerals were presented but at lower levels. The maximum and significant (p < 0.05) level of Ca (2222.989 mg/kg), K (7354.031 mg/kg), Mg (1789.571 mg/kg), P (2957.561 mg/kg) and S (1809.450 mg/kg) was observed in ‘raw’ hazelnut roasted.
Mineral contents of control and roasting hazelnut varieties (mg/kg).

| Varieties   | Ca       | Mg       | Fe       | Cu       | Zn       |
|-------------|----------|----------|----------|----------|----------|
| Control     |          |          |          |          |          |
| Raw         | 0.005    | ±        | ±        | ±        | ±        |
| Tombul      | 0.27     | ±        | ±        | ±        | ±        |
| Sivri       | 0.21     | ±        | ±        | ±        | ±        |
| 540 W       | 0.24     | ±        | ±        | ±        | ±        |
| 360 W       | 0.36     | ±        | ±        | ±        | ±        |
| 180 W       | 0.35     | ±        | ±        | ±        | ±        |

Values within each row followed by different letters are significantly different (p < 0.05).

4 Conclusion

The results of the present study showed that the oil and fatty acids contents of hazelnut varieties had significantly affected by microwave roasting depending on microwave power. The oil content was observed to increase with the increase of microwave power for all varieties. Most the fatty acids of the varieties were observed to increase significantly while others remain stable or decreased. The effect of microwave roasting on minerals content was found to be varied depending on microwave power.

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References

1. Rezaei, F.; Bakhshi, D.; Ghazvini, R.F.; Majd, D.J.; Pourghayoumi, M. Evaluation of fatty acid content and nutritional properties selected native and imported hazelnut (Corylus avellana L.) varieties grown in Iran. J. Appl. Bot. Food Qual. 87, 104-107 (2014).
2. Beyhan, O.; Elmastaé, M.; Gene, N.; Aksit, H. Effect of altitude on fatty acid composition in Turkish hazelnut (Corylus avellana L.) varieties. Afr. J. Biotechnol. 10.
Effect of Heating on Oil Properties of Hazelnut Varieties

1. 

Donno, D.; Beccaro, G.L.; Mellano, G.M.; Prima, S.; Cavicchioli, M.; Cerutti, A.K.; Bounous, G. Setting a protocol for hazelnut roasting using sensory and colorimetric analysis: influence of the roasting temperature on the quality of Tonda Gentile delle Langhe Cv. Hazelnut. Czech. J. Food Sci. 31, 390-400 (2013).

2. 

Vujevic, P.; Petrovic, M.; Vahcic, N.; Milinovic, B.; Cmelik, Z. Lipids and minerals of the most represented hazelnut varieties cultivated in Croatia. Ital. J. Food Sci. 26, 24-30 (2014).

3. 

Donno, D.; Beccaro, G.L.; Mellano, G.M.; Prima, S.; Cavicchioli, M.; Cerutti, A.K.; Bounous, G. Setting a protocol for hazelnut roasting using sensory and colorimetric analysis: influence of the roasting temperature on the quality of Tonda Gentile delle Langhe Cv. Hazelnut. Czech. J. Food Sci. 31, 390-400 (2013).

4. 

Donno, D.; Beccaro, G.L.; Mellano, G.M.; Prima, S.; Cavicchioli, M.; Cerutti, A.K.; Bounous, G. Setting a protocol for hazelnut roasting using sensory and colorimetric analysis: influence of the roasting temperature on the quality of Tonda Gentile delle Langhe Cv. Hazelnut. Czech. J. Food Sci. 31, 390-400 (2013).

5. 

Schmitzer, V.; Slatnar, A.; Veberic, R.; Stampar, F.; Solar, A. Roasting affects phenolic compositions and antioxidative activity of hazelnuts (Corylus avellana L.). J. Food Sci. 76, 14-19 (2011).

6. 

Ciarminelli, L.F.; Piccirillo, P.; Gerardi, C.; Piro, F.; De Luca, A.; D’Imperio, F.; Rosito, V.; Poltronieri, P.; Sartino, A. Microwave irradiation for dry-roasting of hazelnuts and evaluation of microwave treatment on hazelnuts peeling and fatty acid oxidation. J. Food Res. 2(3), 22-35 (2013).

7. 

Wroniak, M.; Rękas, A.; Siger, A.; Janowicz, M. Microwave pretreatment effects on the changes in seeds microstructure, chemical composition and oxidative stability of rape seed oil. LWT-Food Sci. Technol. 68, 634-641 (2016).

8. 

Basaran, P.; Akhan, Ü. Microwave irradiation of hazelnuts for the control aflatoxin producing Aspergillus parasiticus. Innn. Food Sci. Emerging Technol. 11, 113-117 (2010).

9. 

Rosenberg, U.; Bogl, W. Microwave thawing, drying and baking in the food industry. Food Technol. 41, 65-91 (1987).

10. 

Megahed, M.G. Microwave roasting of peanuts: Effects on oil characteristics and composition. Nahrung/Food 4, 255-257 (2001).

11. 

Decarreau, R.V. Microwave foods: New product development. Food and Nutrition Press, Trumbull, Conn. USA (1992).

12. 

Yoshida, H.; Nobuhisa, H.; Kajimoto, G. Microwave energy effects on quality of some seed oils. J. Food Sci. 55, 1412-1417 (1990).

13. 

AOAC. Official Methods of Analysis, 15th ed. Association of Official Analytical Chemists, Washington, DC (1990).

14. 

ISO-International Organization for Standardization. Animal and vegetable fats and oils reperation of methyl esters of fatty acids, ISO. Geneve, Method ISO 5509, pp. 1-6 (1978).

15. 

Skujins, S. Handbook for ICP-AES (Varan-Vista). A Short Guide To Vista Series ICP-AES Operation. Varian Int. AG®Zug. Version 1.0, Switzerland (1998).

16. 

Puskulcu, H.; İkiz, F. Introduction Statistic (İstatistiğe Giriş). Bilgehan Press, Bornova-İzmir, Turkey, p. 333 (1989). (in Turkish)

17. 

Ghafoor, K.; Özcan, M.M.; Al-Juhaimi, F.; Babiker, E.E.; Fadimu, G.J. Changes in quality, bioactive compounds, fatty acids, tocopherols, and phenolic composition in oven- and microwave-roasted poppy seeds and oil. LWT-Food Sci. Technol. 99, 490-496 (2018).

18. 

Bakshabadi, H.; Mirzaei, H.; Ghodsvahti, A.; Jafari, S.M.; Ziaifar, A.M.; Farzaneh, V. (The effect of microwave pretreatment on some physico-chemical properties and bioactivity of Black cumin seeds’ oil. Indus. Crops Prod. 97, 1-9 (2017).

19. 

Al-Juhaimi, F.; Özcan, M.M.; Ghafoor, K.; Babiker, E.E. The effect of microwave roasting on bioactive compounds, antioxidant activity and fatty acid composition of apricot kernel and oils. Food Chem. 243, 414-419 (2018).

20. 

Hojjati, M.; Noguera-Artiaga, L.; Wojdylo, A.; Carbonell-Barrachina, A.A. Effects of microwave roasting on physicochemical properties of pistachios (Pistacia vera L.). Food Sci. Biotech. 24, 1995-2001 (2015).

21. 

Vaidya, B.; Eun, J.B. Effect of roasting on oxidative and tocopherol stability of walnut oil during storage in the dark. Eur. J. Lipid Sci. Technol. 115, 348-355 (2013).

22. 

Kökşal, A.İ.; Artik, N.; Şimşek, A.; Güneş, N. Nutrient composition of hazelnut (Corylus avellana L.) varieties cultivated in Turkey. Food Chem. 99, 509-515 (2006).

23. 

Ozdemir, M.; Açkurt, F.; Kaplan, M.; Yıldız, M.; Loker, M.; Gürcan, T.; Biringen, G.; Okay, A.; Seyhan, F.G. Evaluation of new Turkish hybrid hazelnut (Corylus avellana L.) varieties: fatty acid composition, α-tocopherol content, mineral composition and stability. Food Chem. 73, 411-415 (2001).

24. 

Allam, S.S.H. Utilization of some untraditional sources of high oleic acid oils for improving vegetable oils stability. La Riv. It Delle Sos. Gras. LXVIII, 337-341 (2001).

25. 

Parcerisa, J.; Richardson, D.G.; Rafecas, M.; Codony, R.; Boatella, F. Fatty acid distribution in polar and nonpolar lipid classes of hazelnut oil (Corylus avellana L.). J. Agric. Food Chem. 45, 3887-3890 (1997).

26. 

Mohini, S.; Eram, S.R. Food science experiments and applications. CBS Publishers, 161, 22-27 (2005).

27. 

Mariod, A.A.; Ahmed, S.Y.; Abdelwahab, S.I.; Cheng, S.F.; Eltom, A.M.; Yagoub, S.O.; Gouk, S.W. Effects of roasting and boiling on the chemical composition, amino acids and oil stability of safflower seeds. Int. J. Food Sci. Technol. 47, 1737-1743 (2012).