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Evaluation of Physicochemical Properties and Oxidative Stability of Persian Hazelnut (*Corylus avellana* L.) Kernel Oil Under Different Microwave Roasting Conditions

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ABSTRACT

The aim of this study was to evaluate the physicochemical characteristics (extraction yield, color development, fatty acid profile, iodine value, saponification value, phytosterol profile(, DPPH radical scavenging activity and oxidative stability of cold pressed hazelnut oil extracted from microwave pretreated kernels (0, 2.5, 5 and 7.5 min, 600 W). The results showed that microwave pretreatment of persian hazelnut kernel increased the oil extraction yield, color development and phytosterol contents of all oil samples. Also, no significant differences ($p \geq 0.05$) were observed during microwave pretreatment in saponification value (188-191 mg KOH/g oil) and fatty acids profile of hazelnut kernel oil samples. The predominant unsaturated fatty acids in oil samples in all treatments were determined as oleic acid C18:1c (77.43-78.32%) and linoleic acid C18:2c (9.85-10.18%), respectively. The predominant phytosterols in oil samples in all treatments were determined as β-sitosterol, Δ-5-Avenasterol, Campesterol, Δ-7-stigmastanol and sitostanol. The highest DPPH radical scavenging activity were observed in oil samples of MW-0 (90.62%) and MW-2.5 (89.94%), respectively. In addition, peroxide value, anisidine value and totox value of control hazelnut oil (MW-0) and pretreated hazelnut oil (MW-2.5) at an oven temperature of 160 ° C at 0, 3, 6 and 9 h intervals were determined. Also oxidative stability index (OSI) was determined by rancimat test at 120 ° C. The results indicated that microwave pretreatment is a promising strategy for amplification of oil extraction yield and phytosterol contents in obtained oil from persian hazelnut kernels.

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1. Introduction

hotel (*Corylus avellana*L.) Belongs to the Betulaceae family and is one of the most popular nuts in the world. Hazelnuts are mainly produced on the coast of the Black Sea in Turkey, southern Europe (Italy, Spain, Portugal, France) and some regions of the United States of America (Oregon and Washington). In addition, hazelnut grows in New Zealand, China, Azerbaijan, Chile, Iran, Georgia, Kyrgyzstan, Poland, and Croatia.[1 and 2].Hazelnuts are acceptable and desirable due to the presence of biochemical compounds that promote health, and due to the amount of 60% fat in it, it is considered a good source of energy.[1]. Hazelnuts also contain essential minerals (calcium, magnesium, potassium and phosphorus), vitamin E and group B vitamins, fibers and amino acids. In addition to this, many studies have shown that hazelnuts have high amounts of antioxidant compounds such as tocopherols and polyphenolic compounds, which have a beneficial effect on human health and reduce oxidative stress, the risk of cancer, stroke, inflammation and other diseases. The destroyer becomes nervous[5-3]. Hazelnuts are used in confectionery, chocolate, biscuit and cookie industries. In addition to being used in food products, another widely used hazelnut product is hazelnut oil. The amount of hazelnut oil is more than 50% depending on the region, weather conditions, soil and variety[6]. Hazelnut cultivation areas in Iran are limited to Gilan, Ardabil, Mazandaran, Golestan and Qazvin provinces[7]. Hazelnut oil is used for various purposes such as cooking, baking, salad dressing, flavoring and also in cosmetics and health products.[8]. Hazelnut oil is extracted from peeled hazelnuts using physical and chemical techniques. Raw and roasted hazelnuts are used for the oil production process. Hazelnut roasting is done with the aim of producing products with different aromas and colors. Hazelnuts are rich in monounsaturated and polyunsaturated fatty acids, especially oleic acid and linoleic acid. The higher oxidative stability of hazelnut oil among other vegetable oils with high oleic acid is due to the presence of tocols and phenolic compounds.[9].

Solvent/Soxhlet extraction is widely used on an industrial scale, although cold press extraction has also been proposed.[10]. Cold-pressed oilseed oil contains higher amounts of essential fatty acids and other bioactive compounds (tocopherol, sterol, squalene, etc.).[11]. In recent years, consumers' attention to natural products, compatible with the environment and with little processing (under the title of green processing)[1] is increasing Cold pressed edible oils are considered natural and environmentally friendly products by consumers[12]. In order to increase the yield of oil extraction from kernels and oilseeds, mechanical and thermal preliminary operations are common. Roasting is considered as a new pretreatment method before extracting the oil of edible nuts and an effective approach to improve the taste of the mentioned oils. Roasting changes the chemical composition and nutritional value of the oil[13 and 14].Thermal pretreatments include inactivating undesirable enzymes, mainly lipase, and thus increasing the efficiency of oil extraction. In order to produce high quality oil, it is important to destroy lipolytic enzymes that cause oil spoilage[15]. In addition, the moisture content of oilseeds is an important factor in extracting oil from oilseeds by pressing. Pretreatment with microwave before extraction with a press is a simple and appropriate method to obtain high quality oil. Because the cell membrane is broken and as a result, pores are created that make it easier for the oil to escape. Pretreatment of oil seeds with microwave before mechanical pressing can increase the amounts of tocopherol, phytosterol, phenolic content and oxidative stability of the extracted oil.[18-16]. The research results of various researchers have shown that roasting brains in specific and determined conditions can be confirmed by creating a balance between health-enhancing compounds and potentially harmful brain compounds, as well as achieving desirable sensory characteristics.[24-19]. Babiker Et al(2020) The effect of microwaves on the oil content, composition of fatty acids and minerals of various types of hazelnuts were investigated.They showed that oil, fatty acid and mineral contents of hazelnut varieties were affected by roasting depending on microwave power.[25]. ShafieiEt al(2020) estimated the oxidative indices in raw and roasted hazelnuts through an accelerated shelf life test[26]. Jelokhani Niaraki and Ahmadi

1. green processing

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Kamazani (2022) Effect of microwave roasting on physicochemical properties and oxidative stability index of Iranian walnut kernel oil (*The royal juggler* L.) were investigated. These researchers showed that as a result of microwave pretreatment of Iranian walnut kernels, the efficiency of oil extraction, color development, ratio of acids how fatUnsaturated to saturated (PUFA/SFA) and phytosterol levels increase[27].

Due to its favorable nutritional properties, hazelnut kernel oil is in high demand among consumers, but it is easily oxidized and undergoes rancidity and changes in taste. Several researches show that roasting increases the oxidative stability of oils and fats, however, regarding the effects of microwave pretreatment for roasting Iranian hazelnut kernels before cold pressing extraction (as a green extraction method) and environmentally friendly) and its effect on the physicochemical characteristics of the oil, especially the indices related to oxidative damage during accelerated oxidation, have not been researched. Therefore, the main purpose and necessity of this research is to investigate and achieve a comprehensive understanding of the effects of microwave pretreatment on oil extraction efficiency, color development, fatty acid composition, iodine index, soap index, sterol composition, antioxidant activity, DPPH radical inhibition. The indices of oxidative deterioration of oil during baking (accelerated oxidation) including peroxide index, anisidine index, totox index and oxidative stability index (OSI) were considered.

2- Materials and methods

Solvents and chemicals used in this research have laboratory grade purity They were.

2-1- Preparing samples and extracting their oil

Zarabadi variety hazelnuts were purchased from Alamut region of Qazvin. Then, nuts with similar size and color were selected for roasting by microwave and stored in glass containers with lids in the refrigerator at a temperature of 4C. Roasting pre-treatment was done with a microwave oven with a frequency of 2450 Hz and a power of 600 watts. For each pretreatment, about 40 grams of hazelnut kernels were placed in a single layer in each Petri dish with a diameter of about 9-12 cm and the samples were processed for 0, 2.5, 5 and 7.5 minutes.[20]. Each microwave pretreatment was done with 3 replicates. After roasting, the samples were cooled down to ambient temperature and each pretreatment sample was thoroughly mixed before oil extraction. Extraction**The oil of the roasted samples by microwave as well as the control sample by cold press with temperature** C° 40-50 was done. **After centrifugation at 4500 rpm for 20 minutes to remove suspended solid particles in dark glass bottles with lids.** It was kept at a temperature of 4°C for one day and night until the time of analysis[20].

2-2-Exams

2-2-1- Determining the moisture level of the brain sample, extraction efficiency by Soxhlet method and acid index of hazelnut oil.

The moisture content of the hazelnut kernel sample was calculated according to the weighing method until a constant weight was reached in the oven at a temperature of 100 °C.[28]. **Oil extraction efficiency**[29] And**Acid index** it[30] Was determined.

2-2-2- Evaluation of the effect of microwave roasting pretreatment and its conditions on the physicochemical characteristics of hazelnut oil samples

2-2-2-1- Oil extraction efficiency by cold pressing method

The efficiency of oil extraction by cold pressing method was calculated by weight (gravimetric) (%, weight/weight) from equation 1.

Equation 1

$$\text{Yield } \% = (W2/W1) \times 100$$

IN_2: W weight of sample oil_1: Weight of hazelnut kernel sample.

2-2-2-2- color development

The color of the oil was evaluated by the Levibond method with a Tintometer model F with a one-inch tube[31].

2-2-2-3- The composition and amount of fatty acids

To determine the amount and composition of fatty acids, the oil sample was first methylated[32]. Then the fatty acids of the oil were identified and quantified by gas chromatography[33]. The specifications and conditions of the gas chromatography device were: device name and model (SHIMADZU Nexis 2030, Japan), flame ionization detector

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(FID).[2]Dikmacap-2330 glass capillary column, 60 meters long and 0.25 mm inner diameter, hydrogen gas with a purity of 99.999% As a carrier gas and flow rate of 2 ml/min, the temperature of the injection site is 250°C. The detector temperature is 260°C. The amount of sample injection is 1 microliter, the ratio of the device split 1 to 60 and the temperature program of the device: initial temperature of 60˚C and staying at the same temperature for 2 minutes, then reaching the temperature of 200˚C with a gradient/min of 10C, then reaching a temperature of℃ with a gradient of℃5/min 240, remaining for 7 minutes at the same temperature to remove all fatty acids from the column.

2-2-2-4- Andis Ydi

The iodine index was calculated based on the fatty acid composition of the oil according to equation 2.[34]

IV=(%C16:1××0.95)+(%C18:1×× 0.860)+(%C18:2××1.732)+(%C18:3×× 2.616)+(%C20:1××0.785)+(%C22:1××0.723)

Equation 2

2-2-2-5- soap index

Soap index was calculated through equation 3 [35].

$$S.V = \frac{3\times56.1\times1000}{[(mmw)+92.02]-(3\times18)}$$ Equation 3

mmw: total molecular weight of fatty acids in the sample

Molecular weight of potassium hydroxide: 56.1

: 92.02 molecular weight of glycerol

2-2-2-6- The composition and amount of sterols

First, the oil was saponified by alcoholic potash, then its non-saponifiable compounds were extracted by diethyl ether.[36]. Identification of non-saponifiable compounds was done according to AOAC method No. 970.51 using thin layer chromatography (TLC) method.[37]. Finally, the amount of sterol compounds was identified and determined[38]. The specifications and conditions of the gas chromatography machine were: name and model of the machine (Younglin 6500, Korea), flame ionization detector (FID), Equity-5 capillary column (SUPELCO) made of glass with a length of 30 meters and an inner diameter of 25. 0 mm, hydrogen gas with a purity of 99.999% As a carrier gas and flow rate of 1.5 ml/min, the temperature of the injection site is 300°C. The detector temperature is 310°C. The amount of sample injection is 1 microliter, the ratio of the device split 1 to 10 and the temperature program of the device: initial temperature 240˚C and staying at the same temperature for 2 minutes, then reaching the temperature of 300˚C with a gradient/min℃10, then reaching a temperature of℃ with a gradient/min℃1 305, remaining for 7 minutes at the same temperature to remove all sterols from the column.

2-2-2-7- Radical inhibition activity**DPPH**

DPPH radical scavenging activityOil samplesIt was determined according to the method of Brand-Williams et al. (1995) with some modifications[39]. 0.5 ml of extracted extract was mixed with 2.5 ml of 0.5 mM DPPH solution and completely homogenized and incubated for 30 minutes in the dark at room temperature. The absorption of light at 517 nm against a control was read by a spectrophotometer and the results were calculated in terms of DPPH radical inhibition percentage according to equation 4.

Equation 4

Inhibition DPPH % = [(Abs control -Abs sample)/Abs control] ×100

Abs control: absorption of DPPH solution without extract (control solution)

Abs sample: absorption in the presence of the tested extract

2-3- Evaluation of oxidative stability of oil samples

In order to accelerate the oxidation of lipids and its thermal decomposition (accelerated oxidation), test glass containers containing certain amounts (80 g) of hazelnut oil samples.**witness (**MW-0**)** and pretreated hazelnut oil sample MW-2.5 **(Has the highest radical scavenging activity**DPPH d**between pretreatments)**They were stored in an electric oven with a temperature of 160 °C. Then, the stability of the oil with respect to oxidation at intervals of 0, 3, 6 and 9 hours through the analysis of oxidation indices such as peroxide values[40]، Para-anisidine index[40] And

2. Flame Ionization Detector

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Andis Totox[41] Calculated.

2-3-1- Evaluation of peroxide index of oil samples

Evaluation of peroxide index according to the recommended method of American Chemists Association (AOCS, 1998) It was done with standard number cd 8-53[40].

2-3-2- Evaluation of para-anisidine index of oil samples

The para-anisidine index was evaluated according to AOCS Official Method Cd18-90 during a period of 0, 3, 6 and 9 hours.[40].

2-3- 3- Index evaluation**Totox** Oil samples

The general state of oxidation of the oil samples was evaluated by Totox index during an ovening period of 0, 3, 6 and 9 hours. This index was calculated based on equation 5[41].

Equation 5 TV=2PV+AV

AV: anisidine index

PV: peroxide index

2-3-4- Evaluation**Oxidative stability index (OSI)**Oil samples

Oxidative stability index of the samples was determined by Rensimet (Metrohm 743, Switzerland). The experiment was performed with 3 grams of the oil sample with the highest antioxidant activity in terms of DPPH and the control sample at a temperature of 120 °C and an air flow rate of 20 L/h.[42].

2-4-Statistical analysis

All experiments were performed in 3 replicates. The results were expressed as the average of three repetitions and standard deviation. Then one-way analysis of variance (ANOVA) was performed and finally Duncan's multi-range test was used to determine the significant difference at $p>0.05$ level. Analyzes were done using SPSS 22 software and drawing graphs using Excel software.

3. Results and Discussion

3-1- Determining the moisture content of the hazelnut kernel sample, the extraction efficiency by the Soxhlet method and the acid index of the oil.

The moisture level of the hazelnut kernel sample is 1.2± 55.3%, amount**Its oil extraction efficiency by Soxhlet method 2/35**± 67.63% and the acid index of its oil was determined as 0.22 ± 0.09 mg KOH/g of oil. The moisture content of hazelnut kernels is 1.4-2.7% and its oil content is 62-69%[43]. It should be noted that the maximum standard of acid index of hazelnut kernel oil extracted by cold press method is KOH/g of oil mg 4.[44]

2-3- The effect of microwave roasting pretreatment and its conditions on the physicochemical properties of oil samples

3-2-1- Amount of oil extracted by cold pressing method

Table 1. The effect of microwave roasting pretreatment and its conditions (4 time periods: 0, 2.5, 5, 7.5 minutes) on**Level**Oil**It shows samples extracted by cold press.**According to the results, a significant increase in oil extraction efficiency was observed with increasing duration of roasting treatment ($p<0.05$). The highest oil extraction efficiency was determined in MW-7.5 (66.20%) and the lowest in MW-0 (50.17%). Therefore, the efficiency of oil extraction in MW-2.5, MW-5, and MW-7.5 pretreatments has increased by about 1%, 6%, and 16%, respectively, compared to MW-0.

Table 1 Change in oil content of unroasted (MW-0) and roasted (MW-2.5, roasted at 2.5 min; MW-5, roasted at 5 min and MW-7.5, roasted at 7.5 min) Hazelnut kernel.

Sample	Roasting time (min)	Oil content (%)
Hazelnut-0	Unroasted (control) 0	50.17±0.24^{c}
Hazelnut- 2.5	Roasted 2.5	50.61±0.86^{c}
Hazelnut-5	Roasted 5	56.24±1.75^{b}

Hazelnut-7	Roasted 7	66.20±1.12[a]

Each value is the mean ± standard deviation of triplicate determinations. Values in each heating time with different letters, are significantly different (p>0.05).

The efficiency of oil extraction by cold press method is influenced by heat pretreatment, especially microwave. As a result of microwave pretreatment of oilseeds, extraction efficiency and mass transfer coefficient increase due to the disintegration of cell membranes in oilseeds. In addition, due to the creation of pores in the cell membrane, oil can escape from the permeable cell wall[18]. Pretreatment with microwaves results in the preservation of nutrients by being done in less time[19]. There are fundamental differences between microwave roasting and conventional roasting. In conventional roasting, thermal energy is generated by radiation[3] or convection heating[4] Reached the surface of matter then through conduction[5] It is gradually transferred to the entire material, if in the microwave method, the microwave waves penetrate the material and the electromagnetic energy is converted into thermal energy throughout the material.[20]. Babiker Et al(2020) Showedthat increasing the power and time of microwave roasting leads to an increase in oil extraction efficiency. The increase in oil extraction can be due to the fact that microwaves help to lose water in plant cells and increase the pressure in the internal environment, which leads to the breakdown of cell materials, breaking the cell membrane, and also increasing the efficiency of oil extraction.[25].

2-3-2- Development of oil paint

Table 2 Effect of microwave roasting pretreatment and its conditions on color development **It shows the oil of hazelnut kernel samples extracted by cold pressing method.**According to the results, no significant difference was observed in terms of color index Y in the samples.(p≥ 0.05) whileAs the roasting time increased, the color index R increased. The highest R color index was determined in MW-7.5 treatment (3.25) and the lowest R color index was determined in MW-2.5 (1.20) (p<0.05). According to the results, no significant difference was observed in terms of R color index between MW-0 sample (1.25) and MW-2.5 sample (1.20).(p≥ 0.05).

3. radiation
4. convection
5. conduction

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Table 2 Change in color development of unroasted (MW-0) and roasted (MW-2.5, roasted at 2.5 min; MW-5, roasted at 5 min and MW-7.5, roasted at 7.5 min) Hazelnut kernel oil.

Sample	Roasting time (min)	yellow units	Red units
Unroasted Hazelnut (control)- MW-0	Unroasted (control)-0	20.16± 0.76376 [a]	1.25±0.35 [c]
Roasted Hazelnut- MW-2.5	Roasted-2.5	20.24± 0.69759 [a]	1.20±0.28 [c]
Roasted Hazelnut- MW-5	Roasted-5	20.26± 0.64291 [a]	2.35±0.49 [a]
Roasted Hazelnut- MW-7.5	Roasted-7	20.25± 0.57807 [a]	3.25±0.21 [a]

Each value is the mean ± standard deviation of triplicate determinations. Values in each heating time with different letters, are significantly different (p>0.05).

Color development is an indicator obtained by determining the degree of roasting[45]. Many researches have shown that increasing the time and temperature of roasting seeds such as sesame and rice sprouts causes a significant increase in oil color.[46]. Color is an important quality criterion for nuts and oilseeds. Brown color is obtained during roasting and roasting processes due to Maillard reactions and caramelization. The brown color in hazelnuts and almonds is produced by the reaction of reducing sugars with amino acids. The concentration of sugars and amino acids, humidity, temperature and time are effective parameters in creating the brown color and taste of kernels and oil seeds. There is usually a linear correlation between color and intensity and degree of roasting[47]. Usually, the gentle roasting process creates the desired flavor, taste and color. The oil obtained from roasted products also has a favorable color, smell and taste. The reason for this can be related to factors such as the formation of Maillard reaction products, lipid and protein oxidation, and their decomposition products.[48].

3-2-3- The composition and amount of fatty acids

Table 3 Effect of microwave roasting and its conditions (4 time periods 0, 2.5, 5, 7.5 minutes) on the composition and amount of fatty acids of oil samples**is showing. The fatty acid composition of the oil can be considered as an indicator for the physical properties, stability and nutritional value of the oil.**According to the results, **Composition and amount**The predominant fatty acids of MW-7.5, MW-5, MW-2.5 and MW-0 oils are oleic acid (77.43-78.32%), linoleic acid (10.18-9.85%), palmitic acid (33% 6-87/7) and stearic acid (3.52-3.79%) were determined.

Table 3 Change in fatty acid profiles of unroasted (MW-0) and roasted (MW-2.5, roasted at 2.5 min; MW-5, roasted at 5 min and MW-7.5, roasted at 7.5 min) Hazelnut kernel oil.

7.5 min	5 min	2.5 min	0 min	fatty acid profile
%	%	%	%	
7.03±0.1[b]	7.02±0.15[b]	7.33±0.12[a]	6.87±0.17[b]	**C_{16}:0**
0.26±0.05[a]	0.3±0.05[a]	0.26±0.06[a]	0.27±0.05[a]	**C_{16}:1**
0.06±0.025[a]	0.1±0.05[a]	0.09±0.05[a]	0.07±0.04[a]	**C_{17}:0**
0.08±0.03[b]	0.15±0.04[a]	0.07±0.04[b]	0.09±0.03[ab]	**C_{17}:1**
3.79±0.08[a]	3.52±0.12[a]	3.76±0.0.75[a]	3.52±0.1[a]	**C_{18}:0**
77.77±0.075[b]	77.87±0.05[b]	77.43±0.95[c]	78.32±0.13[a]	**C_{18}:1c**
9.9±0.08[a]	10.16±0.12[a]	9.85±0.095[a]	10.18±0.02[a]	**C_{18}:2c**
0.09±0.05[a]	0.08±0.06[a]	0.08±0.052[a]	0.12±0.1[a]	**C_{18}:3n3**
0.22±0.04[a]	0.21±0.03[a]	0.21±0.08[a]	0.18±0.02[b]	**C_{20}:0**
0.16±0.06[a]	0.16±0.1[a]	0.15±0.08[a]	0.16±0.06[a]	**C_{20}:1**
0.05±0.04[a]	0.05±0.05[a]	0.03±0.02[a]	0.04±0.35[a]	**C_{22}:0**

Each value is the mean ± standard deviation of triplicate determinations. Values in each heating time with different letters, are significantly different (p>0.05).

The fatty acid profile of the oil can be considered as an indicator for the physical properties, stability and nutritional value of the oil. Therefore, it can be emphasized that in all samples, the majority of fatty acids in hazelnut oil are monounsaturated fatty acids, oleic acid, respectively.C_{18}:1c (the maximum amount32.78% in sample MW-0 and the lowest amount 43.77% in sample MW-2.5), polyunsaturated fatty acids with two double bonds, linoleic acidC_{18}:2c (The highest amount is 10.18% in MW-0 and the lowest amount is 9.85% in MW-2.5) and saturated fatty acids, palmitic acid.C_{16}: (The highest amount is

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33.7% in MW-2.5 treatment and the lowest amount is 6.87% in MW-0 treatment). The results showed that the composition of fatty acids of hazelnut kernel oil did not change due to pretreatment of microwave roasting, which was consistent with the results of other researchers.[25 and 27].Babiker Et al(2020) showed thatMicrowave treatment causes slight changes in the fatty acid content of hazelnut oil. The main fatty acids of hazelnut oil were determined as oleic acid, linoleic acid and palmitic acid.[25]. Jelokhani Niaraki and Ahmadi Kamazani (2022) They showed that the composition of fatty acid does not change due to microwave pretreatment of Iranian walnut kernels[27]. In the research done by Ji et al(2019) Also, there was no change in the fatty acid composition of sesame oil extracted from roasted and non-roasted samples[49]. Also, in the research conducted by other researchers, changes in the fatty acid composition of rice germ oil[50]، Olive oil [51], hazelnut oil[52] and sesame oil[53 and 54], Extracted from roasted and non-roasted (raw) samples were not observed. As can be seen in Table 3, the total amounts of SFA, MUFA and PUFA in MW-0 are 10.68%, 78.84% and 10.3%, respectively, and in MW-7.5 they are 11.15%, 78.27% and 99/ 9% was determined. In MW-2.5 treatment, the amount of SFA was 11.42%, MUFA 77.91% and PUFA 93.9%. Amounts of predominant fatty acidsHazelnut kernel oil obtained by cold pressing methodContains oleic acid (79-4.182%), linoleic acid (7.9-13.2%), palmitic acid (7.4-7.1%), and stearic acid (3.1-1%), respectively. 1/5) is mentioned[55]. Standard limitsAmounts of predominant fatty acidsHazelnut kernel oil obtained by cold pressing methodOleic acid (71.9-84%), linoleic acid (7.5-22.2%), palmitic acid (7.4-7.2%), and stearic acid (1.5-2.4%), respectively.) Designated [44].

3-2-4- The composition and amount of sterols

Table 4: Effect of microwave roasting pretreatment and its conditions (4 time periods: 0, 2.5, 5, 7.5 minutes) on the composition and amount of sterols of hazelnut kernel oil samples. **is showing.** According to the resultsb- Sitosterol is the main component of sterols in hazelnut kernel oil. The major sterols of hazelnut oil includeb- Sitosterol (ppm 1141-31-1307-42), Δ-5-onasterol (ppm 53-80-80-98), campestrol (ppm 19-77-39-61), Δ-7-stigmastanol (ppm 19/19 40-72-58) and sitostanol (54-54-40 ppm) were determined.

Table 4 Change in sterol profiles of unroasted (MW-0) and roasted (MW-2.5, roasted at 2.5 min; MW-5, roasted at 5 min and MW-7.5, roasted at 7.5 min) Hazelnut kernel oil.

7.5 min ppm	5 min ppm	2.5 min ppm	0 min ppm	Sterol sterol
4.16±0. 9[a]	2.66±0. 8[b]	0.84±0.02[c]	1.82±0. 5[b]	Cholesterol
77.19±1.1[a]	61.39±1.18[b]	64.26±1.2[b]	64.9±1.3[b]	Campesterol
3.5 ±0.15[a]	3.03±1.1[a]	3.23±0. 8[a]	4.38±1.1[a]	Campestanol
23.86±0. 85[a]	19.7±0. 79[b]	19.76±0. 9[b]	18.81±0. 5[b]	Stigmasterol
28.85±0.19[a]	1.74±0. 5[c]	13.14±0. 3[b]	1.65±0.18[c]	Δ5-campesterol
29.01±0.26[a]	19.41±0. 96[c]	22.64±1.15[b]	19.41±1.1[c]	clerosterol
1307.42±0.52[a]	1141.31±0.89[d]	1231.34±1.71[b]	1200±1.88[c]	β-sitosterol
54.4±0.28[a]	45.96±0.98[c]	44.5±1.46[c]	50.08±1.35[b]	Sitostanol
98.53±0.28[a]	80.8±0.24[c]	93.97±0.45[a]	89.76±1.38[b]	D-5-avenasterol
27.14±0.35[b]	15.31±0.54[d]	30.98±0.29[a]	18.32±1.56[c]	Δ-5,24-stigmastadienol
40.72±0.26[d]	44.59±0.38[c]	58.19±0.28[a]	48.4±1.46[b]	Δ-7-stigmastenol
24.28±0.26[b]	19.4±0. 96[c]	23.78±0.15[b]	31.18±1.1[a]	D-7-avenasterol
0.04±0.05[c]	0.03±0.01[c]	3.88±0. 9[b]	45.31±0. 9[a]	Other sterols

Each value is the mean ± standard deviation of triplicate determinations. Values in each heating time with different letters, are significantly different (p>0.05).

The highest amount of total sterol was determined in MW-7.5 oil and the lowest amount was determined in MW-0 control oil. The change in the amount of sterols is due to the change in the amount of moisture during roasting, which facilitates the extraction of sterols.[14]. The standard limits of total sterol content of hazelnut kernel oil obtained by cold pressing method are 1200-3469ppm.[44]. Phytosterols are lipophilic steroids synthesized in plants, which are among the important groups of bioactive compounds in vegetable oils.[56] which have attracted the attention of consumers due to their health effects,

especially the property of reducing blood cholesterol. In addition, the mentioned compounds are important components of non-saponifiable ingredients of vegetable oils[57]. Research shows that during the roasting treatment, the amount of phytosterols can be changed by adjusting the roasting time.[58]. Gao et al. (2019) evaluated the effect of microwave roasting on sterol compounds in walnut kernel oil and showed that roasting walnut kernels and subsequent extraction by cold press increases the amount of phytosterols.[14].Jelokhani Niaraki and Ahmadi Kamazani (2022) showed that as a result of pretreatment of Iranian walnut kernels by microwave,The amount of total phytosterols in the MW-0 oil sample changes from 1184.09 ppm to 1342.5 ppm in the MW-7.5 oil sample, which indicates an increase in the amount of total phytosterols after roasting walnuts. [27].

5-3-2-5-Yidi index changes

Figure 1: Effect of microwave roasting pretreatment and its conditions (4 time periods: 0, 2.5, 5, 7.5 minutes) on the iodine index of hazelnut kernel oil samples. is showing**.** Iodine index of g I oil samples$_2$/100 g oil 1/88-22/84 Was determined. According to the resultsThere is a significant difference between the control sample and the samples treated with microwaves ($p<0.05$). The results of this research show that microwave pretreatment before extracting hazelnut kernel oil leads to a decrease in the iodine index of the oil, which can be related to the decrease in the number of unsaturated double bonds caused by oxidation, polymerization or decomposition of long chain fatty acids. be Because the ionic index represents the degree of unsaturation. This index shows the relationship of physical and chemical characteristics with the fatty acids of oils and depends on the molecular weight and degree of unsaturation of fatty acids in oils.[59]. The determined standard limits of iodine index of hazelnut kernel oil obtained by cold pressing g I method$_2$83-90/100 g of oil is determined[44]. Javidipour et al. (2017) evaluated the oxidative changes in hazelnut, olive, soybean and sunflower oil during microwave heating and showed that iodine index decreases in the mentioned oil samples.[60].

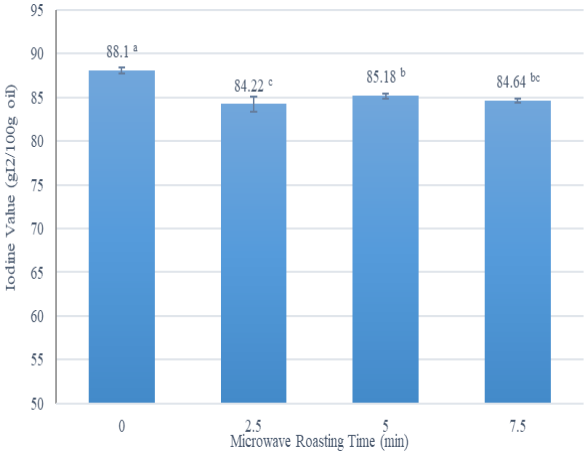

Fig 1 Change in Iodine Value of unroasted (MW-0) and roasted (MW-2.5, roasted at 2.5 min; MW-5, roasted at 5 min and MW-7.5, roasted at 7.5 min) Hazelnut kernel oil. Each value is the mean of triplicate determinations. Values in each heating time with different letters, are significantly different ($p>0.05$).

6-3-2- Changes in soap index

Figure 2 Effect of microwave roasting pretreatment and its conditions (4 time intervals 0, 2.5, 5, 7.5 minutes) on the soap index of hazelnut oil samples **is showing.** Saponification index of oil samples mg KOH/gOil191-188Was determined. According to the results, no significant difference was observed between the samples.($p\geq 0.05$) The reason for this can be related to the lack of significant changes in the composition of the fatty acids of the oil and of course the lack of change in the soap index as a result of microwave roasting pretreatment. Soap index is one of the distinguishing characteristics of oils and shows the average molecular weight or chain length of the fatty acids that make up the oil.The standard limits of the saponification index of hazelnut kernel oil extracted by cold pressing method are 188-191 mg KOH/g oil.[44].

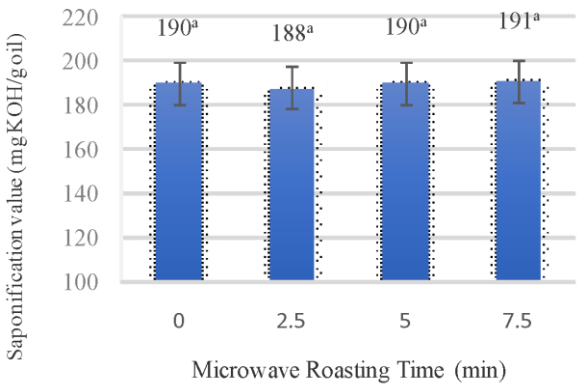

Fig 2 Change in Saponification Value of unroasted

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(MW-0) and roasted (MW-2.5, roasted at 2.5 min; MW-5, roasted at 5 min and MW-7.5, roasted at 7.5 min) Hazelnut kernel oil. Each value is the mean of triplicate determinations. Values in each heating time with different letters, are significantly different (p>0.05).

3-2-7- Changes DPPH radical scavenging activity

Figure 3. The effect of microwave roasting pretreatment and its conditions activity Radical inhibitionDPPH of hazelnut oil samplesit shows.

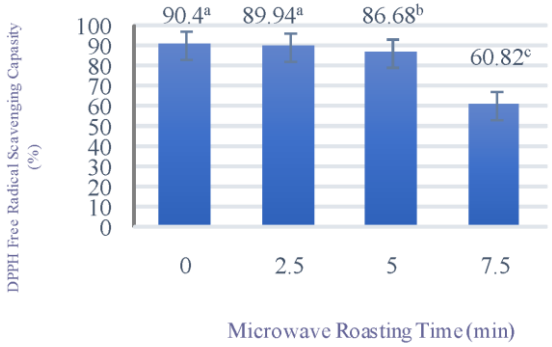

Fig 3 Change in DPPH free radical scavenging capacity of unroasted (MW-0) and roasted (MW-2.5, roasted at 2.5 min; MW-5, roasted at 5 min and MW-7.5, roasted at 7.5 min) Hazelnut kernel oil. Values in each heating time with different letters, are significantly different (p>0.05).

According to the results, DPPH radical scavenging activity has shown a decreasing trend over time, and a significant difference was observed between MW-0 and MW-2.5 pretreatment with MW-5 and MW-7.5 (p<0.05).. Besides, the most activityInhibition of DPPH radicals in MW-0 (90.4%) and MW-2.5 (89.94%) The lowest DPPH radical inhibition activity in MW-5 (86.68%) and MW-7.5 (60.82%) was determined became. Ozcan Et al(2018) evaluated the effect of heat treatment on the antioxidant activity of Brazil nuts and hazelnuts and showed that The antioxidant activity of untreated samples is higher than roasted samples[61].

3-3- Oxidative stability evaluation of hazelnut oil samples

3-3-1- Peroxide index of hazelnut oil samples

Hazelnut oil samples with the highest DPPH (roasting time 0 minutes and time 2.5 minutes) for baking in 4 time intervals of 0, 3, 6 and 9 hours withtemperature of˚C160 was selected. The change curve of peroxide index of hazelnut oil samples as a function of MW-0 and MW-2.5 pretreatment and greenhouse time (0, 3, 6 and 9 hours at temperature^{O}C 160) under conditions of accelerated oxidation in Figure 4 is presented.The amount of peroxide index during 0 to 9 hours of baking at temperature˚C160In the oil sampleMW-0 From$meqO_2$/kg oil 21/0 to $meqO_2$/kg oil0.53 changed while this change in the sampleMW-2.5 of $meqO_2$/kg oil21/0 to $meqO_2$/kgoil0.81 was determined.(p<0.05)

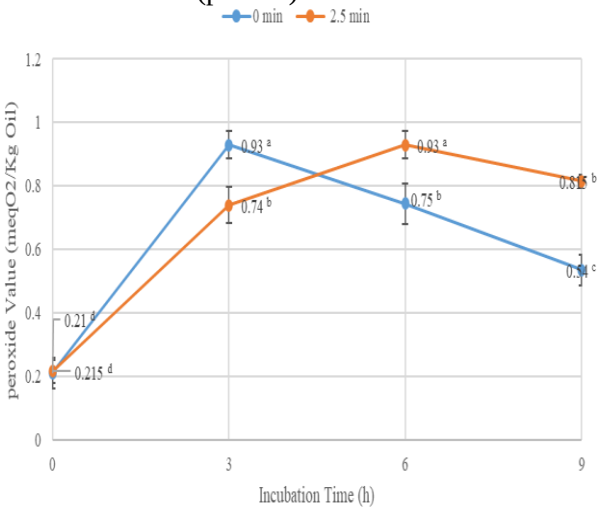

Fig 4 Change in peroxide Value (PV) of unroasted (MW-0 min) and roasted (MW-2.5 min) Hazelnut kernel oil.

Peroxide index changes up to 6 hours of baking at temperature˚C160For exampleMW-2.5 It is accompanied by an increasing trend compared to the 0 time of baking, and after that, until the end of the baking time, the said trend decreases with a significant difference. At the same time, the peroxide index changes up to 3 hours of baking in the temperature˚C160For exampleMW-0 It is associated with an increasing trend compared to the 0 time of baking, and after that, until the end of the baking time, the mentioned trend decreases with a significant difference. It is worth noting that in the exampleMW-2.5, increasing the peroxide index up to the first 3 hours of baking with a slower slope compared to the sampleMW-0 It took place and then the oppositeMW-0 Until the end of the baking time, changes in the peroxide index were associated with a weaker decreasing trend. The reason for this can beLower amountAndis my hand in MW-0 sample compared to MW-2.5 sample. In the initial stage of oxidation, the speed of formation of hydroperoxides is higher than the speed of their decomposition, and this is reversed in the next stage. Therefore, the

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peroxide index is a sign of the initial stage of oxidative changes. Peroxide index is a measure of hydroperoxides. Hydroperoxides have been identified as primary oxidation products and can be decomposed into volatile and non-volatile secondary products.[62]. The peroxide value decreases as a result of the oxidation process due to the rapid decomposition of hydroperoxides[20] which is consistent with the results of other researchers.The mentioned process with the research resultsVaidya And Eun (2013) and Ji et al. (2019) were consistent[49 and 63].Javidipour et al. (2017) evaluated the oxidative changes in hazelnut, olive, soybean and sunflower oil during microwave heating and showed thatperoxide In all the oil samples, it increased significantly during 3 minutes of heating, then it decreased until 6 minutes, and after that it increased sharply until 9 minutes.[60]. ShafieiEt al(2020) estimated the oxidative indices in raw and roasted hazelnuts through the accelerated shelf life test and showed that peroxide The oil extracted from roasted hazelnuts is more than raw hazelnut oil[26]. According to the allowed amount of peroxide index of virgin oils in the Codex standard,meqO_2/kg oil 15, all the samples had peroxide values lower than the permissible limit[64].

3-3-2- para-anisidine index of hazelnut oil samples

The change curve of para-anisidine index of hazelnut oil samples as a function of treatment (MW-0 and MW-2.5) and greenhouse time (0, 3, 6 and 9 hours at temperature^{O}C 160) under conditions of accelerated oxidation in Figure 5 is presented.Changes of anisidine index during 9 hoursgreenhouse Put in the temperature˚ C160In the samplesMW-2.5 AndMW-0 It is associated with a significant increasing trend compared to its zero time.($p<0.05$) This is an incremental process with resultsAnjum et al (2006) ،Ali et al(2017) AndYoshida et al. (2003) agree[46، 54، 20]. The amount of the indexAnisidine During zero to 9 hours greenhouse Put in the temperature˚ C160For exampleMW-0 From 1/15 to 25/62 changes, while these changes in the sampleMW-2.5 from1.25 to 21/46 was determined.($p<0.05$) The results show a slower increase in para-anisidine index during 9 hours of baking in the sampleMW-0 is. The reason for this can beLower amountAndis my hand in MW-0 sample compared to MW-2.5 sample.

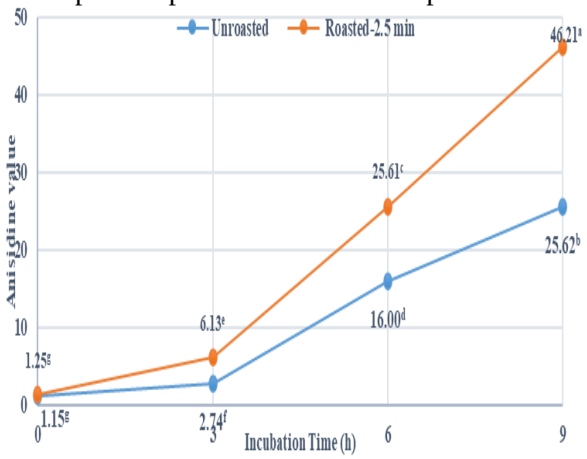

Fig 5 Change in Anisidine Value (AV) of unroasted (MW-0 min) and roasted (MW-2.5 min) Hazelnut kernel oil.

The peroxide index alone does not determine oil oxidation, because this index is an indicator of the existence of primary oxidation products and does not determine the production of secondary oxidation products. Therefore, it seems necessary to determine the anisidine index, which is an indicator of the rate of oxidation development and the production of secondary products of this reaction. In the anisidine test, the values of alpha and beta-unsaturated aldehydes are determined, mainly 2-alkanals and 2,4-dienals, which are the secondary products of the oxidation of fats and oils. Aldehydes are reacted with anisidine reagent to form a colored compound, then the amount of absorption of colored compounds is evaluated by spectroscopic methods.Javidipour et al. (2017) evaluated the oxidative changes in hazelnut, olive, soybean and sunflower oil during microwave heating and showed that para-anisidine index increases in all oil samples.[60]. Shafiei Et al(2020) estimated the oxidative indices in raw and roasted hazelnuts through the accelerated shelf life test and showed that the indicesPara-anisidine in oil extracted from roasted hazelnuts is more than raw hazelnut oil[26].

3-3-3- Totox index of hazelnut oil samples

The change curve of Totox index of hazelnut oil samples as a function of pretreatment (MW-0 and MW-2.5) and baking time (0, 3, 6 and 9 hours at temperature^{O}C 160) under conditions of accelerated oxidation in Figure 6 is presented.

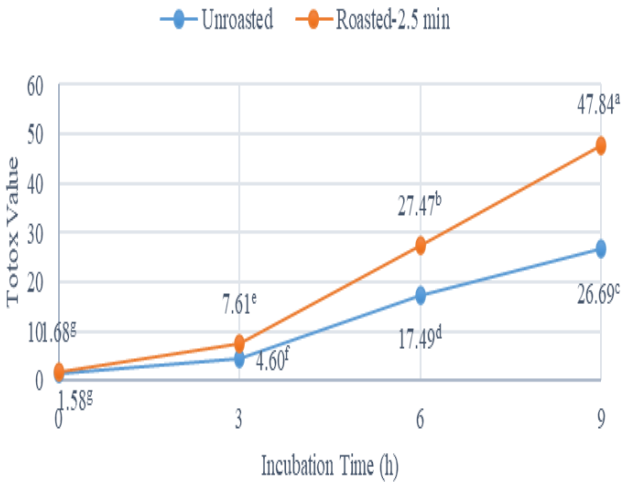

Fig 6 Change in Totox Value (TV) of unroasted (MW-0 min) and roasted (MW-2.5 min) Hazelnut kernel oil.

index changesTotox During 9 hours of baking at temperature˚C160 in both oil samples MW-2.5 AndMW-0 It was associated with a significant increasing trend compared to the baking time.($p<0.05$)The amount of the index Totox during 0 to 9 hours of baking at temperature˚ C160In the oil sampleMW-0 From 1/58 to 69/26 increases, while this increase in the oil sampleMW-2.5, from 1.68 to 47/84 was determined($p<0.05$) thisThe results show a slower increase in the Totox index during 9 hours of baking in the sampleMW-0 is. The reason for this can beLower amountAndis my hand in MW-0 sample compared to MW-2.5 sample.These changes with resultsAnjum et al (2006) ،Ali et al(2017) AndYoshida et al. (2003) agree[46, 54, 20].

Totox index is a measure of total oxidation that includes primary and secondary oxidation products and is a combination of anisidine index and peroxide index.Totox index is used to express the complete oxidation of the sample using peroxide and anisidine values. Considering that in the evaluation of the peroxide index, the amount of hydroperoxides (increasing at first, then decreasing) and in the evaluation of the paraanisidine index, the amount of aldehydes (products from the decomposition of hydroperoxides with a continuous increasing trend) are determined, usually the Totox index during oil oxidation and fats increase. The reason for this can beLower amountAndis my hand in MW-0 sample compared to MW-2.5 sample. Or Et al(2017) showed that the oxidative stability of peanut oil exposed to microwaves at 170°C changes and oxidative spoilage indicators such as free fatty acids, peroxide index, totox index, para-anisidine index and thiobarbituric acid increase.[20]. ShafieiEt al(2020) estimated the oxidative indices in raw and roasted hazelnuts through the accelerated shelf life test and showed that the indicesTotox oil extracted from roasted hazelnuts is more than raw hazelnut oil[26].

3-3-4- Oxidative stability index (OSI) of hazelnut oil samples

Oxidative stability index by Rancimet method in MW-0 and MW-2.5 hazelnut oil samples is shown in Figure 7. The amount of this index was determined at 120°C in samples MW-0 (14.97 hours) and MW-2.5 (14.56 hours) ($p<0.05$). The reason for this can beLower amountAndis my hand in MW-0 sample compared to MW-2.5 sample.

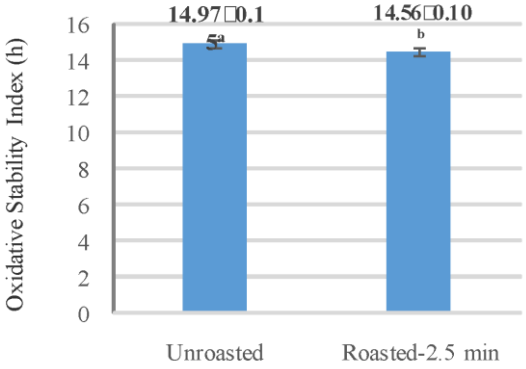

Fig 7 Change in oxidative stability index of unroasted (MW-0 min) and roasted (MW-2.5 min) Hazelnut kernel oil. Values in each heating time with different letters, are significantly different ($p>0.05$).

Oxidative stability index determines the oil's resistance to oxidation and is an important parameter to determine the condition of maintaining oil quality. Oxidative stability is the time required to reach a point where oxidation indicators such as the amount of hydroperoxide or carbonyl compounds suddenly increase and cause an unpleasant flavor in the oil. Various factors such as the composition of fatty acids, the composition of triacylglycerol, the presence of antioxidant compounds such as tocopherols and carotenoids, the presence of prooxidant compounds such as heavy metals, etc. are effective in the oxidative stability of oils. In the Rensimet method, the secondary products resulting from the oxidation of oils and fats, including aldehydes, ketones, and alcohols, are evaluated.[64].

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4 - Conclusion

The results of this research showed that roasting leads to changes in the physicochemical properties of hazelnut oil. Microwave pretreatment leads to increased oil extraction efficiency, color development, phytosterol content, **peroxide index,** Anisidine index and Totox index and decrease in OSI **became**The predominant unsaturated fatty acids in all oil samples are linoleic acid C_{18}2c: and oleic acid C_{18}1c was determined. Although increasing the duration of microwave pretreatment (7.5 minutes) increases the efficiency of oil extraction, But in order to prevent the negative effects of the long treatment time and considering that there is no significant difference between the antioxidant activity of the pretreatment sample MW-2.5 and MW-0, the duration of 2.5 minutes of roasting hazelnut kernels with microwave before Oil extraction is recommended. ToIn general, it can be concluded that**roastedN** With microwave, as an effective solutionto improve The efficiency of oil extraction as well as increasing the content of nutrients such asPhytosterols are considered.

5-Resources

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ارزیابی ویژگی های فیزیکوشیمیایی و پایداری اکسیداتیو روغن مغز فندق ایرانی(*Corylus avellana* L.) تحت شرایط مختلف برشته نمودن توسط مایکروویو

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چکیده

هدف از این مطالعه، ارزیابی ویژگی های فیزیکوشیمیایی (راندمان استخراج، توسعه رنگ، ترکیب اسیدهای چرب، اندیس یدی، اندیس صابونی، ترکیب استرول ها)، فعالیت مهار رادیکال آزاد DPPH و شاخص پایداری اکسیداتیو روغن استخراج شده توسط پرس سرد از مغز های فندق تیمار شده (برشته نمودن برای ۰، ۲/۵، ۵ و ۷/۵ دقیقه توسط مایکروویو) بود. نتایج نشان داد که در اثر پیش تیمار مغز فندق ایرانی توسط مایکروویو، میزان راندمان استخراج روغن، توسعه رنگ و میزان فیتواسترول افزایش می یابد. همچنین طی این پیش تیمار در اندیس صابونی (۱۸۸-۱۹۱ mg KOH/g oil) و ترکیب اسیدهای چرب نمونه های روغن مغز فندق اختلاف معنی داری مشاهده نگردید ($p \geq 0.05$). اسیدهای چرب غالب غیر اشباع در نمونه های روغن در کلیه تیمارها به ترتیب اسید اولئیک C18:1c (۴۳/۳۲-۷۷/۷۸) و اسید لینولئیک C18:2c (۱۰/۱۸٪-۹/۸۵٪) تعیین شد. درکلیه تیمارها، فیتواسترول های غالب β- سیتوسترول،Δ -7-اونا استرول، کامپسترول،Δ -7-استیگمااستانول و سیتواستانول تعیین شد. بیشترین فعالیت مهار رادیکال DPPH به ترتیب در نمونه های MW-0 (۹۰/۶۲ ٪) و MW-2.5 (۸۹/۹۴ ٪) مشاهده شد. علاوه بر این اندیس پراکسید، اندیس آنیزیدین و اندیس توتوکس روغن فندق شاهد (MW-0) و روغن فندق پیش تیمارشده (MW-2.5) در دمای آون با ۱۶۰ °C در فواصل ۰، ۳، ۶ و ۹ ساعت تعیین شد. همچنین شاخص پایداری اکسیداتیو (OSI) با استفاده از آزمون رنسیمت در دمای ۱۲۰ °C تعیین شد. نتایج نشان داد که پیش تیمار با مایکروویو یک راهکار نوید بخش جهت ارتقاء راندمان استخراج روغن، محتوای فیتواسترول‌ها و توسعه رنگ R در روغن حاصل از مغز فندق ایرانی می باشد.