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Microwave-assisted extraction of non-polar compounds from pistachio hull and characterization of extracts

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SUMMARY: Soxhlet and microwave assisted extraction (MAE) methods were used to obtain non-polar compounds from pistachio hull. MAE parameters (liquid to solid ratio, microwave power, and extraction time) were studied to obtain maximum extraction yield. The optimal conditions were found to be liquid to solid ratio of 15:1 (v/w), microwave power of 250 W and extraction time of 12.5 min. The extraction yields were 9.81 and 9.50% for MAE and Soxhlet methods, respectively. The total phenolic content, antioxidant activity and tocopherol content of the extract obtained by MAE was found to be significantly higher than those of the Soxhlet extract ($p < 0.05$). The results showed that the extract contained α-tocopherols (567.65 mg/kg) and oleic acid (48.46%) as the major tocopherols and fatty acids. These findings propose that hull extracts can be considered as a good source of natural bioactive compounds and MAE can be a good alternative to the traditional Soxhlet method.

***KEYWORDS**: Antioxidant activity; Fatty acids; Microwave assisted extraction; Pistachio hull; Tocopherols; Total phenolic content*

RESUMEN: ***Extracción asistida por microondas de compuestos no polares de cáscaras de pistacho y caracterización de los extractos.*** Se utilizó la extracción mediante Soxhlet y métodos de extracción asistida mediante microondas (MAE) para obtener compuestos no polares de las cascaras de pistacho. Se estudiaron los parámetros para la MAE (relación líquido-sólido, potencia de microondas y tiempo de extracción) para obtener el máximo rendimiento de la extracción. Se encontró que las condiciones óptimas eran una relación líquido a sólido de 15:1 (v/p), potencia de microondas de 250 W y un tiempo de extracción de 12,5 minutos. Los rendimientos de extracción fueron 9.81 y 9.50% para los métodos MAE y Soxhlet, respectivamente. El contenido fenólico total, la actividad antioxidante y el contenido de tocoferoles de los extractos obtenidos por MAE fueron significativamente más altos que los de los extractos de Soxhlet (p <0,05). Los resultados muestran que el extracto contiene α-tocoferol (567.65 mg/kg) y ácido oleico (48.46%) como los principales tocoferoles y ácidos grasos, respectivamente. Estos hallazgos proponen que los extractos de las cascaras pueden considerarse como una buena fuente de compuestos bioactivos naturales y MAE puede ser una buena alternativa al método Soxhlet tradicional.

***PALABRAS CLAVE:** Ácidos grasos; Actividad antioxidante; Cáscara de pistacho; Contenido fenólico total; Extracción asistida por microondas; Tocoferoles*

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1. INTRODUCTION

The interest for biologically active compounds from plants has increased in recent years due to their health-promoting activities and possible protection against several diseases associated with oxidative stress such as cancer, and neurological and cardiovascular diseases (Garavand *et al.*, 2017; Olas *et al.*, 2018). The main protective effect of these plant metabolites has been attributed to the presence of phenolic compounds such as flavonoids, flavones, isoflavone etc. On the other hand, recent studies have shown that the non-polar compounds also contribute to the antioxidant activity of plants (Oboh *et al.*, 2008). These non-polar compounds include lipophilic vitamins, phytosterols and unsaturated fatty acids (Grace *et al.*, 2016). In recent years, using fruit and vegetable processing residues which are considered an environmental problem has been attracting interest by researchers as sources of bioactive compounds (Moreira *et al.*, 2017). Phytochemicals from agro-industrial wastes can be used as natural antioxidants and functional food ingredients to replace their synthetic equivalents (Tumbas Šaponjac *et al.*, 2016).

The pistachio nut (*Pistacia vera* L.) is one of the tree nuts which is widely consumed due to its health-related benefits, and sensory and nutritional characteristics (Grace *et al.*, 2016). Turkey is the second largest pistachio producer after The United States with an annual production of 155,000 tonnes (USDA, 2017). When pistachios are processed into nuts after harvesting, their reddish purple hulls are removed as a waste after processing (Öztürk *et al.*, 2010). As the pistachio contains 18% hull, the hull is the major waste from the pistachio industry (Demiral *et al.*, 2008). Pistachio hull is often mixed with soil and less commonly used for feedstuff for local livestock farmers. If not processed further, this by-product becomes waste and has potential to cause environmental pollution.

The pistachio hull is a good source of protein, fat, minerals and vitamins. It is also one of the richest sources of antioxidants, phenolic compounds and essential oil such as α-pinene and (Z)-α-terpineol (Özel *et al.*, 2004; Goli *et al.*, 2005). Recently, the research on phenolic compounds has been growing due to the increasing worldwide demand for phenolic compounds and their increasing application in the food industry (Rodrigues and Pinto, 2007). The pistachio hull has attracted the interest of researchers because of its natural phenolics and antioxidants. It has been shown that pistachio hull extracts have antioxidant, antimicrobial and antimutagenic activities (Öztürk *et al.*, 2010; Rajaei *et al.*, 2010). Investigations have also shown that the antioxidant effect of pistachio hull extracts were similar to the synthetic antioxidants BHA and BHT, which makes the pistachio hull an alternative to synthetic ones (Goli *et al.*, 2005).

In recent years, faster and more automatic extraction methods for solid samples have been replacing traditional methods such as Soxhlet extraction (Gogus *et al.*, 2015). Several extraction methods and solvents are used for obtaining phenolic extracts from pistachio hull. These methods include solvent extraction (SE), ultrasound-assisted extraction (UAE), supercritical fluid extraction (SFE) and microwave-assisted extraction (MAE) (Goli *et al.*, 2005; Rajaei *et al.*, 2010). However, no study has been found on the microwave-assisted extraction of non-polar compounds from pistachio hull or characterization of the extract. The objectives of this study were: (i) to determine the chemical composition of pistachio hull, (ii) to obtain non-polar extracts by using MAE and traditional Soxhlet methods (iii) to determine and compare some chemical characteristics of these two non-polar extracts.

2. MATERIALS AND METHODS

2.1. Chemicals and reagents

Folin-Ciocalteau phenol reagent, gallic acid, α-, β-, γ- and δ-Tocopherols standards were provided by Merck (Darmstadt, Germany). 2,2-diphenyl-1-picrylhydrazyl radical (DPPH), sodium carbonate, 6-hydroxy-2,5,7,8-tetramethyl-chroman-2-carboxylic acid (Trolox), hexane, methanol, 2-propanol and other solvents were purchased from Sigma Aldrich. All solvents and reagents were of analytical or chromatographic grade.

2.2. Sample preparation

Mature healthy pistachio nuts were harvested from a village near Gaziantep in September, 2015. The hulls of the harvested nuts were removed and dried in a vacuum oven (Binder VD53, WTB Binder, Tuttlinge, Germany) at 40 °C for 5 h. Then the hulls were ground and the fraction that was sieved through a 250-mesh sieve was stored at −20 °C in a freezer until use. The final moisture content of the hull was less than 3% (w/w on wet basis).

2.3. Chemical composition of pistachio hull

The moisture, protein and ash contents of the samples were analyzed by the standard methods of ASTM E1756-01, ASTM E1755-01 and AOAC 984.13, respectively. A non-polar extract was obtained by the Soxhlet method. Carbohydrate content was calculated by subtracting other components from 100.

2.4. Preparation of extracts

Soxhlet extraction. Dried pistachio hull sample (10 g) was extracted with 220 mL hexane for 8 h on a hot plate using a Soxhlet apparatus. At the end of extraction, the solvent was evaporated at 40 °C using a rotary evaporator and the extract was stored at −20 °C until analysis.

Microwave assisted extraction (MAE). Dried pistachio hull sample (1.5 g) and different amounts of hexane were placed in a 35 mL vessel. The mixture was stirred at a high level under a closed system using a microwave reactor (CEM Corporation, USA). The extraction was performed in dynamic mode. Synergy software was used to set the microwave extraction conditions. The extraction variables, liquid to solid ratio (5:1-20:1 v/w), microwave power (170-280 W) and irradiation time (5-17.5 min) were studied to obtain the maximum extraction yield (%). After the extraction process, the mixture was centrifuged at 6000 rpm for 15 min and the upper layer was collected. The solvent was evaporated at 40 °C using a rotary evaporator and the extract was stored at -20 °C prior to analysis.

2.5. Preparation of cold pressed pistachio oil

Pistachio oil was extracted from pistachio kernels by cold pressing to compare its fatty acid composition with that of hexane extracts from the hull. The dry pistachio kernels were pressed at room temperature with a manual cold press (YP 0420, Ceselsan Makina, Giresun Turkey) and stored at 4 °C in a refrigerator before analysis.

2.6. Characterization of non-polar extracts

Determination of total phenolic content. The TPC of non-polar extracts was determined according to the Folin-Ciocalteu colorimetric as described by Fuentes *et al*., (2012) at a wavelength of 765 nm using a Perkin Elmer Lambda 25 UV/Vis spectrophotometer (Connecticut, USA). The phenolic content of the extracts was calculated using a gallic acid calibration curve and reported as gallic acid equivalent per gram dry weight of sample (mg GAE/g dw).

Determination of antioxidant activity. The antioxidant activity of the pistachio hull extracts was evaluated in terms of radical scavenging ability using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical according to the procedure described by Kalantzakis *et al*., (2006). Briefly, 1 mL of an ethyl acetate solution of the extract at different concentrations (0.05-25 mg/mL) was mixed with 4 mL of a freshly prepared DPPH solution (0.1mM) in ethyl acetate. The mixture was shaken vigorously and incubated in the dark for 30 min at room temperature. At the end of the incubation period, the absorbance value of the solution monitored at 515 nm using a Perkin Elmer Lambda 25 UV/Vis spectrophotometer (Connecticut, USA). The antiradical action of the extracts was determined from the difference in absorbance with or without sample (control). The percent inhibition was calculated using the following formula:

$$\text{Percent Inhibition (I\%)} = [(A_{control} - A_{sample}) / A_{control})] \times 100$$

The IC_{50} value is the effective concentration at which DPPH radicals were scavenged by 50% and was obtained from the graph of percent inhibition versus the concentration of the samples. Trolox was used for comparison.

Determination of tocopherols. The individual tocopherols of non-polar extracts were quantified by HPLC following the ISO 9936 Standard Method. Briefly, the extract was dissolved in hexane and a 10 µL aliquot was analyzed by HPLC using a silica column and by eluting with hexane:2-propanol (99.5:0.5 v/v) at a flow rate of 1 mL/min. A fluorescence detector was set at 290 nm excitation wavelength and 330 nm emission wavelength. The tocopherols were identified by comparing the retention times with standards of α-, β-, γ- and δ-tocopherols.

Determination of fatty acid composition. The fatty acid compositions of pistachio oil obtained from pistachio kernel by cold pressing and non-polar extracts were determined after converting to fatty acid methyl esters (FAME) prior to GC analysis according to the procedure described by Ciftçi *et al*., (2009) with some modifications. After methylation, the fatty acid composition was determined using a 7890A gas chromatography system (Agilent Technologies, USA) equipped with a flame ionization detector (FID), a split/splitless injector (operated with a split ratio of 1:50), and a capillary column HP-88 (88% Cianopropylaryl 100 m × 0.250 mm ID × 0.20 µm). Helium was used as the carrier gas. The injection temperature was 250 °C and the injection volume was 1µL. Firstly, the oven temperature was held at 120 °C for 1 min. Then, it was set to increase by 10 °C/min until 175 °C, held for 10 min, followed by an increase of 5 °C/min up to 210 °C, and held for 5 min. Finally, the increase in temperature of 5 °C/min up to 230 °C was applied and held for 5 min. The detector was set at 260 °C with 350 mL/min air flow, 35 mL/min hydrogen flow, and 15 mL/min helium makeup flow. The fatty acids were identified from retention times based on comparison with fatty acid standards.

2.7. Scanning electron microscopy (SEM) analysis

To investigate the influence of Soxhlet and microwave extraction on the surface morphology of the samples, the solid residues after hexane extraction were collected and analyzed with scanning electron microscopy. Three samples (untreated and residues after Soxhlet and microwave extraction) were used for the SEM analysis. The samples were mounted onto aluminium SEM stubs and coated with gold:palladium in an Emitech SC7620 (Kent, UK) sputter coater and imaged with JSM-6390LV (JEOL Ltd., Japan). The SEM photographs were taken at a magnification of 300 times.

2.8. Statistical Analysis

All extractions and analysis were performed in triplicate. The results were expressed as mean ± standard deviation. The experimental data were statistically analyzed by One-Sample T-Test using the SPSS statistical software, version 21.0 (SPSS Inc., Chicago, IL, USA). The significance level was set at $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1. Chemical composition of pistachio hull

Some chemical characteristics of pistachio hull are given in Table 1. The moisture content was 70.81 ± 0.77% (wb). The contents of ash, protein and non-polar extract were 11.40 ± 0.41, 8.54 ± 0.37 and 9.50 ± 0.16 % on the dry basis, respectively. The non-polar extract consisted of oil, lipophilic vitamins, phenolic compounds, phytosterols and fatty acids (Grace *et al*., 2016). These results are similar to those obtained by Moghaddam *et al.,* (2009) except for the protein content. This could be related to differences in the pistachio cultivars, growing practices, kernel maturity and the de-hulling process as reported by Bakhshizadeh *et al*., (2014).

TABLE 1. Some chemical characteristics of pistachio hull.

Compound	Pistachio hull
Moisture content (%wb)[a]	70.81 ± 0.77[b]
Ash (%db)[c]	11.40 ± 0.41
Protein (%db)	8.54 ± 0.37
Non-polar extract (%db)	9.50 ± 0.16
Total carbohydrates (%db)	70.56 ± 0.89

[a]wet basis.
[b]each value in the table represents the mean ± standard deviation of triplicate (N = 3) analyses.
[c]dry basis

3.2. Extraction of pistachio hull

Non-polar extracts from pistachio hull were obtained using the Soxhlet and MAE methods. Soxhlet extraction is a traditional and accepted method for the extraction of solid samples (De Castro and Garciá-Ayuso, 1998). The extraction yield for the Soxhlet method was 9.50 ± 0.16% (db).

MAE parameters including liquid to solid ratio, power and extraction time were investigated to obtain the maximum extraction yield (%). As for the liquid to solid ratio, Figure 1 shows that the extraction yield increased when the liquid to solid ratio increased from 5:1 to 15:1 (v/w). Furthermore, with an increase in the liquid to solid ratio from 15:1 to 20:1 (v/w), a slight decrease was observed in the extraction yield. This was probably because a larger volume of solvent caused a greater absorption of microwave energy, but sufficient microwave energy may not be available for breaking the cell walls to release the target constituents (Liu *et al*., 2014). Hence, a 15:1 (v/w) liquid to solid ratio was selected for further experiments.

The effect of power on the extraction yield is shown in Figure 2. The extraction yield increased from 8.10 to 9.78% by increasing the microwave power from 170 to 250 W. This can be explained by the rapid generation of heat inside the sample with the absorption of microwave energy and the subsequent formation of a higher pressure gradient inside the plant material when subjected to higher microwave power levels as reported by Ranitha *et al*., (2014). However, the extraction was almost complete at 250 W and after this point a further increase in yield was not observed. Based on these results, the microwave power setting of 250 W was chosen for further extraction experiments.

Figure 3 shows the effect of extraction time on the extraction yield of pistachio hull. The extraction yield increased from 8.53 to 9.81% by increasing extraction time from 5 to 12.5 min. With a further increase in time

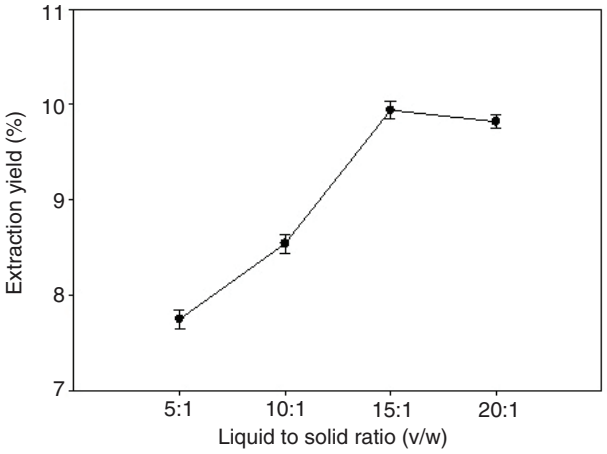

FIGURE 1. The effect of liquid to solid ratio on the extraction yield (%). Extractions were performed at 275 W for 15 min. Data are presented as the mean of three experiments with error bars denoting standard deviation.

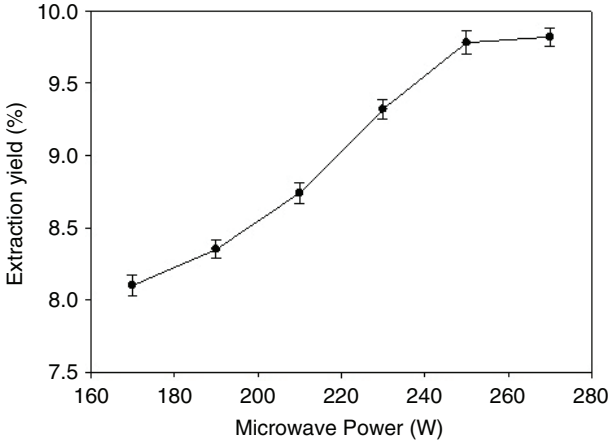

FIGURE 2. The effect of microwave power on the extraction yield (%). Extractions were carried out for 15 min and at a liquid to solid ratio of 15:1 (v/w). Data are presented as the mean of three experiments with error bars denoting standard deviation.

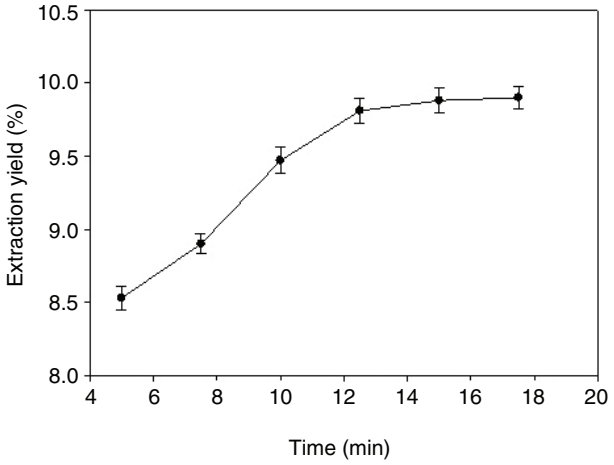

FIGURE 3. The effect of time on the extraction yield (%). Extractions were performed under 250 W and at a liquid to solid ratio of 15:1 (v/w). Data are presented as the mean of three experiments with error bars denoting standard deviation.

to above 12.5 min the extraction yield remained almost constant. A similar trend in the relation between extraction yield and time was also observed in other studies (Kittiphoom and Sutasinee, 2015). According to these results, 12.5 min was chosen as the extraction time. Rajaei *et al*., (2010) also studied the MAE of pistachio hull using a household microwave oven and found the optimum extraction time as 45 min. The shorter extraction time obtained in this study could be due to running the extraction under a high pressure compared to the atmospheric pressure in Rajaei *et al*.,'s study. In addition, the MAE using a closed-vessel microwave system and Soxhlet extraction methods were compared in this study and MAE had the higher extraction yield with reduced extraction time and less solvent consumption. Based on these results, MAE can be a good alternative to the Soxhlet method.

3.3. Characterization of non-polar extracts

The total phenolic content (TPC), antioxidant activity and tocopherol content of pistachio hull extracts were investigated and the results are summarized in Table 2.

The TPC of the extract obtained by MAE was higher (33.37 mg GAE/g dw) than the Soxhlet extract (24.84 mg GAE/g dw). There was a significant difference (p <0.05) in the TPC between the extracts of the two mentioned methods. During the MAE process, the extraction temperature did not exceed 60 °C and the time was 12.5 min. However, the traditional Soxhlet method involved long extraction time (8 h) and exposure to high temperatures that may lead to the thermal degradation of phenolic compounds. Goli *et al*., (2005) studied the total phenolic content of pistachio hull extracts which were extracted by different solvents (water, methanol and ethyl acetate). They have reported that the water and methanol extracts have high phenolic content (32.0–34.0 mg TAE/g dry weight of sample). However, there is no study in the literature about the TPC of non-polar extracts from pistachio hull.

TABLE 2. Total phenolic content, antioxidant activity and tocopherol content of extracts obtained by Soxhlet and MAE methods.

Properties[a]		Soxhlet extraction	MAE
Phenolic content (mg GAE[b]/g dw)		24.84 ± 0.32[c]	33.37 ± 0.59
Total antioxidant activity (DPPH assay, IC_{50}, mg extract/ml)		2.58 ± 0.15	2.47 ± 0.18
Tocopherol content (mg/kg extract)	α-tocopherol	466.44 ± 3.73	567.65 ± 2.53
	γ-tocopherol	23.94 ± 1.03	14.69 ± 0.47
	δ-tocopherol	268.47 ± 1.38	264.49 ± 1.22
	Total	758.85 ± 1.47	846.84 ± 1.05

[a]All comparisons between MAE and Soxhlet extractions in all analyses were significant at $p < 0.05$. Comparison was made by the One-Sample T-Test.
[b]GAE: gallic acid equivalent.
[c]Each value in the table represents the mean ± standard deviation of triplicate (N = 3) analyses

The IC_{50} values of the extracts obtained by the Soxhlet and MAE methods were 2.58 and 2.47 mg extract/mL, respectively. The difference between the IC_{50} values of the extracts was not statistically significant ($p > 0.05$). However, all the extracts showed lower antioxidant activity than that of trolox (IC_{50} value for trolox was 0.021 mg/mL). Valavanidis *et al*., (2004) reported that the IC_{50} values of extra virgin olive oil, corn oil, sunflower oil and soybean oil were 11.00, 15.00, 14.00 and 10.00 mg/mL, respectively. Thus, the non-polar extracts of pistachio hull might actually possess better antioxidant activity when compared with commercial edible oils.

Tocopherols are one of the minor components of vegetable oils and have antioxidant properties which make them an essential nutrient for human health (Kiralan *et al*., 2014). Tocopherol content of pistachio hull extracts were determined (Table 2) and α-tocopherol was the major tocopherol (466.44 and 567.65 mg/kg extract for the Soxhlet and MAE methods, respectively) while γ-tocopherol was the rare tocopherol (23.94 and 14.69 mg/kg extract for the Soxhlet and MAE methods, respectively) found in extracts. It can be reported that the concentration of tocopherols in non-polar extracts was affected by the extraction method. MAE resulted in significantly higher tocopherol concentration (846.84 mg/kg extract) than that of Soxhlet extraction method (758.85 mg/kg extract) ($p < 0.05$). This can be due to the effect of microwave irradiation, which causes damage to hull cell membranes and allows an increased release of tocopherols which also enhances their amount in the extract (Azadmard-Damirchi *et al*., 2010). Gliszczynska-Swiglo *et al*., (2007) studied the tocopherol contents in edible plant oils and reported that refined corn and soybean oils have the highest tocopherol contents (829 mg/kg) while refined grapeseed and extra virgin olive oils have the lowest tocopherol contents (121 and 177 mg/kg, respectively). Özrenk *et al*., (2012) demonstrated that pistachios contained 1.36–26.93 mg/kg of α-tocopherol, 36.17-170 mg/ kg of γ-tocopherol, 0.45–2.61 mg/kg of δ-tocopherol. But there is no literature study on the tocopherol content of pistachio hull and our results showed that pistachio hull is a rich source of tocopherols.

The fatty acid composition of pistachio kernel oil and non-polar extracts are presented in Table 3. The results indicate that oleic and linoleic acids were the main unsaturated fatty acids, while palmitic acid was the predominant saturated fatty acid of the non-polar extracts. These results were similar with the results of Ghaffari *et al*., (2014) who determined the fatty acid composition of pistachio by-products. Although *trans* fatty acids were found in both extracts, their level in Soxhlet extract was higher than the extract obtained by MAE. Pérez-Serradilla *et al*., (2007) reported that the formation of *trans* fatty acids could be due to thermally induced *cis-trans* isomerization. In MAE, the extraction time was much shorter and the extraction was conducted at lower temperatures than those applied in the Soxhlet method.

Similar to the non-polar extracts of pistachio hull, the major saturated fatty acid of cold pressed pistachio kernel oil was palmitic acid while the major unsaturated fatty acids were oleic and linoleic

Table 3. Fatty acid compositions (g/100 g FA) of pistachio kernel oil and oil in hexane extracts obtained by Soxhlet and MAE methods.

	Fatty acid composition (g / 100 g fatty acid)		
Fatty acid	**Pistachio kernel Oil**	**Soxhlet extraction**	**MAE**
Palmitic (C16:0)	8.80 ± 0.02[a]	15.90±0.25	16.40±0.58
Palmitoleic (C16:1)	0.61 ± 0.01	nd[b]	nd
Heptadecenoic (C17:1)	0.07 ± 0.01	nd	nd
Stearic (C18:0)	1.85 ± 0.01	4.36±0.28	5.78±0.16
Elaidic (C18:1 *trans*)	nd	4.10±0.26	3.21±0.04
Oleic (C18:1 *cis*)	70.36 ± 0.01	42.01±1.17	48.46±1.54
Linoelaidic (C18:2 *trans*)	nd	4.37±0.36	nd
Linoleic (C18:2 *cis*)	17.05 ± 0.01	20.90±0.69	19.01±0.51
γ-linolenic (C18:3 *n*-6)	0.17 ± 0.02	nd	nd
α-linolenic (C18:3 *n*-3)	0.22 ± 0.03	9.69±0.50	7.14±0.27
Eicosenoic (C20:1)	0.43 ± 0.01	nd	nd
Eicosatrienoic (C20:3 *n*-6)	1.13 ± 0.03	nd	nd

[a]Each value in the table represents the mean ± standard deviation of triplicate (N = 3) analyses.
[b]Not detected

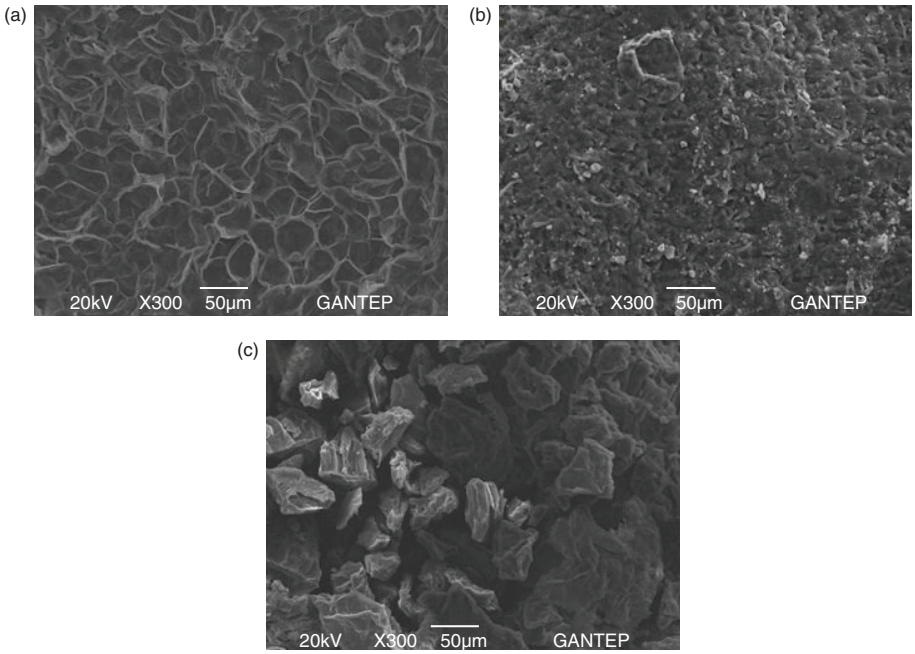

FIGURE 4. Scanning electron microscope images of pistachio hull before (a) and after extraction by Soxhlet (b) and microwave assisted extraction (c).

acids. Kirbaslar *et al*., (2012) reported similar results. Pistachio kernel oil had a higher oleic acid concentration but lower palmitic, stearic and α-linolenic acid concentrations compared to hull extracts. *Trans* fatty acids were not detected in kernel oil. This could be due to the fact that the kernel oil was extracted by cold press and was not exposed to temperature.

3.4. Scanning electron microscopy (SEM) analysis

The untreated pistachio hull and pistachio hull residues after Soxhlet and microwave assisted extraction methods were examined by SEM for structural analyses to investigate the effect of different extraction techniques (Figure 4). After Soxhlet extraction, a few slight ruptures were observed on the surface of the hull sample when compared to the untreated hull (Figure 4(b)). In the Soxhlet method, a heated solvent slowly diffuses into the solid matrix, dissolving and extracting the components that cause little destruction on sample microstructure. After MAE, obvious changes on the surface morphology were observed (Figure 4c). These changes suggested that microwave treatment played an important role in breaking up plant cell walls. Microwave irradiation affected the physical cell structure owing to the potential of electromagnetic waves to sudden temperature rises during microwave irradiation and internal pressure increases due to high vapor pressure inside the plant cells (Dahmoune *et al*., 2015).

4. CONCLUSIONS

In this study, the chemical characterization and extraction of non-polar compounds from pistachio hull were performed. The results indicated that pistachio hull can be considered as a good source of natural bioactive compounds. Microwave assisted extraction conditions were chosen as liquid to solid ratio of 15:1 (v/w), power of 250 W and time of 12.5 min to obtain the maximum extraction yield (%). Under these conditions, higher extraction yield (%) and extract with higher antioxidant activity, and total phenolic and tocopherol contents were obtained by MAE when compared to the traditional Soxhlet method. SEM observation of the extraction residues suggested that microwave irradiation destroyed the plant tissue, which probably enhanced the release of chemical substances into the solvents.

Further studies should be developed for the characterization of pistachio hull extracts and identification of compounds responsible for bioactivity. Additionally, the potential showed by pistachio hull extracts can lead to the valorization of a significant by-product of pistachio industrial processing which nowadays has an inadequate use. Moreover, MAE as an alternative extraction technique should be investigated for plant trials and continuous microwave systems to recover the high value-added products from biomass residues.

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