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A COMPARATIVE STUDY OF CONVENTIONAL AND GREEN EXTRACTION METHODS ON OIL YIELD AND PHYSICOCHEMICAL PROPERTIES OF APRICOT KERNEL

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Keywords

Prunus Armeniaca L., *Apricot Kernel Oil, Green Extraction, Waste Assessment, Ultrasound and Microwave Assisted Extraction.*

Abstract

Apricot kernel is a byproduct of fruit processing that is used for nuts but has a high economic value due to its high oil content. The aim of this research was to compare the green extraction techniques microwave-assisted extraction (MAE) and ultrasound-assisted extraction (UAE) with the traditional Soxhlet extraction method (SXHE). Time (min), amplitude (%), and temperature (°C) in the UAE method, power (W) and, time (min) in the MAE method, and time (min) in the SXHE method were used as oil extraction process parameters. The time required to achieve the oil yield similar to SXHE (43.65%) is 79% and 83% less in UAE and MAE methods, respectively. Extraction methods are ranked as UAE>MAE>SXHE when they are compared in terms of low free fatty acid (FFA), peroxide value (PV), and Delta-K, high antioxidant activity and total phenolic content (TPC), fatty acid composition, and accelerated shelf-life test (up to 20 days). However, after the 20th day of the shelf-life test, this ranking changes as UAE>SXHE>MAE. The UAE method had better results than MAE and SXHE methods due to same oil yield and higher functional oil content, especially at low extraction temperatures, and should be recommended for oil extraction from different kernels in the food industry.

KAYISI ÇEKİRDEĞİNİN YAĞ VERİMİ VE FİZİKOKİMYASAL ÖZELLİKLERİ ÜZERİNDE GELENEKSEL VE YEŞİL EKSTRAKSİYON YÖNTEMLERİNİN KARŞILAŞTIRMALI İNCELENMESİ

Anahtar Kelimeler

Prunus Armeniaca L., *Kayısı Çekirdeği Yağı, Yeşil Ekstraksiyon, Atık Değerlendirme, Ultrason ve Mikrodalga Destekli Ekstraksiyon.*

Öz

Kayısı çekirdeği, kuruyemiş olarak tüketilen ancak yüksek yağ içeriği nedeniyle ekonomik değeri yüksek olan bir meyve işleme yan ürünüdür. Bu araştırmanın amacı kayısı çekirdeklerinden yağ eldesinde, yeşil ekstraksiyon teknikleri olan mikrodalga destekli ekstraksiyon (MDE) ve ultrason destekli ekstraksiyon (UDE) ile geleneksel Soxhlet ekstraksiyon yönteminin (SXHE) karşılaştırılmasıdır. Yağ ekstraksiyonu proses parametreleri olarak UDE yönteminde zaman (dak), genlik (%) ve sıcaklık (°C), MDE yönteminde güç (W) ve zaman (dak), SXHE yönteminde ise zaman (dak) kullanılmıştır. SXHE ile aynı yağ verimini (%43.65) elde etmek için gereken süre, UDE ve MDE yöntemlerinde sırasıyla %79 ve %83 oranında daha kısadır. Ekstraksiyon yöntemleri, düşük FFA, PV ve Delta-K, yüksek antioksidan aktivite ve TPC, yağ asidi kompozisyonu ve hızlandırılmış raf ömrü testi (20. güne kadar) bakımından kıyaslandığında UDE>MDE>SXHE olarak sıralanmaktadır. Ancak raf ömrü testinin 20. günden sonra bu sıralama UDE>SXHE>MDE şeklinde değişmektedir. UDE yöntemi, özellikle düşük ekstraksiyon sıcaklıklarında daha yüksek yağ verimi ve daha yüksek fonksiyonel yağ içeriği nedeniyle MDE ve SXHE yöntemlerinden daha iyi sonuçlar vermiştir ve gıda endüstrisinde farklı çekirdeklerden yağ ekstraksiyonu için tavsiye edilmektedir.

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A COMPARATIVE STUDY OF CONVENTIONAL AND GREEN EXTRACTION METHODS ON OIL YIELD AND PHYSICOCHEMICAL PROPERTIES OF APRICOT KERNEL

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Highlights

- Apricot kernel is a valuable by-product with high oil content.
- Extraction method impacts apricot kernel oil's properties (fatty acids, antioxidants, phenolic compounds).
- UAE and MAE, as green alternatives, can effectively replace SXHE for fruit seed oil extraction.

Purpose and Scope

The primary goal of this study is to achieve maximal oil yield within a minimal timeframe from apricot kernels, a byproduct of fruit processing known for its valuable oil content. This research aims to conduct a comparative assessment of oil quality, comparing conventional Soxhlet extraction against green extraction techniques such as microwave-assisted extraction and ultrasound-assisted extraction.

Design/methodology/approach

In the present study, the oil yield obtained in Soxhlet extraction was taken as a criterion, and alternative green techniques (ultrasound and microwave) to this traditional method were investigated. Ultrasound-assisted extraction utilized an ultrasonic probe, while microwave extraction involved a modified oven equipped with a precise electronic temperature control panel. Furthermore, total phenolic content and capacity for free radical scavenging were investigated. Statistical analysis was performed to evaluate the results of these analyses.

Findings

Recently, non-thermal extraction methods or treatments involving minimal heat exposure have gained significant attention. Within the confines of this research, apricot kernel oil, much like other valuable oils containing elevated levels of unsaturated fatty acids, exhibits susceptibility to heat. The study reveals that the application of green extraction techniques to procure apricot kernel oil has yielded commendable outcomes. When the findings of the analyzes used in the study were evaluated, it was determined that the oil obtained with the ultrasonic extraction technique was the highest quality, followed by the oils obtained by microwave and Soxhlet, respectively. According to the current study, there was a statistical difference in peroxide value in oils extracted by different methods, while the content of free fatty acids was found to be quite close in oils produced by Soxhlet and ultrasonic extraction, but higher in oils obtained by microwave extraction ($p \leq 0.05$).

Practical implications

The outcomes distinctly establish the ultrasonic extraction technique as capable of delivering superior-quality vegetable oils in less time compared to alternative extraction procedures. Consequently, it is recommended that the ultrasonic extraction technique be further developed in alignment with industrial practices and implemented in oil extraction processes. Furthermore, the conversion of oilseed-derived oil into diverse products across the cosmetics, pharmaceutical, and food sectors, destined for both domestic and international markets, promises heightened economic benefits.

Originality

Reviewing both domestic and international literature to this investigation, it becomes evident that the national literature lacks studies exploring the application of environmentally conscious extraction methods for apricot kernel oil and the subsequent impacts of varying techniques on the resultant oil. Although the international literature presents a limited number of relevant studies, none have undertaken a comparative analysis between Soxhlet, ultrasound-assisted, and microwave-assisted extraction methods. Also, the chosen "Hacıhaliloğlu" apricot variety, the most extensively processed apricot strain for drying process in Turkey, which consequently highest quantity of apricot kernels. This variety has been selected as the subject material to uncover the extraction conditions, oil yield, and associated properties.

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1. Introduction

Apricot fruit (*Prunus armeniaca* L.) is a member of the Rosaceae family and is of the Prunus species (Davis, 1975; Güner et al., 1999). Turkey, Iran, Uzbekistan, Italy, Algeria, France, and Spain are the main apricot producers. Annual world fresh apricot production is 3.5-4 million tons, and the dried apricot production is 150-200 thousand tons. Turkey is the world leader in fresh apricot production with an annual production of 500-800 thousand tons. Most of the production in Turkey is from Malatya region and the most important dried apricot variety in the region is Hacıhaliloğlu (Anonymous, 2015; Gezer et al., 2009). Apricot kernel consists of about 15% of the fruit and is a valuable by-product. Apricot kernels are usually separated from the fruits during the production process, especially before drying. Kernels removed from fruit are consumed directly as an important source of oil, protein, and fiber and are used as a flavor in bakery products and as a flavor instead of dry almonds (Tareen et al., 2021).

Apricot kernel consists of 15-20% protein, 4-5% cellulose, and 45-52% oil. The oil consists of 8.27% saturated fatty acids and 91.73% unsaturated fatty acids of the total fatty acid content (Açkurt, 1998). These fatty acids are mostly oleic acid and linoleic acid. Oleic acid content is approximately 58-73%, and linoleic acid content is approximately 19-32%. In addition, seed oil contains considerable amounts of ɣ-tocopherol as well as α- and β-tocopherol but at limited levels (Durmaz, 2002; Górnaś et al., 2019; Pavlović et al., 2018 Stryjecka et al., 2019; Bhanger et al., 2020) Besides, it has been reported that fat-soluble vitamins and minerals are high in this oil source (Yılmaz, 2010; Shariatifar et al., 2017).

Recent research indicates that apricot kernel oil is a potential oil source for both dietary and cosmetic industries due to its health beneficial fatty acid composition and biologically active components (Stryjecka et al., 2019; Bhanger et al., 2020). According to the research, apricot kernels have higher antibacterial and antioxidant activity than fruit pulp (Tareen et al., 2021). Another study found that apricot kernel oil has a cardioprotective effect and could be evaluated as a food ingredient to help preventing myocardial diseases (Zhang et al., 2011). In addition to lowering blood pressure, apricot kernels can also help treating diseases such as cancer and cancer immunotherapy. Almond oil, benzaldehyde, furfuryl alcohol, activated carbon, aroma essence, amygdalin (vitamin B17), and hydrocyanic acid are made from apricot kernels (Ünal, 2010). Although apricot kernels are generally consumed as snacks, they can also be used in the production of low-fat biscuits, cookies, and cakes, as well as antimicrobial films, especially in the food industry (Akhone et al., 2022).

To extract oils from oilseeds there are different methods such as cold pressing, solvent extraction, supercritical fluid extraction, enzyme-assisted extraction, or a combination of these methods (Bhanger et al., 2020). In a study, it was discovered that ultrasound and microwave-assisted oil extraction methods had a positive effect on oil quality extracted from rapeseed and black cumin seed (Şeran, 2011). In another study comparing microwave-assisted extraction and the traditional Soxhlet method for obtaining high-efficiency oil from hazelnut, soybean, and rice bran, it was discovered that microwave-assisted extraction can be effective in terms of oil yield with a shorter time at lower temperature levels (Tunç et al., 2014). When studying oil extraction from apricot kernels, the following methods have been investigated: supercritical CO_2 extraction (Özkal et al., 2005; Pavlović et al., 2018), ultrasonication (Górnaś et al., 2019) ;(Hao et al., 2022) Soxhlet extraction (Al Juhaimi et al., 2018; Shariatifar et al., 2017; Stryjecka et al., 2019)), cold pressing (Hao et al., 2022) Numerous studies have been published on the chemical analysis of apricots and their seeds, their nutritional value, and their medicinal use (Akhone et al., 2022). However, few studies on high-efficiency oil extraction from apricot kernels have been found. Green extraction techniques such as MAE and UAE extraction have not been compared in any study focusing on oil extraction from apricot kernels.

In this study, the seed oil of Hacıhaliloğlu cultivar, which is the most widely processed apricot variety in Turkey, was extracted using MAE and UAE methods and the extraction yields were compared with the SXHE method. In addition, it is aimed to determine the extraction parameters (time, power, and temperature effects) for the highest yield. Then, the shelf life and deterioration rates of the obtained oils were determined. It is thought that the results obtained from this research will guide the extraction and preservation of other seed oils.

2. Material and Method

2.1. Material

To achieve kernels, "Hacıhaliloğlu" variety of apricot fruit was obtained from apricot gardens in the Kuluşağı village of Malatya province.

2.2. Method

Apricot kernels were removed from the fruit and dried in the drying oven until they reached up to 10% moisture content. The drying process is critical for more effectively removing the oil from the kernel and standardizing the prepared samples. The kernels were crushed-shredded and sized to increase the surface area in order to perform mass transfer more effectively during the extraction process. The crushed kernels were sieved and classified as larger than 1mm and smaller than 2mm. The extracted oils were kept at -20 °C until they were analyzed. The appropriate circumstances were set in the vegetable oil analysis laboratory of Suleyman Demirel University Faculty of Engineering to identify the physicochemical and chemical properties of the produced oils, and the analyses were carried out here.

2.2.1. Extraction

Apricot kernel oil was produced using different extraction techniques. For a reference, the traditional solid-liquid extraction method, SXHE was performed. For extraction, filter paper cartridges were prepared, dried, and crushed-sized apricot kernels weighed 11.50 g. The preliminary experiments revealed that using a solid/ solvent ratio of 1:20 (g/ml) was suitable for efficient extraction. The cartridge was placed in the Soxhlet apparatus, and 230 ml of hexane was added at a solvent-solid ratio of 1:20 (g/ml) to the Soxhlet extraction apparatus. Preliminary trials were conducted, and it was determined that an extraction time of 6 hours was appropriate for completed extraction.

2.2.1.1. Ultrasound-Assisted Extraction

Hexane was used as a solvent in. In terms of oil yield and quality requirements, the effects of solid/liquid ratio (1:20 (g/ml)), ultrasonic amplitude (60-100%), and application time (10-75 min) factors were investigated. For ultrasonication, an ultrasonic probe (Comecta Optic Ivymen System Cy-500, Spain) was used.

2.2.1.2. Microwave-Assisted Extraction

MAE extraction is another technique used in this research. In contrast to traditional microwave systems, a modified and designed microwave oven (Arçelik, MD 574, Turkey) was used in this case. The electronic control unit integrated into the device allows monitor solvent temperature level and to control it during operation. Furthermore, the temperature was measured with an accuracy of 1°C every second by directly measuring the temperature of the extraction liquid rather than the surrounding temperature. For this method, the following parameters were used: temperature (30-40°C), duration (10-60 minutes), and solvent-solid ratio (1:20 (g/ml)).

2.2.3. Oil Yield

The yield (%) values of the oils extracted were determined for each extraction procedure. The yield was determined as grams of crude oil / 100 grams of the dry kernel.

2.2.4. Determination of Specific Absorbance Values in UV Light (K232, K270)

The Codex Alimentarius method was used to determine the specific absorbance values in UV light (Anonymous, 2001). 100 mg of oil sample was dissolved in 10 ml of cyclohexane to make a 1% solution. The absorbances of the produced solution were measured spectrophotometrically (T70+UV/VIS spectrophotometer, PG Instruments, UK) at wavelengths of 232, 266, 270, and 274 nm, respectively, to compute the K232 and K270 values. Analyses were run in three parallels. The Delta K value was calculated using Equation (1) below. In general, a low delta K value indicates that the oil is of excellent quality and fresh.

$$Delta\ K = K^{270} - \frac{K^{266} + K^{274}}{2} \qquad (1)$$

2.2.5. Determination of Free Fatty Acids

Free fatty acids (FFA) are one of the most essential characteristics used in the quality evaluation and classification of oils. To determine the amount of FFA, the Ca 5a-40 standard method was used (AOCS, 1997a). All analyses were performed as three parallels, with findings estimated in terms of % oleic acid.

2.2.6. Determination of Peroxide Value

The Cd 8-53 standard method was used to measure the peroxide value (PV) utilized in the determination of primary oxidation products of oils (AOCS, 2003). The analyses were performed as three parallels and the results were given as the peroxide oxygen in one kilogram of oil in milliequivalent oxygen.

2.2.7. Determination of Total Phenolic Content

Using the Folin-Ciocalteu method, the total phenolic content (TPC) quantities of phenolic substances extracted from the oil three times with a mixture of water: methanol (20:80; v/v) were determined (Singleton ve Rossi, 1965). 40 µl of the phenolic extract was pipetted into a tube and diluted with 2.40 ml distilled water. Then 200 µl of Folin-Ciocalteu reagent was mixed in. Then the mixture was added 600 µl of saturated sodium carbonate solution (38%, w/v). Finally, 760 µl of distilled water was added and mixed up. After being left in the dark for two hours at room temperature, the absorbance of the sample solutions against the blank solution was measured in a spectrophotometer (T70+UV/VIS spectrophotometer, PG Instruments, UK) at a wavelength of 765 nm.

2.2.8. Free Radical Scavenging Activity Determination (DPPH)

The ability of antioxidant compounds in apricot kernel oil to bind hydrogen was determined using the 2,2-diphenyl-1-picryl-hydrazyl (DPPH) free radical scavenging activity assay (Dorman et al., 2003). 50 µl of apricot kernel oil extracts with using methanol: water (80:20; v/v) in three times extraction were pipetted into tubes, and 450 µl Tris-HCl buffer (50mM, pH:7.4) was added. The mixture was then treated with 1 mL of DPPH (0.10mM in methanol) solution and left in the dark for 30 minutes at room temperature. The absorbance of the solution at 517 nm was measured using a spectrophotometer (T70+UV/VIS spectrophotometer, PG Instruments, UK) at the end of the reaction time. As a control, pure water was utilized instead of the extract. The DPPH free radical scavenging activity was calculated using the following Equation (2).

$$\%\ Inhibition = \frac{Abs_{Control} - Abs_{Sample}}{Abs_{Control}} \times 100 \qquad (2)$$

2.2.9. Determination of Fatty Acid Composition

Fatty acid composition was determined by gas chromatography (GC) using and flame ionization detector (FID) (Agilent Technologies, 7820A, USA). To determine the fatty acid composition, the oil samples were esterified by Ce 1-62 method (AOCS, 1997b). The fatty acid composition (%) of esters was measured using gas chromatography. The arrival times of the chromatogram peaks were determined first by using reference methyl esters (FAME) and then compared to the sample arrival times. The following sections describe the features and working conditions of the gas chromatography instrument. Column: Restek Rtx-2330 60m x 0.25mm diameter x 0.20µm, Flow rate: 30ml/min Hydrogen, 300ml/min dry air, Split 10:1 Column temperature: 240 °C, Injection: 1µl, 240 °C, Oven temperature: 175-240°C, Detector temperature: FID, 240 °C.

2.2.10. Accelerated Shelf-life Analysis of Oil (Schaal oven test)

Oxidation reaction accelerated method (Cg 5-97) oven test was used to determine the shelf life of oil samples (AOCS, 1999). According to this method, oil samples were stored in 100 ml dark glass bottles in an airflow drying oven for 30 days at 60 ± 2°C. The oxidation reaction that took place during the storage was monitored in 5-day periods. Oxidative change in conjugated diene and triene values was determined by peroxide value and spectrophotometric analysis.

2.2.11. Statistical Analyses

The SPSS statistical program was used for a statistical analysis of the received data. Analysis of variance was used to establish the significance of the difference between groups. To determine the difference between groups, the Duncan multiple comparison tests were used.

3. Result and Discussion

The mean values of length, width, thickness, and weight measurements of Hacıhaliloğlu apricot kernel samples used in the study were found to be 18.69± 0.11, 10.22± 0.07, 5.59± 0.05, 0.55± 0.07, respectively (n=50). The independent variables of the extraction process and the resultant oil yields were given in Table 1.

Table 1. Extraction process design table. *

Method	Time (min)	Temperature (°C)	Amplitude (%)	Oil Yield (%)
SXHE	240	68	-	23.36± 0.99[a]
	270	68	-	30.60 ± 1.06[b]
	300	68	-	40.00 ± 0.47[c]
	360	68	-	43.65 ± 0.84[d]
MWE	30	30	-	38.09 ± 0.49[e]
	45	30	-	39.62± 0.56[f]
	60	30	-	42.31 ± 0.46[g,f]
	30	40	-	41.99 ± 0.51[g,f]
	45	40	-	41.25 ± 0.48[f,h]
	60	40	-	43.66 ± 0.20[d]
USE	60	55	60	39.19 ± 0.90[c]
	60	55	80	41.85 ± 0.32[g,f,h]
	45	55	100	41.15 ± 0.20[h]
	60	55	100	42.38 ± 0.10[g]
	75	55	100	43.73 ± 0.20[d]

*; Oil yield: g crude oil/100 g dry kernel, MAE; Microwave-assisted extraction, SXHE; Soxhlet extraction, UAE; Ultrasound-assisted extraction, different capital letters in the same column are statistically different from each other (p≤0.05).

When Table 1 was examined, the amount of oil obtained at the ratio of 20:1 solvent/solid in 6 hours with Soxhlet extraction was found to be 43.65%. This oil yield was achieved with MAE at 40°C in 60 minutes (43.66%), and with UAE at 100% ultrasound power in 75 minutes (43.73%), and the difference between oil yields was statistically insignificant (p>0.05). The oil extraction, which required 6 hours with the traditional extraction method, was achieved in an average of 1 hour using the green extraction techniques. The decrease in extraction time saved both time and energy, increasing production per unit time while decreasing cost.

Peroxide value (PV) is used to express the primary oxidation products formed in the oxidation reactions (Tunç et al., 2014). The PV in oils is a measure of the amount of active oxygen and reflects the milliequivalent grams of peroxide oxygen in 1 kg of oil (Frankel, 2012). The number of free fatty acids (FFA) is one of the analyses used to measure the quality of oils. The amount of FFA is an expression of the total unbound free fatty acids in oils expressed as a percentage of oleic acid (Huber et al., 2017). Table 2 shows the FFA, PV, K232, K270, and Delta K values of apricot kernel oils obtained using SXHE, MAE, and UAE methods.

Table 2. FFA, PV, K232, K270 and Delta K values of apricot kernel oils. *

Extraction Methods	FFA	PV	K_{232}	K_{270}	Delta K
SXHE (360 min)	0.36±0.00[a]	1.03±0.01[a]	1,409±0.01[a]	0,262±0.01[a]	0.0040±0.00[a]
MAE (40°C, 60 min)	0.70±0.02[b]	0.69±0.02[b]	1,307±0.12[b]	0,180±0.01[b]	0.0035±0.00[b]
UAE (%100 amplitude, 75 min)	0.35±0.01[a]	0.46±0.02[c]	1,278±0.13[c]	0,190±0.01[b]	0.0030±0.00[c]

*; PV: meq O_2 /kg, FFA: % oleic acid, different capital letters in the same column are statistically different from each other (p≤0.05).

According to the results, the oil with the highest peroxide value was obtained using SXHE, compared to MAE, and UAE. Green extraction techniques produce oils with lower peroxide content, and this difference is statistically significant (p≤0.05). The effects of process factors (temperature, time, and power) on peroxide values are statistically significant (p≤0.05). Because the application temperature and time in UAE and MAE procedures are significantly lower than in SXHE, oils with reduced peroxide content were achieved. According to Annex-2 of the "Turkish food codex communiqué on oils referred to by plant name" (communiqué no: 2012/29), the FFA and PV of apricot kernel oil are below the prescribed limit values and can be evaluated without refining.

Oil oxidation affects the conjugated diene and triene structures. Secondary oxidation products are compounds generated as a result of this oxidation. Secondary oxidation products absorb UV light at 232 and 272 nm wavelengths. After dissolving the oil in a suitable solvent, its absorbance is measured at wavelengths of 232, 264, 268, and 272 nm. Excessive absorption at these wavelengths indicates high oxidation and poor-quality oil. Table 2 shows the specific absorbance values of K232, K270, and Delta K of apricot kernel oils extracted using three distinct procedures. When the extraction techniques were compared, the oil recovered by UAE had the best values, followed by MAE and SXHE. The various extraction procedures used had a statistically significant influence on the K232 and K270 values of the extracted oils (p≤0.05). In the Turkish food codex, there are no published standards

for K232, K270, or Delta K values of apricot kernels.

The best quality oils were determined to be those produced by the UAE method and SXHE method, with the amount of free fatty acids of the oils obtained by MAE being substantially different and higher ($p \leq 0.05$). Similar to our findings, it has been reported in the literature that microwave heating enhanced the amount of free fatty acids in sunflower oil, soybean oil, corn oil, and olive oil (Tunç et al., 2014). According to another research, microwave energy causes the ester bonds in vegetable oils, which contain high quantities of polyunsaturated fatty acids, to break and the triglyceride molecules to break down, increasing the quantity of free fatty acids (Yoshida et al., 1992). The percentage of free radical inhibition in the extracted oil, as well as the total quantity of phenolic compounds detected at 765 nm, are given in Table 3.

Table 3. Phenolic compounds and free radical inhibition levels of apricot kernel oils. *

Method	Inhibition %	TPC
SXHE	25.17±0.64[a]	121.22±0.78[a]
MAE	27.11±0.45[a]	149.21±0.96[b]
UAE	32.04±0.87[b]	196.81±0.31[c]

*; TPC: μg GAE/ml Oil, different capital letters in the same column are statistically different from each other ($p \leq 0.05$).

According to our findings, it was discovered that the UAE method outperformed the MAE and SXHE methods significantly in terms of the free radical scavenging capacity of the oils ($p \leq 0.05$). At the same time, the total phenolic content of the oils obtained by the UAE method was found to be higher and statistically significant compared to the oils obtained by the MAE and SXHE method ($p \leq 0.05$). When we compare the MAE and SXHE methods among themselves, the total amount of phenolic content in the oils obtained by the MAE method was found to be higher than in the oils obtained by the SXHE method, and the difference is statistically significant ($p \leq 0.05$).

Table 4 shows the fatty acid composition of the oils obtained in the study using three different methods.

Table 4. Faty acid components of apricot kernel oils (%).

Faty acid composition	Extraction techniques		
	SXHE	**MAE**	**UAE**
Palmitic acid	5.63±0.09[a]	5.29±0.06[b]	5.46±0.03[a]
Palmitoleic acid	0.79±0.04[a]	1.01±0.10[a]	0.75±0.04[a]
Heptadecanoic acid	0.13±0.01[a]	0.12±0.00[a]	0.12±0.01[a]
Stearic acid	1.04±0.06[a]	1.25±0.02[a]	1.25±0.07[a]
Oleic acid	65.44±0.06[a]	68.15±0.04[b]	68.25±0.02[b]
Linoleic acid	24.01±0.16[a]	23.07±0.02[b]	24.07±0.01[a]
Arachidic acid	0.19±0.01[a]	0.10±0.00[b]	0.11±0.01[b]
ΣSFA	6.86±0.04[a]	6.64±0.04[a]	6.81±0.09[a]
ΣMUFA	66.35±0.03[a]	69.26±0.13[b]	69.12±0.07[b]
ΣPUFA	24.01±0.16[a]	23.07±0.02[b]	24.07±0.01[a]

*; ΣSFA; total saturated fatty acid, ΣMUFA; total monounsaturated fatty acid, ΣPUFA; total polyunsaturated fatty acid, different capital letters in the same line are statistically different from each other ($p \leq 0.05$).

Oleic acid (65.44–68.25%) and linoleic acid (23.07–24.07%) are the unsaturated fatty acids that were in the highest concentration in apricot kernel oils extracted using various techniques. Palmitic acid (5.29-5.63%) and stearic acid (1.04–1.25%) were determined to have the greatest levels of saturated fatty acids. The study's data are consistent with previous research (Femenia et al., 1995; Kamel and Kakuda, 1992; Turan et al., 2007; Bhanger et al., 2020). The oils produced with UAE had the highest concentration of essential fatty acids in the apricot kernel oils, followed by those produced with SXHE and MAE, respectively. SXHE contains statistically significantly higher palmitic acid, and arachidic acid than MAE and UAE. The amounts of oleic acid and total polyunsaturated fatty acids were significantly higher in UAE extraction technique and other methods.

The Schaal oven test was used in the study to determine the accelerated shelf life of oils. Oxidative change in conjugated diene and triene values were determined by peroxide value and UV analysis, and the results are shown in Figure 1.

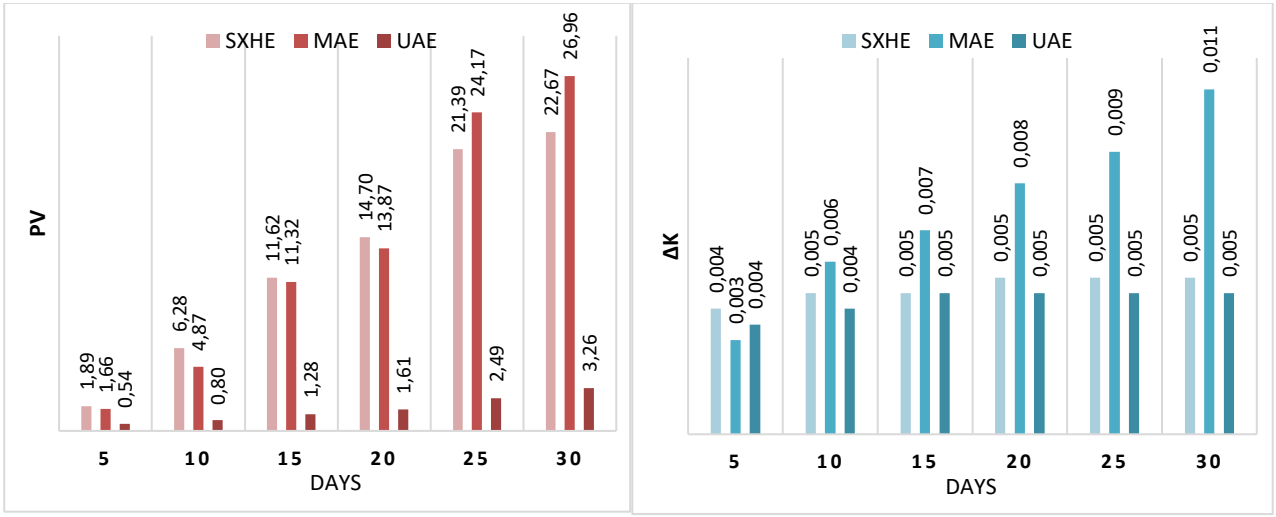

Figure 1. Peroxide (meq O_2 /kg) and Δk values in the Schaal oven test.

During the Schaal oven test, the peroxide value of the oils obtained with UAE was much lower than that of the other two methods. The peroxide value of the oils obtained with SXHE was higher than the other two methods during the first 20 days of the test, but on the 25th day and after, the peroxide value of the oils obtained with MAE exceeded those obtained with SXHE and reached the highest level. The effect of the various methods on the peroxide value was discovered to be statistically significant ($p \leq 0.05$). In this context, oils obtained through MAE should be better preserved (in the dark, oxygen-free, and cool) than oils obtained through other methods.

In crude form and on the 5th day of the Schaal oven test, the oil obtained by SXHE had a higher secondary oxidation value than the other two methods, and the statistical difference between them was found to be significant ($p \leq 0.05$). The secondary oxidation values of the oils obtained by SXHE and MAE between 10 and 25 days were close to each other, and the difference was statistically insignificant ($p > 0.05$). The secondary oxidation values of the oils obtained by MAE were higher than the other two methods after the 20th day, and the difference was statistically significant ($p \leq 0.05$). The oils obtained by the UAE method had the lowest secondary oxidation values during the Schaal oven test period.

4. Conclusion

Recently, non-thermal extraction techniques or pretreatments with minimum heat treatment parameters have attracted attention. In this context, the sensitivity of compounds intended for extraction in oils to temperature, which is a factor in conventional solid/liquid extraction procedures, is at the forefront. Within the scope of the study, apricot kernel oil is also heat sensitive, similar to other valuable oils containing high unsaturated fatty acids. In this study, UAE and MAE extraction techniques used to obtain apricot kernel oil were found to be quite successful in terms of offering the same oil yield as SXHE at low temperatures and in a short time. When the findings of the analyzes used in the study were evaluated, it was determined that the oil obtained by the UAE technique was of the highest quality, followed by the oils extracted by MAE and SXHE, respectively. According to the current study, while there was statistical difference in peroxide value in oils extracted with UAE, MAE and SXHE, the content of free fatty acids was found to be quite close in oils prepared with SXHE and UAE, but higher in oils obtained with MAE ($p \leq 0.05$). The results show that the UAE technique can yield higher quality vegetable oils in less time than several alternative extraction processes currently in use.

According to the literature, there is no study comparing UAE and MAE in oil extraction from apricot kernels using solvents. In particular, it is recommended that the UAE technique be developed and applied in the industry. In addition, the oil obtained from its seeds will be industrially transformed into various products in the cosmetics, pharmaceutical, and food sectors and presented to the domestic and foreign markets will provide more economic gain to our country. Given the economic importance of the issue, it is recommended to develop and test the procedure on an industrial scale.

Conflict of Interest

No conflict of interest was declared by the authors.

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