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Physicochemical Attributes and Antioxidant Potential of Kernel Oils from Selected Mango Varieties

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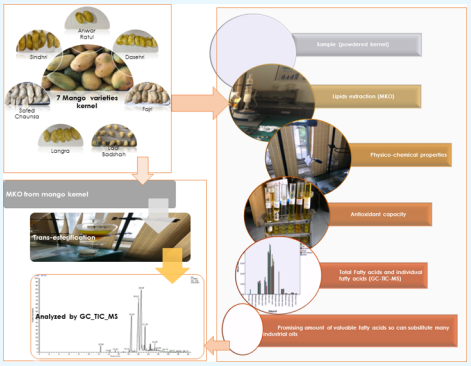
ABSTRACT: The current study appraises the variations in the yield and physicochemical and antioxidant attributes among kernel oils from the seven most widely consumed varieties of Pakistani mangoes, namely, Anwar Ratul, Dasehri, Fajri, Laal Badshah, Langra, Safed Chaunsa, and Sindhri. The yield of mango kernel oil (MKO) among the tested varieties of mangoes varied significantly ($p < 0.05$), ranging from 6.33% (Sindhri) to 9.88% (Dasehri). Physicochemical properties, including the saponification value, refractive index, iodine no., P.V, % acid value, free fatty acids, and unsaponifiable matter, for MKOs were noted to be 143.00−207.10 mg KOH/g, 1.443−1.457, 28.00−36.00 g/100 g, 5.5−2.0 meq/kg, 1.00−7.7%, 0.5−3.9 mg/g, and 1.2−3.3%, respectively. The fatty acid composition determined by GC-TIC-MS revealed the presence of 15 different fatty acids with variable contributions of saturated (41.92−52.86%) and unsaturated (47.140−58.08%) fatty acids. Among unsaturated fatty acids, values of monounsaturated and polyunsaturated fatty acids ranged from 41.92 to 52.85 and 7.72 to 16.47%, respectively. Oleic acid (25.69−48.57%), stearic acid (24.71−38.53%), linoleic acid (7.72−16.47%), and palmitic acid (10.00−13.26%) were the prominent fatty acids. The total phenolic content (TPC) and DPPH radical scavenging (IC_{50}) capacity of MKOs varied from 7.03 to 11.00 mg GAE/g and 4.33 to 8.32 mg/mL, respectively. The results of most of the tested attributes varied significantly ($p < 0.05$) among the varieties selected. It can be concluded from the findings of this research work that MKOs from the tested varieties are potential sources of valuable ingredients for the development of nutrapharmaceuticals due to their potent antioxidant properties and high oleic fatty acid profile.



1. INTRODUCTION

As a result of fruit processing, a large amount of agrowaste materials such as peels, seeds, stones, and oilseed meals are being generated every year,[1] which can be explored as potential sources of high-value food ingredients, antioxidants, and bioactive compounds. Nevertheless, in line with the global demand for eco-friendly practices, sustainable utilization of fruit waste can also help to cope with the challenge of waste disposal.[2] Currently, there is increased global interest in extracting antioxidants and other valued components from under-utilized agrowaste to explore their commercial utilization in cosmetics, drugs, and food preservation. In this regard, different extraction techniques can be employed for the efficient recovery of bioactives from agrowaste.[3,4] In line with the concept of biorefining, extraction of oils from fruit seeds might be a step forward toward value addition and sustainable utilization of agrowaste.[5−7]

Among tropical fruits, mango has emerged as an important functional food with the potential to be explored as a rich source of nutritional and nutraceutical components in the pharmaceutical and cosmo-nutraceutical industries.[8] Mango, belonging to the Anacardiaceae family, is distributed across the world, including the Indian subcontinent (India, Pakistan, and Bangladesh) and the Southeast. Being an exotic and multi-purpose super fruit, it is the second most traded tropical fruit, which is extensively used in the food, juice, flavoring, and fragrance industries.[7−10] As a seasonal fruit, a huge quantity of mangoes is being consumed fresh, thus yielding a sizeable quantity of peels and kernels as waste. Moreover, around 15−20% of mango fruits are processed to prepare various products such as squash, nectar, canned slices, chutney, juices, ice cream, fruit bars, and pies.

During the processing of ripened mango, its peels and seeds are discarded, while the seed represents 20−60% of the total whole fruit weight.[11] It is estimated that several metric tons of mango seeds are yielded and wasted every year regardless of their nutritive and medicinal importance.[12] Traditionally, mango seeds (kernels) are used against gastrointestinal pathogens, particularly in children, and as an antidiarrheal agent.[13] It has also been reported to have anticarcinogenic

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Figure 1. Mango seeds of selected varieties: (A) Anwar Ratul, (B) Dasehri, (C) Fajri, (D) Laal Badshah, (E) Langra, (F) Safed Chaunsa, and (G) Sindhri.

activity against breast and colon cancer as well as antibacterial activity against both types of bacteria, i.e., Gram-positive and Gram-negative bacteria.[14] Both *in vivo* and *in vitro* studies suggest that bioactive compounds and antioxidants from mango kernels could offer protection against cardiovascular and hepatic effects and possess antiaging and anticarcinogenic activities. The lipids in mango kernels of various varieties have drawn immense interest from researchers because of their potential applications in the confectionery industry as a source of a cocoa butter substitute. Nutritional and toxicological studies of mango seed kernels indicated that mango kernel fat is of edible quality without adverse effects.[15] However, the nutritional and possible health benefits of mango kernel fat are yet to be realized because mango kernels have not been exploited to their full potential and are often under-utilized materials.[16]

Pakistan, with a production of around 1.8 Million tons of the fruit, is the 6th largest mango producer in the world. The mango production in Pakistan is mainly from two provinces—Punjab and Sindh—contributing 99.7% of the total mangoes produced every year. Among various Pakistani mango varieties, the most dominant are Safed Chaunsa, Sindhri, Langra, Anwar Ratul, Fajri, Dasehri, and Laal Badshah. As a result of large-scale mango consumption and utilization, a large quantity of mango kernels is yielded on an annual basis and has the potential to be used for value addition.[17]

To the best of our knowledge, no detailed studies have been reported earlier on the fatty acid composition and antioxidant attributes of mango kernel oils from the selected mango varieties of Pakistan. Keeping in view the nutritional, functional food, and nutra-pharmaceutical potentials of mango kernels, in the present work, a comprehensive study is planned to appraise the oil yield from kernels of selected Pakistani mango varieties and evaluate the physicochemical properties, fatty acid compositions, and antioxidant attributes of extracted mango kernel oils.

2. EXPERIMENTAL DETAILS

2.1. Materials. Fruit samples of selected mango varieties, namely (a) Laal Badshah, (b) Sindhri, (c) Safed Chaunsa, (d) Dasehri, (e) Langra, (f) Fajri, and (g) Anwar Ratul (Figure 1), were obtained in the summer season (May–July 2018) from the local fruit market of Sargodha, Punjab, Pakistan. For each mango variety, three different samples (3 kg from each source) were purchased and then pooled. The selected mango varieties were further authenticated by a Taxonomist, Professor Dr. Kafeel Ahmad (Department of Botany, University of Sargodha, Sargodha), and voucher samples were matched with those available at the Mango Research Institute, Shuja Abad, Multan, Punjab. All of the mange samples were peeled, and then the pulp was separated, thus obtaining the seeds. The kernels from each variety were obtained by cracking the sun-dried seeds and were further ground into a fine powder with a domestic grinder and put through a sieve to obtain a particle size of about 2–5 mm to extract oil through a Soxhlet. All chemicals (analytical grade) utilized in experiments were procured from Sigma-Aldrich Chemical Corporation, Germany.

2.2. Extraction of Mango Kernel Oil (MKO). The oil extraction was performed using the Soxhlet extraction apparatus with *n*-hexane solvent as described by Kittiphoom (2012).[10]

2.3. Determination of Physicochemical Properties. The physicochemical characteristics (saponification value (mg KOH/g), refractive index, iodine no. (g/100 g), P.V. (meq/kg), % acid value, free fatty acid (mg/g), % unsaponifiable matter, and color) of MKO were determined according to various standard AOCS methods.[13]

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2.4. Fatty Acid Analysis of MKO by GC-TIC-MS. The extracted MKOs from different mango varieties were analyzed to evaluate the fatty acids by gas chromatography coupled with mass spectrometry. The samples were trans-esterified to convert fatty acids into their respective fatty acid methyl esters (FAMEs). In brief, 100 mg of MKO was taken in a vial, then 1.90 mL of *n*-hexane was added and shaken vigorously to dissolve the MKO, and 0.1 mL of sodium methoxide was also added to each variety and again shaken. The mixture was divided into two clear layers. After some time, the upper layer of each sample containing the fatty acid methyl ester was transferred into a separate vial for fatty acid analysis.[18] FAMEs were analyzed using the "Thermo Scientific (DSQII, GC-MS)" system. The machine was equipped with a TR-5MS capillary column of length 30 m and an internal diameter of 0.25 mm (film thickness, 0.25 μm). The carrier gas used was helium, and the flow rate was 1 mL/min. The injector temperature with split mode was 250 °C. A sample volume of 1 μL was injected into the column with the initial temperature of the oven set to 50 °C and held for 2 min; then, the temperature was increased up to 150 °C at a rate of 08 °C/min and further increased to 300 °C at a rate of 15 °C/min and finally held for 5 min.

GC/MS was performed in electron ionization (EI) mode (possessing an ionization energy of 70 eV) for detection. While the injector and MS transfer line were set at 300 and 310 °C, respectively, the mass scanning range varied over 50−550 m/z. The separated FAMEs were identified based on matching retention times (RTs) of the unknowns with those of the standards and further authenticated by comparing their mass spectra with those given in the NIST mass spectral library of the GC/MS system. The individual FA content (%) is given as a relative percentage of the total peak area.[18]

2.5. Evaluation of Antioxidant Activity of MKOs. For subject purposes, antioxidant components were initially extracted from the MKOs and then evaluated for antioxidant potential following two *in vitro* assays.

2.5.1. Extraction of Antioxidants. Antioxidant components were extracted from MKOs by using aqueous methanol ($MeOH/H_2O$, 80:20 v/v) as described in our previous study.[19]

2.5.2. Determination of Total Phenolic Content. The total phenol content (TPC) of the MKO was estimated by the Folin−Ciocalteu assay, as described by Latif and Anwar (2011)[19] with slight modifications. The calibration curve was constructed by using different concentrations of gallic acid as the standard reference. The absorbances of tested samples and standard (gallic acid) solutions were recorded at 765 nm using a spectrophotometer (CECIL CE 7200). The amount of TPC was calculated by gallic acid calibration within the range of 10−200 ppm (R^2 = 0.9983). The TPC was expressed in gallic acid equivalents (GAE) mg/g of oil.

2.5.3. DPPH Scavenging Activity Assay. The antioxidant activity of MKO toward scavenging the α,α diphenyl-β-picrylhydrazyl radical (DPPH$^\bullet$) was assessed colorimetrically[19] with slight modifications. The absorbance was measured at 517. Butylated hydroxyl anisole (BHA) values were measured as the positive control, while a blank solution was employed as the negative control. IC_{50}, the concentration of extract that scavenged/neutralized 50% of DPPH free radicals, was calculated using the following formula

$$\%\ \text{scavenging activity} = (\text{absorbance}_{\text{control}} - \text{absorbance}_{\text{oil extract}}) / \text{absorbance}_{\text{control}} \times 100$$

Absorbance $_{\text{control}}$ = absorbance of all reagents except the sample

2.6. Statistical Analysis. Data were expressed as mean values ± standard deviation (SD) for triplicate experiments. Analysis of variance (1-way ANOVA) was performed to analyze significant differences of means among the selected mango varieties at $p < 0.05$. All statistical analyses were evaluated in SPPS software version 22.0.0.0.

3. RESULTS AND DISCUSSION

3.1. Yield of Mango Kernel Oils (MKOs). The % extraction yield of mango kernel oils from seven varieties of mangoes and their physical states are shown in Table 1. The yield of oil from different mango kernels varied over the range of 6.33−9.88% (g/100 g of DW). The maximum yield (9.88%) was obtained for Dasehri, while the minimum (6.33%) was obtained for Sindhri. The order of % yield of samples varied as follows: Dasehri > Anwar Ratul > Safed Chaunsa > Langra > Fajri > Laal Badshah > Sindhri. The differences in oil yields may be due to differences in the genetic makeup, ripening stage, and harvesting times of the selected mango varieties.[20−23]

Table 1. Oil Yields (g/100g DW) from Kernels of the Selected Varieties of Mangoes[a]

mango variety	oil yield (g/100g DW)	physical state	color
Anwar Ratul	8.65 ± 0.14^c	solid	30Y+2.8R
Dasehri	9.88 ± 0.11^d	semiliquid	30Y+10R
Fajri	6.75 ± 0.03^a	solid	16Y+1.7R
Laal Badshah	6.54 ± 0.03^a	solid	28Y+2.5R
Langra	8.00 ± 0.20^b	solid	30Y+2.8R
Safed Chaunsa	8.23 ± 0.10^b	solid	17Y+1.7R
Sindhri	6.33 ± 0.11^a	solid	28Y+2.8R

[a]Values are means ± SD (n = 3). Different superscripts within the same column show significant differences in mean values among the selected mango varieties.

The present MKO yields are in good agreement with those of some mango varieties studied previously in the literature (10.61−6.39 g/100 g)[7,13,24,25] but less than those of other reported mango varieties (19.6−7.6 g/100 g).[12,15,26,28] In comparison with some other commercial oils, the MKO yield is less than those of palm oil (30.2%), hemp seed oil (32.4%), and soya bean oil (21.4%).[29−31] However, considering the fact that MKOs are derived from under-utilized waste material, the low yield may be acceptable as the seeds are abundantly available for use at almost no cost;[28] therefore, the mango seed kernel has considerable potential as a source of oil in the vegetable oil industry. The color of MKOs, as determined by a tint meter, in terms of yellow and red units, is quite acceptable as far as edible and industrial applications are concerned.

3.2. Physicochemical Properties of MKOs. The physicochemical properties of MKOs from seven varieties of mangoes are shown in Table 2.

Saponification values of MKOs ranged from 143.00 to 207.10 (mg KOH/g). The highest value was obtained for Safed Chaunsa (207.30 ± 0.10 mg KOH/g) and the lowest for

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Table 2. Physicochemical Properties of MKOs from the Selected Varieties of Mangoes[a]

mango variety	saponification value (mg KOH/g)	refractive index	iodine no. (g/100 g)	P.V (meq/kg)	acid value (%)	free fatty acid (mg/g)	unsaponifiable matter (%)
Anwar Ratul	181.00 ± 2.00^{b}	1.449 ± 0.002^{b}	32.70 ± 0.30^{c}	4.30 ± 0.10^{c}	7.70 ± 0.30^{e}	3.90 ± 0.10^{e}	1.60 ± 0.10^{a}
Dasehri	191.17 ± 4.01^{c}	1.443 ± 0.003^{a}	36.00 ± 1.00^{d}	5.50 ± 0.20^{d}	6.40 ± 0.60^{d}	3.20 ± 0.80^{d}	2.10 ± 0.20^{b}
Fajri	198.30 ± 5.02^{c}	1.457 ± 0.003^{b}	28.00 ± 1.00^{a}	2.00 ± 0.00^{a}	1.00 ± 0.00^{a}	0.50 ± 0.00^{a}	1.40 ± 0.20^{a}
Laal Badshah	143.0 ± 2.00^{a}	1.451 ± 0.001^{b}	33.00 ± 1.00^{c}	3.50 ± 0.50^{b}	2.60 ± 0.40^{b}	1.30 ± 0.30^{c}	3.30 ± 0.20^{c}
Langra	195.67 ± 1.52^{c}	1.456 ± 0.004^{b}	30.70 ± 0.70^{b}	3.00 ± 0.30^{b}	5.40 ± 0.60^{c}	2.70 ± 0.20^{d}	1.70 ± 0.50^{a}
Safed Chaunsa	207.10 ± 1.01^{d}	1.453 ± 0.003^{b}	30.50 ± 0.50^{b}	3.00 ± 0.20^{b}	1.60 ± 0.40^{a}	0.80 ± 0.20^{b}	1.20 ± 0.10^{a}
Sindhri	190.13 ± 5.00^{c}	1.454 ± 0.001^{b}	29.50 ± 0.20^{b}	2.67 ± 0.76^{b}	5.80 ± 0.40^{c}	2.90 ± 0.20^{d}	1.60 ± 0.00^{a}

[a]Values are means ± SD (n = 3). Different superscripts within the same column show significant differences in mean values among the selected mango varieties.

Laal Badshah (143.00 ± 0.20 mg KOH/g). Saponification values of MKOs from different mango varieties in increasing order are as follows: Safed Chaunsa > Fajri > Langra > Dasehri > Sindhri > Anwar Ratul > Laal Badshah. Higher saponification values of the tested MKOs suggest that these oils can be useful in the cosmetic industry (liquid soaps, shampoos, and lather shaving creams)[15,25] and for bioresin production.[28] The present values of MKOs are also quite comparable to those of other oils and butter that are usually used for industrial purposes, such as shea butter (178−193), cocoa butter (188−200), peanut oil (187−196), cottonseed oil (189−198), and colza seed oil (168−181). These results are also comparable to values reported for Sudanese, Malaysian, Iranian, Cote d'Ivoire, Saudi, and Bangladeshi mangoes[13,15,18,23,27,32] but higher than those reported for Nigerian, Kenyan, and Thai mangoes.[7,25,33]

The refractive index (RI) increases with the unsaturation or with the presence of secondary functional groups on the fatty chains. The refractive index value of MKOs is the highest for Dasehri (1.457 ± 0.003) and the lowest for Fajri (1.443 ± 0.000). The RI values were found to be in the order of Fajri > Langra > Safed Chaunsa.> Laal Badshah > Anwar Ratul > Dasehri. These values are comparable to those of other vegetable oils and fats[34] such as cocoa butter (1.455−1.458), palm oil (1.454−1.456), cottonseed oil (1.458−1.466), and shea butter (1.463−1.468).

In the present research work, the iodine value (IV) of MKOs tested varied from 28.00 to 36.00 g/100 g. The differences in iodine values of MKOs among various varieties may be due to the variations in the fatty acid composition depending upon the genetic makeup of the samples. Fajri had the lowest IV (28.00 ± 1.00 g/100 g), while Dasehri showed the highest value (36.00 ± 1.00 g/100 g). The iodine value of MKOs for different mango varieties was in the order of Dasehri > Laal Badshah > Anwar Ratul > Langra > Safed Chaunsa > Sindhri > Fajri. Low iodine values of the MKOs reflect their higher resistance to oxidation and longer shelf-life. The lower iodine values of MKOs also indicate that these oils may be used in the manufacture of biodegradable hydraulic fluids, lubricants, soaps, leather, dressings, cosmetics, and in the candle industry.[32,35] The present IV values of MKOs are quite comparable to those reported for Thai mangoes[33] but less than those of Nigerian, Malaysian, Saudi, Bangladeshi, Iranian, and Cote d'Ivoire mangoes.[13,15,18,25,27,28,32] Also, MKOs have lower iodine values (g/100 g) than shea butter (57−66), cottonseed oil (100−105), palm oil (50−55), and cocoa butter (33−42).[34]

Peroxide values of MKOs from the selected mango varieties were in the range of 2.00−5.50 meq/kg, with the least value for Fajri (2.00 ± 0.0 Meq/kg) and the highest for Dasehri (5.50 ± 0.20 Meq/kg). The P.V. values of MKOs from the selected mango varieties were found to be in the order of Dasehri > Anwar Ratul > Laal Badshah > Langra > Safed Chaunsa > Sindhri > Fajri. Lower P.V. values indicate the stability and good quality of MKOs. Vegetable oils with low peroxide content[34] can be considered fit for edible purposes. Peroxide values of MKOs for the selected varieties are in line with the values reported for Nigerian and Cote d'Ivoire mango cultivars,[13,25] but higher than those reported for Ire, Iranian, Kenyan, Saudi, and Bangladeshi mango varieties[7,15,27,32,35] and lower than those of Thai mangoes.[33]

Free fatty acid values of the tested MKOs ranged from 0.50 to 3.9 mg/g, while the % acid values ranged from 1.00 to 7.70, with the highest values observed for Anwar Ratul and the lowest for Fajri. Free fatty acid values were in the order of Anwar Ratul > Dasehri > Sindhri > Langra > Laal Badshah > Safed Chaunsa > Fajri. The higher acid value of MKOs of the Anwar Ratul variety indicated a somewhat higher magnitude of hydrolysis as primary oxidation products are produced due to hydrolysis. Free fatty acids values in the present analysis of MKOs are similar to those of different mango varieties of Nigeria and Kenya reported in the literature.[7,25,28] It can be noted that values for both parameters are slightly higher than those reported for Sudanese and Thai mangoes.[23,33] Overall, a relatively lower acidity of MKOs indicates that they are quite resistant to the rancidity caused by lipases and/or chemical hydrolysis so that these can be used for various industrial applications without further neutralization.[15] The present acidity values of MKOs are comparable to those of cocoa butter, tallow butter, palm oil, hemp oil, and soya bean oil.[30]

The unsaponifiable matter of the MKOs tested ranged from 1.20 to 3.30%, with the highest values observed for Laal Badshah (3.30 ± 0.30%), while Safed Chaunsa showed the lowest value (1.20 ± 0.10%). These values are comparable to the values reported for Nigerian[25] and Iranian mangoes.[15] However, present values of unsaponifiable matter are lower than those reported for Indian mangoes.[36] The unsaponifiable matter in oil or fat comprises components that could not be saponified and can be used to indicate and assess the magnitude of minor components such as tocopherols, phytosterols, coloring pigments, and other nonlipidic fractions.[37]

3.3. Fatty Acid Composition of MKOs. The results of the GC-TIC-MS analysis show the presence of a total of 15 fatty acids in the tested MKOs, namely, myristic acid (C14:0), pentadecylic acid (C15:0), palmitoleic acid (C16:1), palmitic acid (C16:0), margaric acid (17:0), linoleic acid (18:2), oleic acid (18:1), stearic acid (18:0), isostearic acid (C18), ricinoleic acid (12-OH C18:1), arachidic acid (C20:0), behenic acid

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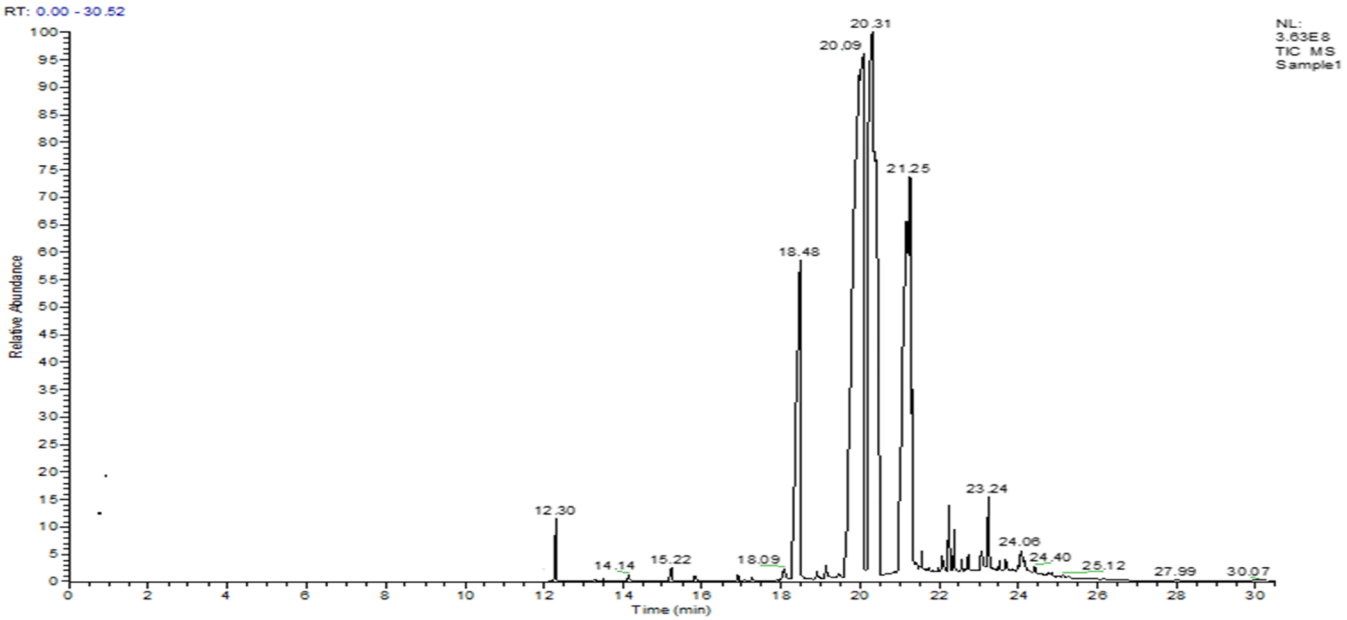

Figure 2. GC-TIC-MS chromatogram showing the presence of fatty acids in Fajri kernel oil.

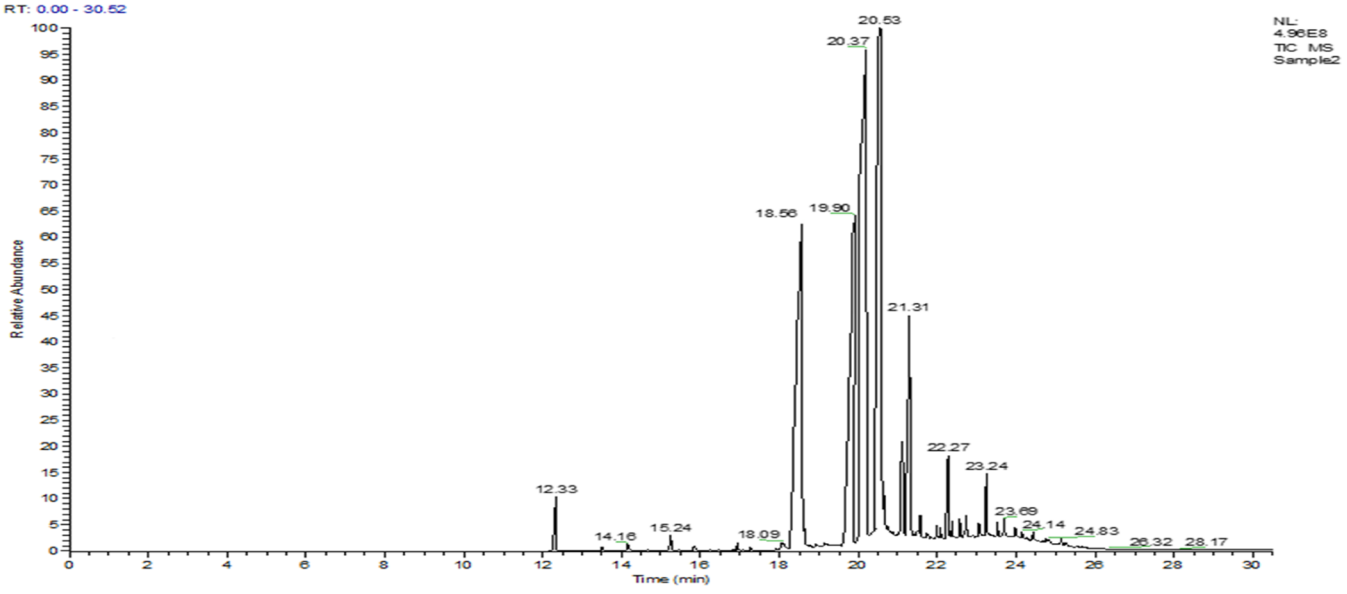

Figure 3. GC-TIC-MS chromatogram showing the presence of fatty acids in Safed Chaunsa kernel oil.

(C22:0), tricosylic acid (C23:0), lignoceric acid (C24:0), and hyenic acid (C25:0) (Figures 2−8). The fatty acid composition varied significantly among MKOs of selected varieties. The total % composition of saturated fatty acids (TSFAs) of MKOs ranged from 41.92 to 52.86, with the highest value for Fajri and the lowest for Dasehri. Their values vary in the order Sindhri > Fajri > Langra > Safed Chaunsa > Laal Badshah > Anwar Ratul > Dasehri. Total unsaturated fatty acids (TUSFAs) are in the range of 58.08−47.14%, with the lowest values for Sindhri and the highest for Dasehri, and their order was Dasehri > Anwar Ratul > Laal Badshah > Safed Chaunsa > Langra > Fajri > Sindhri. Dasehri has the highest unsaturated fatty acid content (58.24%), which explains its liquid appearance at room temperature (Table 1,3). Among unsaturated fatty acids, the content of monounsaturated fatty acids (MUSFAs) varied from 39.59 to 48.61% and that of total polyunsaturated fatty acids (TPUFAs) were in the range of 16.47−7.72%.

In the present analysis of MKOs, oleic acid (48.57−25.69), stearic acid (38.53−24.71), linoleic acid (16.47−7.72), palmitic acid (13.26−10.00), arachidic acid (5.43−3.74), myristic acid (4.63−0.05), lignoceric acid (1.55−0.72), and behenic acid (1.11−0.19) were the dominant fatty acids with respect to percentage composition (Figures 2−8). Among these, stearic C18:0, oleic C18:1, and linoleic C18:2 were the main fatty acids, and their contents were the highest in Fajri, Langra, and Dasehri and the lowest in Dasehri, Fajri, and Safed Chaunsa, respectively. The tested MKOs contained a considerable amount of one of the essential fatty acids, namely, C18:2, which cannot be synthesized by the human body and needs to be provided by the diet. The differences in fatty acids among MKOs in these varieties may be mainly

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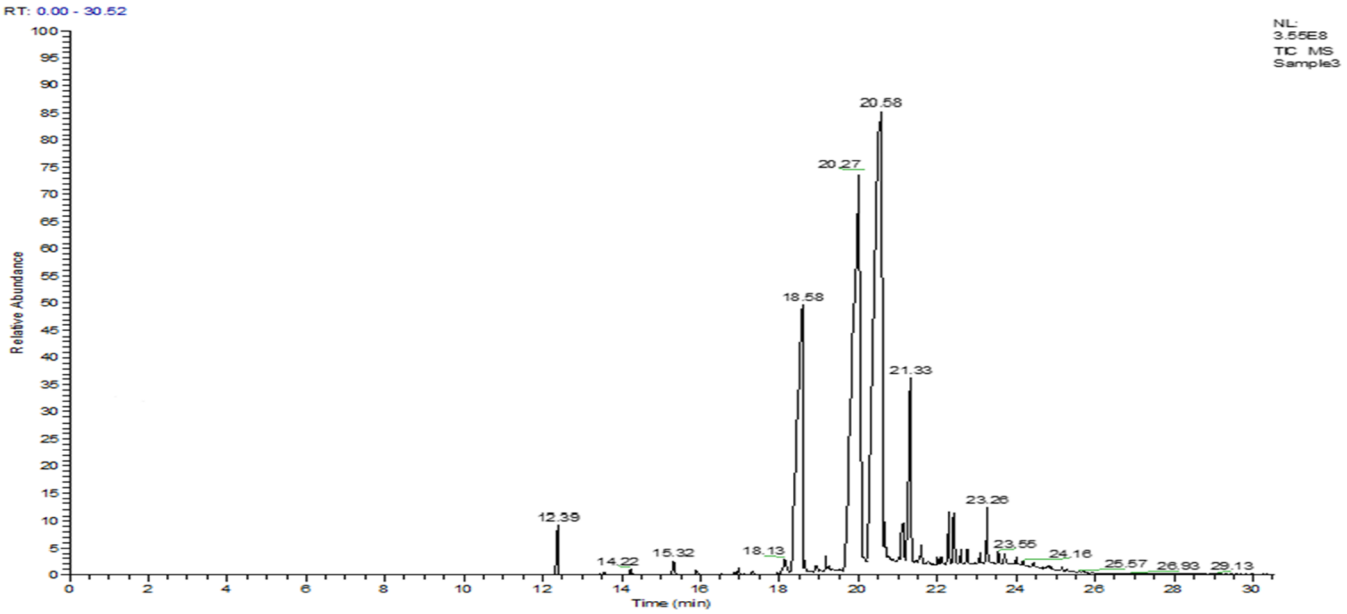

Figure 4. GC-TIC-MS showing the presence of fatty acids in Laal Badshah kernel oil.

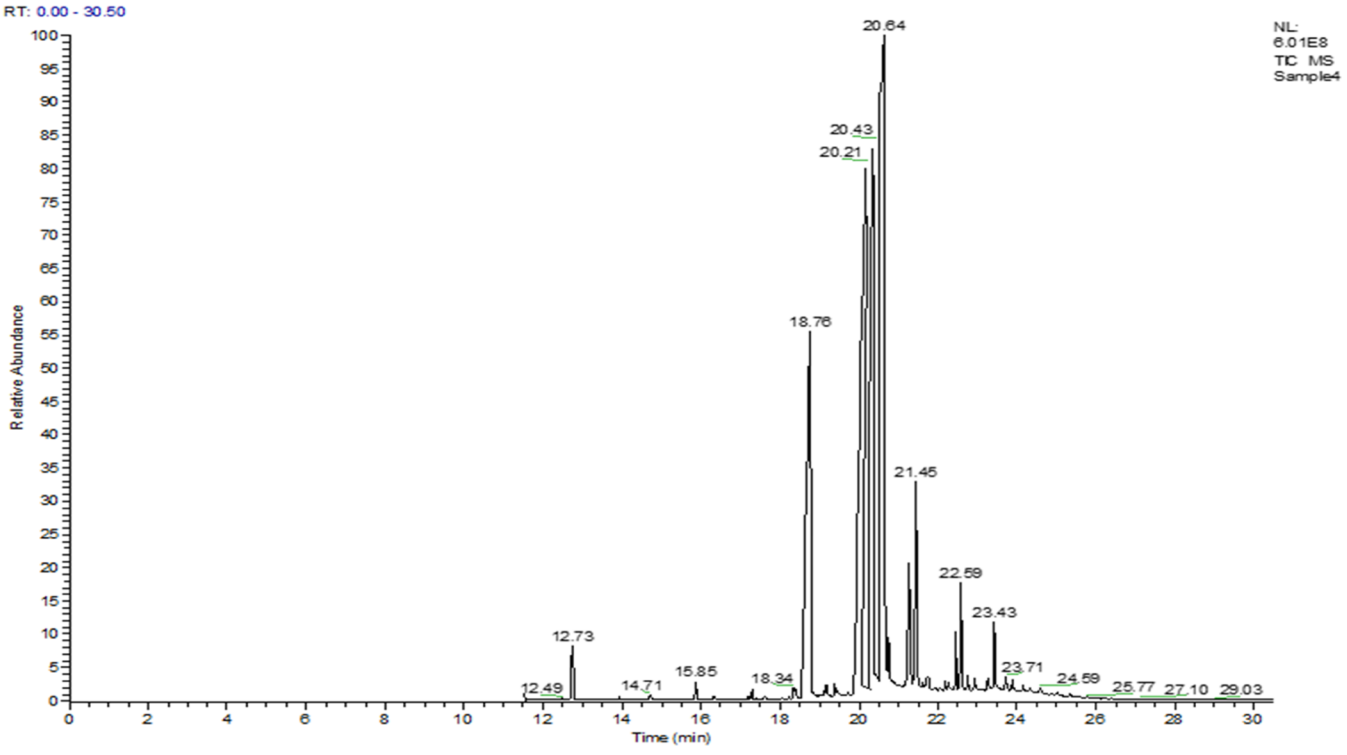

Figure 5. GC-TIC-MS chromatogram showing the presence of fatty acids in Dasehri kernel oil

linked to differences in the genotypes, agroclimatic and harvesting conditions, and harvesting times of the mangoes.[23]

The amounts of major fatty acids in MKOs determined in this study were in close agreement with those of six Malaysian varieties[18] and were also comparable to fatty acid values reported for Indian[36] and four Kenyan varieties. Gaydou and Bouchet,[38] Muchiri et al.,[7] and Jahurul et al.[18] also reported these fatty acids in different mango varieties, with their results very close to the data of the present study. The presence of some important fatty acids, especially C18:1 and C18:2, makes MKOs fit for edible purposes as well as for industrial applications such as the manufacture of candles, soaps, detergents, cosmetics, shaving soaps, lubricants, and pharmaceuticals. In addition to their utilization for food purposes, these oils can also be good for biodiesel production.[25]

3.4. Evaluation of the Antioxidant Activity. The antioxidant activity of MKOs was evaluated in terms of their TPC and DPPH radical scavenging activity.

3.4.1. Determination of the Total Phenolic Content (TPC). The total phenolics determined for MKOs of various varieties are shown in Table 4.

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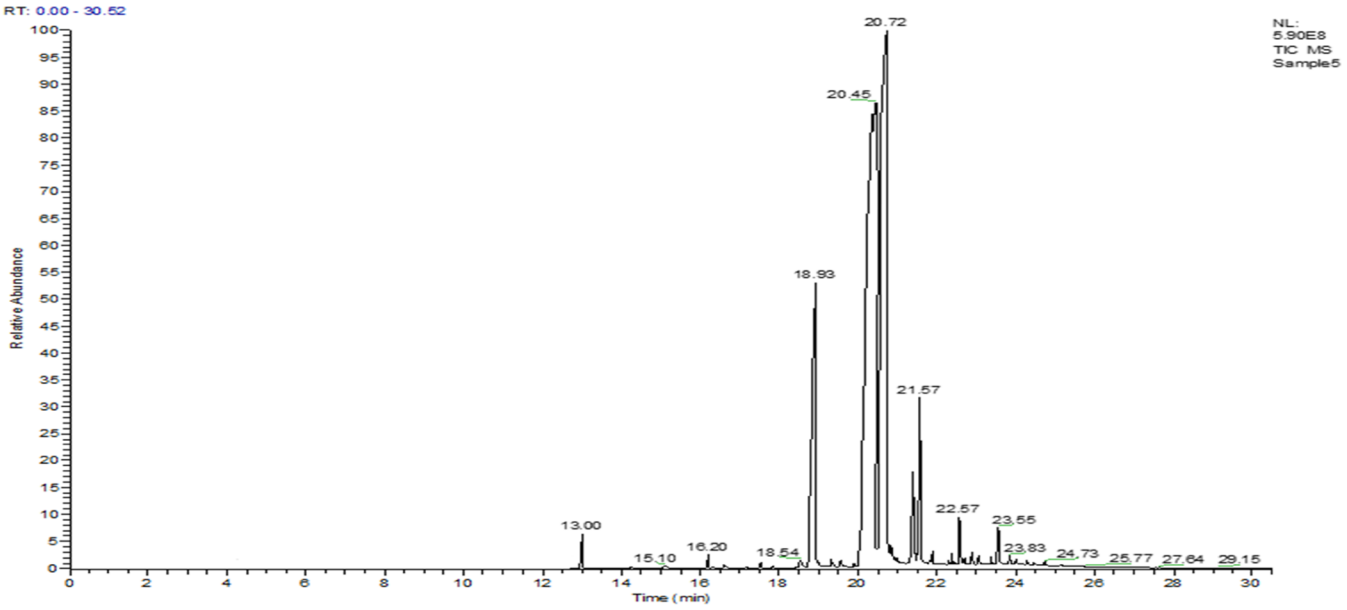

Figure 6. GC-TIC-MS chromatogram showing the presence of fatty acids in Sindhri kernel oil.

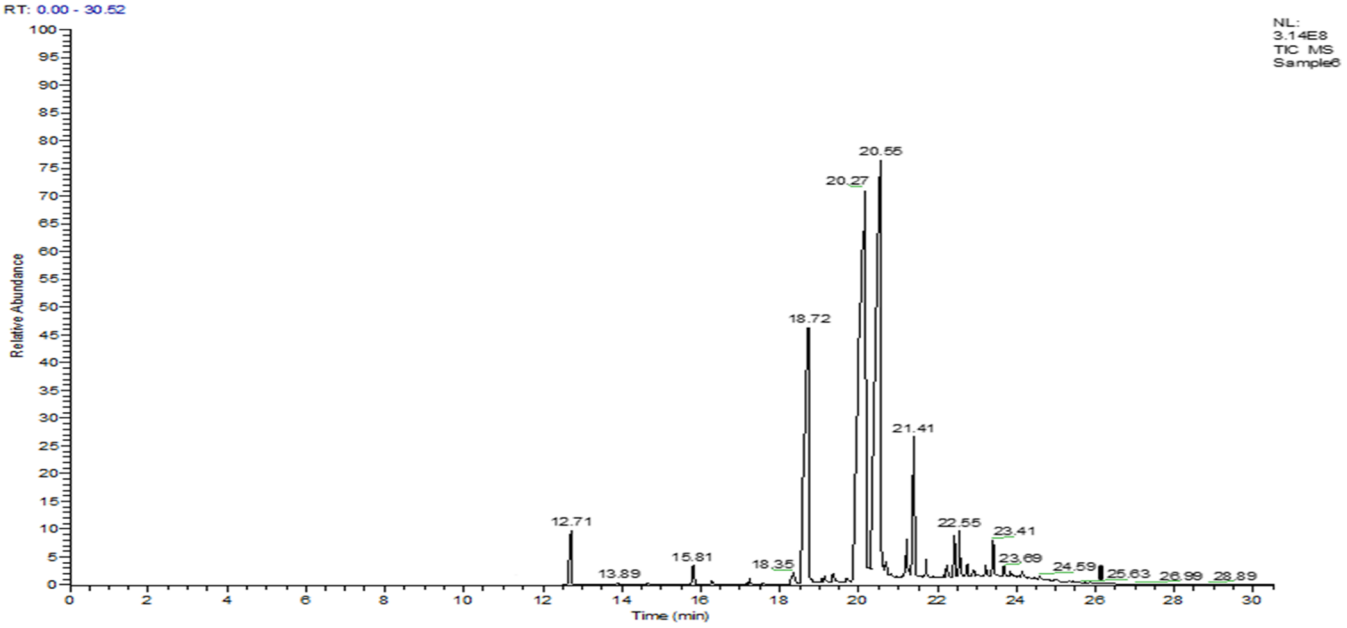

Figure 7. GC-TIC-MS chromatogram showing the presence of fatty acids in Langra kernel oil.

Determination of TPC is a widely accepted method to estimate antioxidant activity due to its easiness, reproducibility,[19] and the good correlation between TPC and antioxidant activity. Total phenolic contents for MKOs of the seven mango varieties ranged from 70.03 to 110.00 (mg GAE/g oil). Among the varieties, the lowest TPC was noted for Dasehri (7.03 mg GAE/g), while the highest values were obtained for Safed Chaunsa (11.00 mg GAE/g). The TPCs (mg GAE/g) of MKOs of different varieties were as follows: Dasehri (7.03) < Anwar Ratul (8.25) < Laal Badshah (8.69) < Fajri (9.11) < Langra (9.99) < Sindhri (10.51) < Safed Chaunsa (11.00). The present results show that the TPC varied significantly ($p < 0.05$) among the tested varieties. The TPCs determined in the present study were found to be quite comparable to the values reported for MKO by Kittiphoom and Sutasinee (2013)[33] and Nadeem et al.[39]

3.4.2. DPPH Scavenging Activity Assay. The DPPH radical scavenging assay is another highly accepted method commonly used to assess the free radical scavenging activity of plant materials. The DPPH scavenging activity (in terms of IC_{50} values) of MKOs of various varieties ranged from 4.33 to 8.32 mg/mL (Table 3). The highest value was noted for the MKO of Dasehri (8.32 mg/mL), while the lowest value was noted for the MKO of Safed Chaunsa (4.33 mg/mL). IC_{50} (mg/mL) values for different varieties of MKOs were as follows: Safed Chaunsa (4.33), Sindhri (5.26), Langra (6.33), Fajri (6.76), (Fajri), Laal Badshah (7.67), Anwar Ratul (7.98), and Dasehri (8.32). The ability of MKOs to scavenge free radicals varied significantly ($p < 0.05$) in relation to different varieties. Moreover, a lower IC_{50} value indicates a higher scavenging ability and so high antioxidant activity. On the basis of varieties, the free radical scavenging order was as follows: Safed

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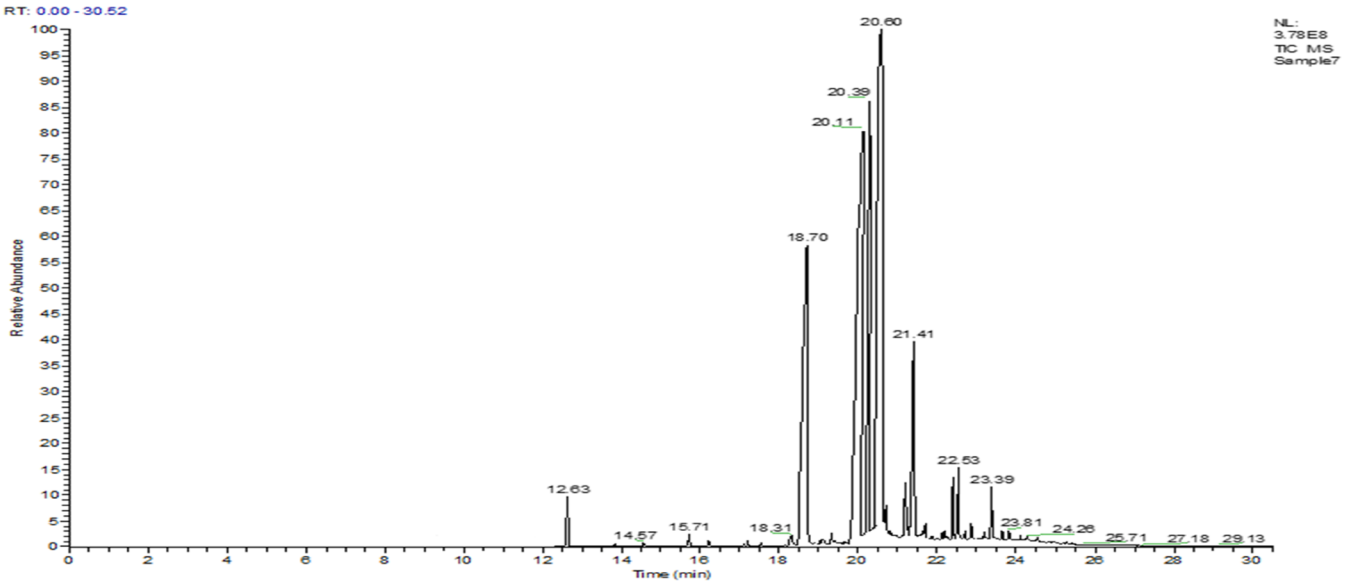

Figure 8. GC-TIC-MS chromatogram showing the presence of fatty acids in Anwar Ratul kernel oil.

Table 3. Fatty Acid Composition (%) of MKOs from the Selected Varieties of Mangoes

mango variety			Anwar Ratul	Dasehri	Fajri	Laal Badshah	Langra	Safed Chaunsa	Sindhri
name of fatty acid	abbreviation	RT	(%)	(%)	(%)	(%)	(%)	(%)	(%)
myristic acid	C:14:0	16.14	0.10	0.05	0.09	0.06	0.08	0.06	4.63
pentadecylic acid	C:15:0	17.48	0.04	0.03	0.05	0.03	0.02	0.04	0.03
palmitoleic acid	9cc:16:1	18.13		0.23				0.01	
palmitic acid	C:16:0	18.68	12.12	10.82	10.00	12.67	11.92	13.26	10.41
margaric acid	C:17:0	19.29	0.22	0.24	0.17	0.31	0.20	0.22	0.15
linoleic acid	9c12c-18:2	20.13	13.44	16.47		11.87		7.72	
oleic acid	9cc:18:1	20.28	40.31	41.18	25.69	39.58	48.57	42.48	47.14
stearic acid	C:18:0	20.56	26.88	24.71	38.53	27.71	34.09	27.03	31.42
isostearic acid	16-Me-C:17:0	20.69			0.04		0.03	0.16	
ricinoleic acid	12-OH,9c-18:1	21.25			21.81				
arachidic acid	C:20:0	21.41	5.02	4.81		4.94	3.74	5.43	4.80
behenic acid	C:22:0	22.31		0.19	1.11	0.63		0.96	0.58
tricosylic acid	C:23:0	22.85	0.23		0.33			0.57	0.12
lignoceric acid	C:24:0	23.22	1.40	1.27	1.55	1.32	1.34	1.31	0.72
hyenic acid	C:25:0	23.72	0.25		0.64	0.88		0.76	
saturated fats	TSFAs		46.25	41.92	52.50	48.54	51.39	50.42	52.86
unsaturated fats	TMUFAs		40.51	41.61	47.50	39.59	48.61	41.86	47.14
	TPUFAS		13.44	16.47		11.87		7.72	
	TUFAs		53.75	58.08	47.50	51.46	48.61	49.58	47.14

Table 4. TPC and DPPH Scavenging Potential (IC_{50}) of MKOs from the Selected Varieties of Mangoes[a]

variety	TPC (mg GAE/g)	DPPH (IC_{50} mg/mL)
ascorbic acid		3.27 ± 0.56*
Anwar Ratul	8.25 ± 02.76^{b}	7.98 ± 0.20^{d,e}
Dasehri	7.03 ± 0.67^{a}	8.32 ± 0.20^{e}
Fajri	9.11 ± 01.15^{bc}	6.76 ± 0.10^{c}
Laal Badshah	8.69 ± 0.62^{d}	7.67 ± 0.10^{d}
Langra	9.99 ± 01.00^{d}	6.33 ± 0.02^{c}
Safed Chaunsa	11.00 ± 4.45^{f}	4.33 ± 0.08^{a}
Sindhri	10.51 ± 05.00^{e}	5.26 ± 0.67^{b}

[a]Values are means ± SD (n = 3). Different superscripts within the same column show significant differences in mean values among the selected mango varieties. * Ascorbic acid is used as the reference standard for DPPH.

Chaunsa > Sindhri > Langra > Fajri > Laal Badshah > Anwar Ratul > Dasehri.

3.4.3. Correlation between the TPC and the Results of the DPPH Assay. The DPPH radical scavenging activity of the MKOs tested in this study can be related to a high TPC in these samples. In the present analysis, a high correlation coefficient value (R^2 = 0.9127) depicts a strong direct relationship between the results of these two assays. Literature reports also reveal that phenolic compounds are strong scavengers of free radicals, and this is evident from the very good correlation between these two assays.[19,40,41]

4. CONCLUSIONS

The findings of the current study showed considerable variations in the physicochemical properties, antioxidant attributes, and fatty acid compositions of MKOs of the seven

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selected varieties of Pakistani mangoes. Among physicochemical properties, Safed Chaunsa has a relatively high extraction yield, saponification value, and unsaponifiable material, whereas Fajri has low iodine, peroxide, refractive index, % acid, and free fatty acids values. In the case of % fatty acid composition, Dasehri has a higher level of unsaturated fatty acids, while Sindhri has higher contents of saturated fatty acids. With regard to the antioxidant potential, in terms of the TPC and DPPH radical scavenging activity, the MKO of Safed Chaunsa is superior to others. Most of the studied properties and attributes of MKOs have shown significant variations ($p < 0.05$) among the selected mango varieties. These variations can be linked and attributed to differences in the agroclimatic conditions, harvesting time, and genetic makeup of varieties. Technically acceptable physicochemical properties, a high oleic oriented fatty acid composition, good stability, and high antioxidant value support the potential applications of the tested MKOs for edible purposes, in cosmetics, in the nutra-pharmaceutical industry, as well as in the manufacture of biodegradable hydraulic fluids, lubricants, leather, dressings, and candle, with the perspective of value addition.

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Notes

The authors declare no competing financial interest.

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