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Physico-Chemical Characterization of *Moringa concanensis* Seeds and Seed Oil

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Abstract The present work reports the characterization and comparison of *Moringa concanensis* seed oil from Tharparkar (a drought hit area), Pakistan. The hexane-extracted oil content of *M. concanensis* seeds ranged from 37.56 to 40.06% (average 38.82%). Protein, fiber, moisture and ash contents were found to be 30.07, 6.00, 5.88 and 9.00%, respectively. The extracted oil exhibited an iodine value of 67.00; a refractive index (40 °C) of 1.4648; its density (24 °C) was 0.8660 mg mL^{-1}; the saponification value (mg of KOH g^{-1} of oil) was 179.00; unsaponifiable matter 0.78%; color (1 in. cell) 1.90R + 19.00Y; and acidity (% as oleic acid) 0.34%. Tocopherols (α, γ, and δ) in the oil accounted for 72.11, 9.26 and 33.87 mg kg^{-1}, respectively. Specific extinctions at 232 and 270 nm were 3.17 and 0.65, respectively. The peroxide and *p*-anisidine values of the oil were found to be 1.75 and 1.84 meq kg^{-1}, respectively. The induction periods (Rancimat, 20 L h^{-1}, 120 °C) of the crude oil was 10.81 h and reduced to 8.90 h after degumming. The *M. concanensis* oil was found to contain high levels of oleic acid (up to 68.00%) followed by palmitic, stearic, behenic, and arachidic acids up to levels of 11.04, 3.58, 3.44 and 7.09%, respectively. The results of the present analytical study, compared with those for other *Moringa* species and different vegetable oils, showed *M. concanensis* to be a potentially valuable non-conventional seed crop for high quality oil.

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Introduction

The plant family Moringaceae consists of 12–14 species belonging to only one genus, *Moringa* [1, 2]. Almost all *Moringa* species are native to India, from where they have been introduced into several countries of the tropics [2, 3].

Moringa is an important food commodity as all plant parts such as leaves, flowers, fruits, and immature pods can be used as a highly nutritive vegetable. These are commonly consumed in India, Pakistan, Philippines, Thailand, Hawaii, and many parts of Africa [3, 4]. The leaves are of highly nutritious, rich in vitamins A and C and act as a good source of natural antioxidants [4, 5]. In addition, *Moringa* is believed to have multiple medicinal qualities. For example, the barks, roots, leaves and flowers of *Moringa* tree are used in traditional medicine and folk remedies in many countries [5–7]. The seeds of *Moringa* are one of the best natural coagulants, possess antimicrobial properties and are also effectively utilized for treatment and purification of highly turbid water [5, 8]. The seeds also contain high quality oil that can be used in cooking, cosmetics and lubrication [2, 3].

In Pakistan, *Moringa* is represented by only two species: *M. oleifera* and *M. concanensis*. The former species locally known as ''Sohanjna'' is generally cultivated in the Punjab plains, Sindh, Baluchistan, and in the North Western Frontier Province (N.W.F.P). The latter species, *M. concanensis* is not common and perhaps limited to only a remote locality (Tharparkar), Sindh. It occurs in tropical dry

forests from South Eastern Pakistan almost to the Southern tip of India [9, 10].

Moringa concanensis is a small tree with thick bark, glabrous, except younger parts and inflorescence. Leaves are bipinnate (very rarely tripinnate), ca. 45 cm long. Pods are linear, 30–45 cm long, sharply three-angled. The horseradish odour of *M. concanensis* is more intense than *M. oleifera. M. concanensis* has a strong central trunk that is covered with an extremely distinctive layer of very furrowed bark that can be more than 15 cm thick. The flowers also have distinctive yellow petals, with red or pink veins [9].

The seed fats of some of the *Moringa* species such as *M. oleifera*, *M. peregrina*, *M. stenopetala* have been studied for their chemical composition and characteristics [2, 3, 11], however, the *M. concanensis* species native to the sub-continental region or elsewhere has not yet been characterized, primarily for its oil. The main objective of the present work was to characterize the physico-chemical characteristics of *M. concanensis* seeds and seed oil from plants indigenous to Tharparkar, Pakistan. Characteristics of the oil extracted from *M. concanensis* seeds were also compared with those of other *Moringa* species, which includes the *M. stenopetala, M. peregrina* and *M. oleifera*.

Materials and Methods

Moringa Concanensis Seeds

Three different seed samples of *M. concanensis* were harvested from five regions (Mithi, Nagarparkar, Diplo, Chachro, Digri) of Tharparker, Sindh, Pakistan. The seeds were triangular, white or pale yellow, with an average seed weight of 0.08 g. The kernel accounted for 70.00–81.00% of the seed dry weight.

Reagents and Standards

All reagents (analytical and HPLC) used were from Merck (Darmstadt, Germany) or Sigma Aldrich (Buchs, Switzerland). Pure standards of tocopherols [DL-α-tocopherol, (+)-δ-tocopherol, (+)-γ-tocopherol], and fatty acid methyl esters (FAMEs) were obtained from the Sigma Chemical Co. (St Louis, MO).

Oil Extraction

After removal of the seed coat, the seeds (500 g) of *M. concanensis* were crushed and extracted in a Soxhlet apparatus fitted with a 1-L round-bottomed flask and a condenser. The extraction was carried out on a water bath for 6 h with 0.70 L of *n*-hexane. The solvent was removed under vacuum in a rotary evaporator (EYELA, N.N. Series, Rikakikai Co. Ltd., Tokyo, Japan). Except for a small quantity (used for the Rancimat analysis), the recovered oil from different batches was degummed.

Degumming of Oil

The oil was heated in a water bath at 70 °C, and hot water was added to give a final volume of 18%. The emulsion was mixed with a glass rod for 10 min. After cooling, the oil was centrifuged (3,000 rpm i.e., 1221×*g*) for 12 min in 100 cm^3 tubes in an automatic refrigerated centrifuge (CHM-17; Kokusan Denki, Tokyo, Japan). The degummed and centrifuged oil was dried for 5 min with the anhydrous sodium sulfate, filtered through a filter paper by gravity in a drying oven (EYELA, VOC-300 SD, Tokyo, Japan) at 50 °C, and stored in separate sealed bottles at 0–4 °C.

Analysis of Oilseed Residues

The oilseed residue (meal) remaining after the extraction of oil from the seeds were analyzed for protein, fiber, and ash content. Protein content was determined according to a semi-automated AOAC official method 976.06 [12]. Sample of meal (1.0 g) was simultaneously digested with 10 mL of H_2O_2 (35%), 12 mL of concentrated H_2SO_4 (98%) and 5 g of K_2SO_4 in presence of selenium dioxide (0.25 g) as a catalyst. Absorbance of NH_3–salicylate complex was read at 660 nm using a spectrophotometer (U-2001, Hitachi Instruments Inc., Tokyo, Japan).

Fiber content was determined according to the ISO method 5983 [13]. A finely ground sample of 2.5-g of meal was weighed and freed from fat by extraction with 15 mL of *n*-hexane. The test portion was boiled with a sulfuric acid solution (0.255 mol L^{-1}), followed by separation and washing of the insoluble residue. The residue was then boiled with sodium hydroxide (0.313 mol L^{-1}), followed by separation, washing, and drying. The dried residue was weighed and ashed in a muffle furnace (EYELA, TMF-2100, Tokyo, Japan) at 600 °C, and the loss in mass was determined.

Ash content was determined according to the ISO method 749 [14]. Two grams of the test portion was taken and carbonized by heating on a gas flame. The carbonized material was then ashed in an electric muffle furnace (EYELA, TMF-2100, Tokyo, Japan) at 550 °C until constant mass was achieved.

Analysis of Extracted Oils

Density, refractive index, iodine value, peroxide value, acidity, saponification value and unsaponifiable matter of the extracted oil were determined by AOCS official

methods Cc 10a–25, Cc 7–25, Cd 1–25, Cd 8–53, F 9a–44, Cd 3–25, and Ca 61–40, respectively [15]. Oil color was determined by a Lovibond Tintometer (Tintometer Ltd, Salisbury, Wiltshire, United Kingdom), using a 1-in. cell. Specific extinctions at 232 and 270 nm were determined using spectrophotometer (U-2001, Hitachi Instrument Inc. Tokyo, Japan). Samples were diluted with *iso*-octane to bring the absorbance within limits (0.2–0.8) and ($\varepsilon_{1\,\mathrm{cm}(\lambda)}^{1\%}$) was calculated following IUPAC method II D.23 [16].

The determination of the *p*-anisidine value was carried out following IUPAC method II.D.26 [16]. The oil samples dissolved in *iso*-octane were allowed to react with *p*-anisidine to produce a colored complex and the absorbance values were noted at 350 nm by using spectrophotometer (U-2001, Hitachi Instruments Inc., Tokyo, Japan).

An automated Metrohm Rancimat apparatus, model 679, capable of operating over a temperature range of 50–200 °C, was used to determine the oxidative induction periods (IP) of the non-degummed and degummed oils [17]. Testing was carried out at 120 ± 0.1 °C, and oxidative stability was measured, following the procedure described elsewhere [18]. Briefly, oil (2.5 g) was carefully weighed into each of the six reaction vessels and analyzed simultaneously. IPs of the sample were recorded automatically and corresponded to the break point in the plotted curves.

Tocopherol (α, γ and δ) analysis was performed according to Lee et al. [19]. An HPLC (Sykam GmbH, Kleinostheim, Germany) equipped with a S-1121 dual piston solvent delivery system and an S-3210 UV/Vis diode array detector was used. One gram of oil was accurately weighed and made up to volume with acetonitrile in a 10 mL volumetric flask wrapped in foil to inhibit oxidation. A 20-μL amount of the filtered sample was injected into an analytical Hypersil (Thermo Hypersil, GmbH, Germany) ODS reverse phase (C18) column (250 × 4.6 mm; 5 μm particle size) fitted with a C18 guard column. The mobile phase consisted of mixture of HPLC grade methanol and acetonitrile (65:35 v/v). The chromatographic separation was performed by isocratic elution of the mobile phase at a flow rate of 1.3 mL min^{-1} at 30 °C. Detection was performed at a wavelength of 292 nm. Tocopherols were identified by comparing the retention times and quantified on the basis of peak area percent of the unknown with those of pure standards of α-, γ-, and δ-tocopherols Sigma Chemical Co. (St Louis, MO). The peak areas were recorded and calculated by a computer with chromatography data acquisition and integration software (SRI Instrument, Torrance, California, USA).

Fatty acid methyl esters (FAMEs) were prepared according to the standard IUPAC method 2.301 [16] and analyzed on a SHIMADZU gas chromatograph model 17-A, fitted with a SP-2330 (SUPLECO, inc., Bellefonte, PA) methyl lignoserate coated (film thickness 0.20 μm), polar capillary column (30 m × 0.25 mm) and a flame ionization detector. Oxygen-free nitrogen was used as a carrier gas at a flow rate of 5 mL min^{-1}. Other conditions were as follow: initial oven temperature 180 °C; ramp rate 5 °C min^{-1}; final temperature 220 °C; injector temperature 230 °C; detector temperature 240 °C. FAMEs were identified by comparing their relative and absolute retention times with those of authentic standards of FAMEs Sigma Chemical Co., (St Louis, MO). The quantification was done by a Chromatography Station for Windows (CSW32) data handling software (Data APEX Ltd, Czech Republic). The fatty acid composition was reported as a relative percentage of the total peak area.

Results and Discussion

Tharparkar forms a part of the large desert of the same name that sprawls over a vast area of Pakistan and India from Cholistan to Nagarparkar in Pakistan and from the south of Haryana down to Rajisthan in India. Overall, it has a tropical desert climate and mostly consists of barren tracts of sand dunes covered with thorny bushes. The only rocky hills in Tharparkar are at Nagarparkar, on the northern edge of the Rann of Kutch, which belongs to quite a different geological series (granite rocks, probably an outlying mass of the crystalline rocks of the Aravalli range) from the rest of the desert. There are wide fluctuations in the amount of rainfall in Tharparkar from year to year and the yearly average for some areas is as low as 100 mm. The mean minimum and maximum temperature ranges from 17.84 to 34.52 °C.

Moringa concanensis seed oil composition was determined for three different *M. concanensis* seed samples from each of the five regions. All data represent the means of three replicated samples.

The hexane-extracted oil content of *M. concanensis* seeds averaged 38.82% (ranging from 37.56 to 40.08%), (Table 1). The oil content (40.08%) of the seeds harvested from Nagarparkar was found to be significantly higher ($P < 0.05$), whereas, the seeds assayed from plants of *M. concanensis* grown in the vicinity of town Mithi, were generally lower (37.56%) in their oil content. The former region generally consists of slopes of low rocky hills, whereas the latter region mainly consists of barren tracts of sand dunes. Higher oil concentration in the *M. concanensis* seeds from Nagarparkar could be attributed to the characteristic geological series and specific soil texture in the vicinity of perennial springs in this region.

The average oil content (38.82%) of *M. concanensis* seeds determined in the present analysis was considerably higher than that reported for *M. oleifera* seeds (variety

Table 1 Analysis of *M. Concanensis* seeds

Oil (%)	38.82 ± 0.80
Fiber (%)	6.00 ± 0.57
Ash (%)	9.00 ± 0.50
Moisture (%)	5.88 ± 0.55
Protein (%)	30.07 ± 1.50

Values are mean ± SD of 5 × 3 *M. concanensis* seeds, analyzed individually in triplicate

Mbololo) (35.70%) from Kenya [20]. However, the oil yield was lower by ca. 11.00%, 6.00% as compared with those of *M. peregrina* (49.80%) and *M. stenopetala* seeds (44.90%) reported from Saudi Arabia [21] and Kokwa Island [2], respectively. The oil content of *M. concanensis* seeds in the present analysis was found to be lower as compared with that of *M. oleifera* seeds (40.39%) from Pakistan [3], whereas it was well in line with that (38.30%) of *M. oleifera* seeds (variety Periyakulam-1) from India [22]. Such variation in oil content across countries and species might be attributable to the environmental and geological conditions of the regions. The range of oil content (37.56–40.08%) of *M. concanensis* seeds in the present analysis was found to exceed those of four conventional oilseed crops: cotton (15.0–24.0%), soybean (17.0–21.0%), safflower (25.0–40.0%), and mustard (24.0–40.0%) [23].

Analysis of the *M. concanensis* oilseed residues revealed a high protein content (30.07% of the seeds), whereas the fiber and ash contents were low, at 6.00 and 9.00%, respectively. The protein content of *M. concanensis* seeds was comparable with that of *M. oleifera* seeds (29.6%) from Pakistan [3], whereas fiber and ash contents varied somewhat to those of the latter (7.2, 6.6%), respectively. The present investigation of *M. concanensis* oilseeds demonstrated the meal to be a good source of protein, which could be added to chicken diets as a source of calories. It could also be utilized as a fertilizer, a potential animal foodstuff (following saponins detoxification if proven to be necessary), and a source of water treatment chemicals, all of which provide value-added products. There are reports in the literature that *Moringa* oilseed residue, left after the oil extraction, and husk contain active fractions that are applicable as water-purifying agents [7, 10].

Various physical and chemical characteristics of the extracted *M. concanensis* oils are depicted in Table 2. The color (1.90R + 19.00Y) of the *M. concanensis* oil was superior, in terms of yellow units to those of *M. oleifera* oils (1.00R + 29.00Y, 0.80R + 35.00Y and 1.90R + 30.00Y) investigated from Pakistan [3], India [22] and Kenya [20], respectively. The color of the vegetable oils is mainly ascribed to the presence of variety of pigments such as chlorophyll, which are efficiently removed during degumming, refining and bleaching step of oil processing. Vegetable oils having a lower color index are more appropriate for edible and domestic uses.

The value for saponification number (179.00 mg of KOH g^{-1} of oil), of *M. concanensis* oil were found to be lower than *M. peregrina* oil (185.00 mg of KOH g^{-1} of oil) [21] and *M. oleifera* oils (186.67 mg of KOH g^{-1} of oil) from Pakistan [3] and India (188.36 mg of KOH g^{-1} of oil) [22]. The saponification number determined in the present analysis of *M. concanensis* oil, not so different with those for *M. stenopetala* oil (177.20 mg of KOH g^{-1} of oil) [2] and Kenyan *M. oleifera* oil (178.11 mg of KOH g^{-1} of oil) [20], was however, with in the range of mustard seed (170–184) and high erucic acid rapeseed (168–181) oils but lower than olive (184–196), pumpkin (185–198), corn (maize) (187–195) and cottonseed (189–198) oils [24].

The unsaponifiable matter (0.78%) of *M. concanensis* oil was found to be lower than that of *M. oleifera* oil (0.90%) [3], however, it was within the range of almond (0.4–1.0%), groundnut (0.2–0.8%), kapok seed (0.5–1.0%), palm (kernel) (0.2–0.8%), soybean (0.5–1.6%), and safflower (0.3–1.5%) oils [24].

The refractive index (1.4648) of the *M. concanensis* oil was comparable to those of *M. oleifera* oil (1.460) reported from Pakistan [3] and *M. peregrina* oil (1.460) from Saudi Arabia [21]. However, the value of refractive index, quite varied from those of *M. stenopetala* oil (1.453) from Kokwa Island [2], *M. oleifera* oil (1.454) from Kenya [20] and India (1.457) [22], was with in the range of almond (1.462–1.465), groundnut (1.460–1.465), kapok seed (1.460–1.466), sheanut (1.463–1.467), and mustard seed (1.461–1.469) oils [24].

The free fatty acid (FFA) contents (0.34%) of the *M. concanensis* oil were almost comparable to those of *M. oleifera* oil (0.40%) investigated from Pakistan [3] and *M. peregrina* oil (0.30%) from Saudi Arabia [21], but lower than those of *M. stenopetala* oil (1.10%) from Kokwa Island [2], and *M. oleifera* oils reported from Kenya (0.85%) [20] and India (1.12%) [22]. A high FFA value is associated with a high deterioration rate of the oils and thus resulting in the development of objectionable flavour and odour. A very low content of FFA for *M. concanensis* oil in the present analysis is indicative of the good resistance of this oil to hydrolysis.

The iodine value (67.00 g of I/100 g of oil) of *M. concanensis* oil was almost comparable to those of *M. oleifera* oils from Pakistan (69.45 g of I/100 g of oil) [3], Kenya (66.83 g of I/100 g of oil) [20] and India (65.58 g of I/100 g of oil) [22], *M. peregrina* Arabian seed oil (69.60 g of I/100 g of oil) [21] and *M. stenopetala* oil (65.00 g of I/100 g of oil) from Kokwa Island [2].

M. concanensis oil also exhibited a good oxidative state as indicated by the determinations shown in Table 2. The

Table 2 Analysis of physico-chemical characteristics of *M. concanensis* oil

Iodine value (g of I/100 g of oil)	67.00 ± 0.70
Refractive index (40 °C)	1.4648 ± 0.002
Density (mg mL^{-1}) 24 °C	0.8660 ± 0.005
Saponification value (mg of KOH/g of oil)	179 ± 1.15
Unsaponifiable matter (%)	0.78 ± 0.04
Color (red units)	1.90 ± 0.05
Color (yellow units)	19.00 ± 0.21
Acidity (% as oleic acid)	0.34 ± 0.05
Conjugated diene ($\varepsilon^{1\%}{}_{1\ \mathrm{cm}}$ (λ_{232})	3.17 ± 0.2
Conjugated triene ($\varepsilon^{1\%}{}_{1\ \mathrm{cm}}$ (λ_{270})	0.65 ± 0.05
Peroxide value (meq kg^{-1})	1.75 ± 0.12
P-anisidine value	1.84 ± 0.10
Oxidative stability (Rancimat method (h))	
Non-degummed oil	10.81 ± 0.85
Degummed oil	8.90 ± 0.75
Tocopherols (mg kg^{-1})	
α-Tocopherol	72.11 ± 3.20
γ-Tocopherol	9.26 ± 0.50
δ-Tocopherol	33.87 ± 2.00
Fatty acids (%)	
$C_{16:0}$	11.04 ± 0.18
$C_{16:1}$	2.38 ± 0.20
$C_{18:0}$	3.58 ± 0.12
$C_{18:1}$	68.00 ± 0.80
$C_{18:2}$	1.83 ± 0.10
$C_{20:0}$	3.44 ± 0.20
$C_{20:1}$	1.73 ± 0.10
$C_{22:0}$	7.09 ± 0.25

Values are mean ± SD of 5 × 3 *M. concanensis* oils, analyzed individually in triplicate

specific extinctions at 232 and 270 nm, which revealed the oxidative deterioration and purity of the oils [11], of *M. concanensis* oil, 3.17 and 0.65, respectively were almost comparable to those of *M. oleifera* oil (3.15 and 1.13) reported from Kenya [20], but varied with regard to *M. oleifera* oil (1.70 and 0.31) from Pakistan [3] and *M. peregrina* Arabian seed oil (1.66 and 0.19) [21]. The peroxide value (1.75 meq kg^{-1} of oil) and *p*-anisidine value (1.84), which measure hydroperoxides and aldehydic secondary oxidation products of the oils, respectively [11], for *M. concanensis* oil were quite low, thus showing high resistance to oxidation. The peroxide value (PV) of *M. concanensis* oil found in the present analysis was generally lower than that reported for *M. oleifera* oil (1.83 meq kg^{-1} of oil) from India [22]. However, the PV was found to be higher than those of *M. peregrina* oil (0.40 meq kg^{-1} of oil) from Saudi Arabia [21] and *M. oleifera* oil (0.59 meq kg^{-1} of oil) from Pakistan [3]. The PV of *M. concanensis* oil was found to be comparable to those of *M. stenopetala* oil (1.65 meq k^{-1}g of oil) from Kokwa Island [2] and *M. oleifera* oil (1.80 meq kg^{-1} of oil) from Kenya [20]. There were no previously reported data of *M. concanensis* oils to compare the results of PV and *p*-anisidine values with our present analysis.

The induction period (Rancimat; 20 L h^{-1}, 120 °C), which is a characteristic of the oxidative stability of the oils and fats [18], of the non-degummed *M. concanensis* oil was 10.81 h, indicating a good stability. After degumming, the induction period (IP) of the oil decreased to 8.90 h, a reduction of 17.67% in oxidative stability, which could be attributed to the degumming process. Some earlier reports also revealed a sizeable reduction in IPs of the crude Moringa oils after degumming [2, 3, 20, 22]. The value of IPs for the degummed *M. concanensis* oil was slightly higher to those of *M. oleifera* oils from Pakistan (8.63 h) [3] and India (8.70 h) [22]. However, the IP value was found to be lower as compared to the degummed *M. stenopetala* oil (12.50 h) from Kokwa Island [2] and *M. oleifera* oil (10.80 h) from Kenya [20]. A reasonably high values of IP of *M. concanensis* oil, exhibited in the present analysis, compared with those of common vegetable oils [18], might be in due part of the high level of monoenoic FA, particularly, $C_{18:1}$, which is less prone to oxidation than polyenoics. Moreover, a high stability of *M. concanensis* oil might be attributed to the presence of considerably high concentration of α-, γ-, and δ-tocopherols. Literature reports also demonstrated a high oxidative stability of seed fat of different species of *Moringaceae,* which include the *M. oleifera* [3, 20, 22], *M. stenopetala* [2], and *M. peregrina* [21].

The contents of different tocopherols (α, γ and δ) in *M. concanensis* oil are depicted in Table 2. The content (72.11 mg kg^{-1}) of α-tocopherol, which has the greatest vitamin E potency [24], was appreciably higher than palm kernel (ND–44 mg kg^{-1}) and coconut (ND–17 mg kg^{-1}) oils and fell in the range of soybean (9–352 mg kg^{-1}), maize (23–573 mg kg^{-1}), groundnut (49–304 mg kg^{-1}) and palm (4–185 mg kg^{-1}) oils [24]. The level (9.26 mg kg^{-1}) of γ-tocopherol was somewhat comparable with those of coconut (ND–14 mg kg^{-1}) and sunflower (ND–34 mg kg^{-1}) oils [24]. While the concentration (33.87 mg kg^{-1}) of δ-tocopherol, which has greater antioxidant activity than either γ-, or α-tocopherol [3], was found to be higher than coconut (ND–2 mg kg^{-1}), cottonseed (ND–17 mg kg^{-1}), groundnut (3–22 mg kg^{-1}), sunflower (ND–7 mg kg^{-1}), high erucic acid rapeseed (5–14 mg kg^{-1}) and low erucic acid rapeseed (4–22 mg kg^{-1}) oils [24]. The contents of α-, γ-, and δ-tocopherols in the present analysis of *M. concanensis* oil was rather lower than those reported for *M. oleifera* oil (134.42, 93.70, and 48.00 mg kg^{-1}) from Pakistan [3] and *M. peregrina* oil (145.00, 58.00 and 66.00 mg kg^{-1}) native to Saudi Arabia [21]. However, the

contents of these isomers of tocopherols were noticeably higher than the values reported for *M. oleifera* oil (15.38, 4.47 and 15.51 mg kg^{-1}) from India [22]. Thus, it would be expected to contribute good oxidative stability and protection to the *M. concanensis* oil during storage and processing.

The fatty acid (FA) composition of *M. concanensis* oil indigenous to Pakistan is shown in Table 2. The contents of total saturates, that is, palmitic ($C_{16:0}$), stearic ($C_{18:0}$), arachidic ($C_{20:0}$), and behenic ($C_{22:0}$) acids, in *M. concanensis* oil was 11.04, 3.58, 3.44 and 7.09%, respectively, of which $C_{16:0}$ was the dominant acid. The concentration (25.15%) of the total saturated FA in *M. concanensis* oil was somewhat higher than those of *M. oleifera* oils reported from Kenya (19.67%) [20] and Pakistan (20.17%) [3] and *M. stenopetala* oil (19.12%) from Kokwa Island [2]. The percentage of total saturates in the investigated *M. concanensis* oil was also not so varied from those of *M. oleifera* oil (22.37%) reported from India [22].

The *M. concanensis* oil was found to contain a high level of oleic acid ($C_{18:1}$ n-9), which accounted for 68.00% of the total fatty acids. A small amount 1.83, 1.73 and 2.38% of linoleic acid ($C_{18:2}$ n-6), gadoleic acid ($C_{20:1}$) and palmitoleic acid ($C_{16:1}$ n-7), respectively was also detected. The *M. concanensis* oil was found to be devoid of linolenic acid ($C_{18:3}$ n-3). The content (68.00%) of the major fatty acid ($C_{18:1}$) was quite varied in comparison to those of *M. oleifera* oils from Pakistan (76.00%) [3], India (71.21%) [22], and *M. stenopetala* oil from Kokwa Island (74.61%) [2] and *M. peregrina* oil from Saudi Arabia (70.52%) [21]. The content (7.09%) of behenic acid ($C_{22:0}$) was found to be higher than those of *M. stenopetala* oil (6.01%) from Kokwa Island [2] and *M. oleifera* oil (5.00%) from Pakistan [3]. The amount of $C_{16:0}$ and $C_{18:0}$ (11.04, 3.58%), also varied from those of *M. stenopetala* oil (6.21, 4.32%) [2], *M. oleifera* oil (6.46, 5.88%) [22], and *M. peregrina* oil (8.90, 3.82%) [21]. As with many of the other traits, there were no previously reported data on the fatty acid composition of *M. concanensis* oil to compare the results with our present analysis. In the *M. concanensis* oil investigated, the FA composition could not be compared with other conventional vegetable oils [24]. In summary, *M. concanensis* oil from Tharparkar, Pakistan is a high-oleic oil and contains a high ratio of monounsaturated to saturated fatty acids. High-oleic oils are of great importance because of their superior stability and nutritional remuneration [25, 26].

Despite the fact that Pakistan is an agrarian country, it is not yet capable of producing enough oils for its domestic needs, which amounts to approximately 2.43 million tons per annum. Local production is about 0.74 million tons, which accounted for 30.4% of the total demand. As a result, a large amount of foreign exchange has to be spent every year for the import of vegetable oils and seeds. As Pakistan is blessed with vast productive plains, diverse lands and a valued irrigation system, *M. concanensis* could emerge as a valuable crop, which could yield a useful oil that might be an acceptable substitute for high-oleic oils. Our present analysis demonstrated that oil from *M. concanensis* seeds native to Pakistan has a good potential for edible and industrial application purposes. It could also be utilized for developing nutritionally balanced, high-stability blended formulations with other high-linoleic oils, provided it is cultivated on a large scale.

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