Chapter 33
Opuntia spp. Seed Oil

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Abstract The *Opuntia*, commonly known as cactus pear or prickly pear, belongs to the *Cactaceae* family and is widely distributed either as indigenous, alien, wild, or domesticated species in various countries across the world. Seeds are usually removed as waste products from the fruit pulp and can constitute important new oil source. The *Opuntia* seed oil, commonly called prickly pear seed oil, has been extracted using maceration-percolation, Soxhlet, cold pressing, supercritical carbon dioxide, and ultrasound extraction, for which yields of 1–20% have been reported. *Opuntia ficus-indica* is the most common *Opuntia* species for which the physicochemical characteristics, the composition of fatty acids, sterols, and tocopherols have been reported. The main fatty acids of prickly pear seed oil are palmitic, stearic, oleic, and linoleic acids. Environmental conditions and maturation stages of prickly pear have effects on the properties of the oil. High levels of sterols are present, with β-sitosterol as the dominant sterol. The dominant tocopherol is γ-tocopherol. The oil exhibited a high *in vitro* antioxidant potential, and with its reported phenolic content, it has various health and cosmetics applications.

Keywords Prickly pear · Cactus fruit · Linoleic acid · Antioxidants · Tocopherols · Phenolics · Health · Cosmetics

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Abbreviations

2-MeO	2-methyloxolane
MP	Maceration-percolation
$scCO_2$	Supercritical carbon dioxide
USM	Ultrasound-assisted maceration

1 Genus *Opuntia* as a Source of Seed Oil

The genus *Opuntia* generally called the cactus pear, or prickly pear belongs to Cactaceae plant family that includes approximately 130 genera with about 1500 species (Guedes Paiva et al., 2016). They are native to Mexico and widespread throughout Central and South America, Australia, Africa, including the Mediterranean area (Ammar et al., 2014; Shedbalkar et al., 2010). Mexico has the highest genetic diversity of *Opuntia* spp. with 150–180 species, of which *O. hyptiacantha* F.A.C. Weber, *O. leucotricha* DC., *O. megacantha* Salm-Dyck, and *O. streptacantha* Lem. are the most common species (Martínez-Tagüeña & Trujillo, 2020). *Opuntia* spp. are cultivated over a broad range in latitude, and it is growing in areas ranging from the sea level to a height of 5100 m (Guedes Paiva et al., 2016). *Opuntia* tends to favor dry, hot areas inhabited with perennial shrubs, trees, and creeping plants (Shedbalkar et al., 2010). The several varieties of the commonly researched *O. ficus-indica* (L.) Mill. are distinguished by characteristics such as having spiny or spineless cladodes, a cladode shape, branching, its fruit and pulp color, epicuticular wax morphology with sweet pulp and limited acidity, and variable weight of the fruit ranging from 43 to 220 g (Ayadi et al., 2009; Medina-Torres et al., 2013; Guedes Paiva et al., 2016; Cota-Sanchez, 2016). This cactus plant's fruit is elongated and oval, with the pulp containing hard seeds (Piga, 2004). The seeds that are a waste product after pulp extraction and conversion can extract edible oil with unique properties. *Opuntia* seed oil has a high content of unsaturated fatty acids (especially polyunsaturated), dominated by linoleic acid and tocopherols, particularly γ-tocopherol (Stintzing et al., 2001; Simopoulos, 2002; Chahdoura et al., 2015). The favorable physicochemical characteristics of the oil allow it to be easily applied for various commercial applications. Although the oil is edible, its presence in the food industry is not very common and has instead entered the cosmetics industry's niche market. Some years ago, the prickly pear plant drew the research community's attention due to its potential versatile economic applications from the pericarp, pulp to its seeds, and its unique composition of several beneficial compounds (Piga, 2004; Ciriminna et al., 2017). This chapter is intended to provide insight into the published data on *Opuntia* seed oil, particularly their extraction methods and yields, physicochemical properties, fatty acid composition, tocopherol, sterol composition, and their potential application in the health and cosmetic sectors.

2 Extraction Methods and Yields

The extraction methods for obtaining *Opuntia* seed oil include cold pressing, organic solvents, supercritical carbon dioxide ($scCO_2$), and ultrasound extractions. Table 33.1 summarizes reported extraction methods and their oil yields obtained from *Opuntia* species and their sampling locations. The *Opuntia* fruit is composed of about 2–12% seeds with an approximate weight of 67–216 g (El Kossori et al., 1998; Piga, 2004; Karabagias et al., 2020) and about 0.24 seeds/g fruit pulp (De Wit et al., 2016; Ciriminna et al., 2017). The general preparation method in obtaining the seeds for oil extraction include the following steps (Chougui et al., 2013; Ghazi et al., 2013; Ramírez-Moreno et al., 2017; Belviranlı et al., 2019; Regalado-Rentería et al., 2020):

1. Undamaged and ripe/mature *Opuntia* fruits are harvested and peeled manually,
2. Fruit is homogenized or liquefied to obtain the fruit pulp containing the seeds,
3. Fruit pulp is sieved or sifted to remove seeds from the pulp,
4. Seeds are then washed with water and dried (sun-dried/room temperature or drying at 60 °C until constant mass), and then
5. Seeds are grounded and used for oil extraction.

The oil yield from a species of *Opuntia* collected from different areas within a region can vary (Matthaüs & Özcan, 2011). Similarly, harvesting times have been shown to affect the oil content of *O. ficus-barbarica* A. Berger from Turkey (Al Juhaimi et al., 2020). Oil content ranged from 3.09% to 6.80% for sample collected from June to August (Al Juhaimi et al., 2020). The use of supercritical carbon dioxide (46.51 °C, 46.96 MPa, 10 kg CO_2/h for 2.79 h) in the extraction of seed oil from *O. dillenii* Haw. resulted in an optimum yield of 6.65% (Liu et al., 2009). The ultrasound extraction method has also been applied to extract oil from *O. ficus indica*, Reyna variety, from Mexico (Ortega-Ortega et al., 2017a). The yield of oil was shown to be proportional to the amplitude level (Ortega-Ortega et al., 2017a). Generally, the oil yield of *Opuntia* species varies from 1% to 20% depending on species, cultivation/growing area, extraction methods, and harvesting times (Table 33.1). Cold pressing produces about 1 L oil from 800 to 1000 kg fruits or 25 kg seeds (Prakash & Sharma, 2014; Mule, 2016), while the use of organic solvents produces a higher oil yield. Green extraction technologies are more favored due to the adverse health and environmental issues associated with organic solvents (Koubaa et al., 2017). Oil extracted from *O. ficus-indica* from Tunisia was reported to be of better quality than the oil extracted with Soxhlet with *n*-hexane (Yeddes et al., 2012). The use of $scCO_2$ and cold pressing extraction technologies are preferred in terms of the oil's application in cosmetics and health products (Koubaa et al., 2017).

Table 33.1 Extraction methods and yields of *Opuntia* seed oil (%)

Specie	Source of *Opuntia*	Extraction method	Yield[a] (%)	Reference
O. ficus-indica L.	Saudi Arabia	Soxhlet-petroleum ether	13.6	Sawaya and Khan (1982)
Tapón (*Opuntia robusta*)	Mexico		20.0	Delgado and Pimienta-Barrios (1994) in: Pimienta-Barrios (1994)
Cascarón (*Opuntia hyptiacantha Weber*)			16.2	
Bola de masa (*Opuntia* sp.)			15.4	
Fafayuco (*Opuntia* sp.)			14.4	
Redonda (Opuntia sp.)			14.4	
Cardona (O. streptacantha)			14.2	
Pachon (O. streptacantha)			11.6	
Chapeada (Opuntia sp.*)*			10.6	
Cristalina (Opuntia sp.*)*			10.1	
Amarilla (O. ficus-indica)			9.8	
Rojo-pelón (O. ficus-indica)			8.4	
Burrona (Opuntia sp.*)*			6.4	
O. ficus-indica L.	Italy	Hexane	8–9	Salvo et al. (2002)
O. ficus-indica L.	Turkey	Soxhlet-petroleum ether	54–69 g/kg	Coşkuner and Tekin (2003)
O. ficus-indica L.	Germany	Chloroform-methanol	98.8 g/kg	Ramadan and Mörsel (2003)
O. ficus-indica L.	Tunisia	Soxhlet-Hexane	11.8	El Mannoubi et al. (2009)

(continued)

Table 33.1 (continued)

Specie	Source of *Opuntia*	Extraction method	Yield[a] (%)	Reference
Opuntia dillenii Haw.	China	$SCCO_2$	6.65	Liu et al. (2009)
Opuntia sp.	South Africa	Chloroform-methanol		Labuschagne and Hugo (2010)
Roedtan			5.54	
Meyers			5.69	
Turpin			4.74	
Algerian			4.45	
Malta			5.43	
Zastron			3.91	
Morado			4.95	
Gymno Carpo			3.94	
Nudosa			5.16	
Fasicaulis			2.24	
Skinners Court			4.40	
O. ficus-indica L.	Turkey	Soxhlet-petroleum ether	5.0–14.4	Matthaüs and Özcan (2011)
O. ficus-indica L.	Tunisia	Soxhlet-petroleum ether	4.4–6.9	Tlili et al. (2011)
O. ficus-indica L.	Turkey	Soxhlet-diethyl ether	5.0	Özcan and Al Juhaimi (2011)
O. joconostle, cv. Cuaresmeño	Mexico	Soxhlet	2.45	Morales et al. (2012)
O. matudae, cv Rosa			3.52	
O. ficus-indica	Algeria	Soxhlet	10.45 mg/100 g	Boukeloua et al. (2012)
O. ficus-indica L.	Morocco	Cold-pressed	6–7	Zine et al. (2013)
O. elatior (Mill.)	India	Soxhlet-Petroleum ether	13.6	Bhatt and Nagar (2013)
O. dillenii	Morocco	Hexane	5.7	Ghazi et al. (2013)
O. ficus-indica	Morocco	Hexane	5.1	Ghazi et al. (2013)
O. ficus-indica	Algeria	Soxhlet-hexane		Chougui et al. (2013)
Red			7.3	
Orange			7.7	
Yellow			9.3	
Green			8.4	

(continued)

Table 33.1 (continued)

Specie	Source of *Opuntia*	Extraction method	Yield[a] (%)	Reference
O. stricta Haw.	Kenya	Petroleum ether	11.5	Kunyanga et al. (2014)
O. ficus-indica	Morocco	Soxhlet-hexane	9.16 (Seed diameter > 2.25 mm)	Taoufik et al. (2015)
Opuntia stricta, Haworth variety (Haw.)	Tunisia	Soxhlet-hexane	235 g/kg	Koubaa et al. (2017)
		Hexane	49%	
		$SCCO_2$	49.9%	
O. ficus-indica (Algerian, Gymno Carpo, Meyers, Morado, Nudosa, Roedtan, Sicilian Indian Fig, Skinners Court, Tormentosa, Turpin, Van As, and Zastron)	South Africa	Chloroform and methanol	5.8–6.7% between locations	de Wit et al. (2016)
			5.8–6.67% between seasons	
			3.45–8.23% among cultivars	
			5.42–6.67% for cultivar × location × season interaction	
O. dillenii	Madagascar	Petroleum ether-ANKOM XT 1 5 extraction system	7.04	Hänke et al. (2018)
O. stricta var. stricta	Madagascar	Petroleum ether—ANKOM XT 1 5 extraction system	8.8	Hänke et al. (2018)
O. albicarpa	Mexico	Hexane	11.83	Ramírez-Moreno et al. (2017)
		Ethanol	10.13	
		Ethyl acetate	10.6	
O. ficus-indica	Mexico	Hexane	6.69	Ramírez-Moreno et al. (2017)
		Ethanol	5.11	
		Ethyl acetate	3.81	
O. ficus-indica (Reyna)	Mexico	Ultrasound	3.75–6.00	Ortega-Ortega et al. (2017a, b)
		Soxhlet-hexane	7–8	
		Maceration	5–6	
O. ficus-indica	South Africa	Chloroform-methanol		de Wit et al. (2017a)
Algerian			7.82	
Meyers			8.00	
Morado			8.04	
Nudosa			6.85	
Tormentosa			8.09	
O. robusta				
Monterey			5.65	
Robusta			6.46	

(continued)

Table 33.1 (continued)

Specie	Source of *Opuntia*	Extraction method	Yield[a] (%)	Reference
O. ficus-indica (40 cultivars)	South Africa	Chloroform-methanol	6.24	De Wit et al. (2017b)
O. robusta (Robusta and Monterey).				
O. ficus-indica L.	Turkey	Soxhlet-petroleum ether	5.34–7.67	Belviranlı et al. (2019)
Opuntia ficus-indica Sanguigna and the yellow fruits of O. ficus-indica Surfarina varieties (voucher MB101/2017 and MB 102/2017, *O. ficus-indica* Sanguigna)	Italy	Soxhlet-hexane	9.3	Loizzo et al. (2019)
		USM	5.4	
O. ficus-indica Surfarina		Soxhlet-hexane	9.5	
		USM	5.6	
O. dillenii	Iraq	Hydro-distillation	6.5	Alsaad et al. (2019)
Amarilla Monteza	Mexico	Cold-pressed	1.66	Regalado-Rentería et al. (2020)
(O. megacantha)		MP	7.63	
Blanca		Cold-pressed	1.19	
(O. albicarpa)		MP	8.72	
Cardona		Cold-pressed	2.52	
(O. streptacantha)		MP	11.64	
Charola		Cold-pressed	0.51	
(*O. streptacantha*)		MP	10.55	
Pico Chulo		Cold-pressed	–	
(*O. megacantha*)		MP	6.16	
Rojo Tapón		Cold-pressed	6.08	
(*O. robusta*)		MP	15.54	
Tapona		Cold-pressed	5.71	
(*O. robusta*)		MP	14.54	
Xoconostle		Cold-pressed	1.65	
(*O. matudae*)		MP	9.68	
O. ficus-indica (L.)	Morocco	n-hexane	8.86	Gharby et al. (2020)
		2-MeO	9.55	
O. ficus-barbarica A. Berger	Turkey	Soxhlet-petroleum ether	3.09–6.80	Al Juhaimi et al. (2020)

$SCCO_2$ supercritical carbon dioxide, *USM* ultrasound-assisted maceration, *MP* Maceration-percolation, *2-MeO* 2-methyloxolane

[a]%, unless otherwise stated within Table; Yield data ranges reported can be indicative of cultivars for the same species, different sample collection sites, harvesting periods and extraction methods

3 Physicochemical Properties

The most-reported physicochemical properties were for *O. ficus-indica* seed oil, while the physicochemical properties of *O. elatior* (Mill.) (Bhatt & Nagar, 2013) and *O. robusta* seed oil (De Wit et al., 2017a) have also been reported (Table 33.2). *Opuntia* seed oil is an edible oil, with reported low toxicity (Boukeloua et al., 2012), which is light green to yellow (Sawaya & Khan, 1982; Moutkane, 2015) and is a liquid at room temperature (El Mannoubi et al., 2009). The seed oil's refractive index and density range from 1.4596 to 1.4831 and 0.904–0.907, respectively (Table 33.2). The iodine values range from 111 to 132 g I_2/100 g oil, which refers to the high degree of unsaturation in the *Opuntia* seed oil (Table 33.3). A significant variation in peroxide values of the *Opuntia* seed oil obtained from different species and their origin have been reported (Table 33.2). The peroxide values recorded are low and indicate the oil's oxidative stability and quality (Table 33.2). The seed oil has low acid values, and saponification values ranging from 173 to 222 mg KOH/g oil. The unsaponifiable matter ranges from 1.19% to 2.65%. The physicochemical properties have been shown to vary among *Opuntia* seed oils obtained from different cultivars (De Wit et al., 2017a). *O. ficus-indica* seed oil from Greece has been reported (Karabagias et al., 2020) to be rich in aroma due to the presence of a wide range of organic compounds and, in particular, volatile compounds. The aroma is described to be of a floral and fruity nature (Moutkane, 2015). The oil has been reported to be stable for about 18 months, if kept under prescribed storage conditions (Moutkane, 2015).

4 Fatty Acid Composition

The main species for which the fatty acid composition of the seed oil has been reported are *O. ficus-indica*; others include *O. streptacantha*, *O. robusta*, *O. boldinghii*, *O. joconostle*, *O. matudae*, *O. elatior*, *O. dillenii*, *O. albicarpa*, *O. ficus-barbarica*, *O. aequatorialis*, *O. leucotricha* and *O. megacantha* (Table 33.3). The dominant fatty acid found in the *Opuntia* seed oil is linoleic acid in a concentration range of 56–77%, followed by palmitic acid (9–23%) and oleic acid (2–29%) (Table 33.3). Other fatty acids found in minor concentrations are myristic acid, palmitoleic acid, stearic acid, linolenic acid, and behenic acid, depending on the origin of the species and the specific species cultivar of *Opuntia*. The fatty acid composition of *Opuntia* seed oil is similar to that of the sunflower and grape seed oils (Labuschagne & Hugo, 2010; El-Mostafa et al., 2014). The content of linoleic acid in *Opuntia* seed oil is higher than that reported for argan oil (El-Mostafa et al., 2014). The fatty acid composition in *Opuntia* species collected from different areas within a region can vary (Matthaüs & Özcan, 2011; Ramadan & Mörsel, 2003). Similarly, harvesting times have been shown to affect the oil content of *O. ficus-barbarica* A. Berger from Turkey (Al Juhaimi et al., 2020). Plant genetics, soil

Table 33.2 Physicochemical characteristics of *Opuntia* seed oil

Specie	Origin	Refractive index	Iodine number (g I_2/100 g)	Saponification number	Acid value (% oleic)	Unsaponifiable matter (%)	Peroxide value (meq O_2/kg)	K_{232} K_{270}	Density	Reference
O. ficus-ndica	Saudi Arabia	1.4596	119	222	0.84	1.96				Sawaya and Khan (1982)
	Italy		106		2.5		10	3.15 0.22		Salvo et al. (2002)
	Tunisia	1.471	107	173	1.27		1.46		0.904	El Mannoubi et al. (2009)
	Turkey	1.4831		181	1.41		1.63		0.907	Özcan and Al Juhaimi (2011)
	Algeria	0.909	93		1.82	1.476			2.04	Boukeloua et al. (2012)
	Morocco	1.4610	131	187	0.56	1.19	3.5	1.72 0.31	0.906	Zine et al. (2013)
	South Africa	1.4666–1.4669	111–124				9.50–18.02			De Wit et al. (2017a)
		1.470					12.0	0.078 0.128		Brahmi et al. (2020)
	Morocco		132		1.26–3.02		3.5–8.6	2.75–3.25 0.51–2.11		Gharby et al. (2020)
O. elatior	India		111	192	1.64	2.65				Bhatt and Nagar (2013)
O. robusta	South Africa	1.4675–1.4676	122–127				20–24			de Wit et al. (2017a)

Note: Data ranges reported can be indicative of cultivars for the same species, different sample collection sites, harvesting periods, and extraction methods

Table 33.3 Fatty acid composition (%) of *Opuntia* seed oil

Specie	Source	C16:0	C18:0	C18:1	C18:2	References
O. ficus-indica	Saudi Arabia, Mexico, Germany, Turkey, Tunisia, Algeria, Morocco, South Africa, Italy	10–20	0.15–5.8	8.8–27	49–77	Sawaya and Khan (1982), Delgado and Pimienta-Barrios (1994) in: Pimienta-Barrios (1994), Ramadan and Mörsel (2003), Coşkuner and Tekin (2003), El Mannoubi et al. (2009), Matthaüs and Özcan (2011), Özcan and Al Juhaimi (2011), Tlili et al. (2011), El Finti et al. (2013), Zine et al. (2013), Ghazi et al. (2013), Chougui et al. (2013), Taoufik et al. (2015), Ramírez-Moreno et al. (2017), R'bia et al. (2017), de Wit et al. (2017a), de Wit et al. (2017b), Belviranlı et al. (2019), Loizzo et al. (2019), Gharby et al. (2020), El Kharrassi et al. (2020)
O. streptacantha	Mexico	4.7–14	1.1–3.9	14–20	61–80	Delgado and Pimienta-Barrios (1994) in: Pimienta-Barrios (1994), Regalado-Rentería et al. (2020)
O. boldinghii	Venezuela	10	3	18	67	García Pantaleón et al. (2009)
O. joconostle	Mexico	12.4	3.3	9.7	72.5	Morales et al. (2012)
O. matudae	Mexico	0.7–9.4	0.3–2	7.8–15.2	79.2–83.8	Morales et al. (2012), Regalado-Rentería et al. (2020)
O. elatior	India	12.2	3.5	16.9	65.8	Bhatt and Nagar (2013)
O. dillenii	Iraq, Morocco	14–15.1	3–7.51		72.9–80	Ghazi et al. (2013), Alsaad et al. (2019)
O. albicarpa	Mexico	0.3–12	0.3–3	16–20.7	67–78.6	Ramírez-Moreno et al. (2017), Regalado-Rentería et al. (2020)
O. robusta	Mexico, South Africa	0.57–16	0.34–2.4	11.2–22	60–86	Delgado and Pimienta-Barrios (1994) in: Pimienta-Barrios (1994), de Wit et al. (2017a), Regalado-Rentería et al. (2020)
O. aequatorialis	Morocco	12.2	3.5	21.5	60.9	El Kharrassi et al. (2020)
O. leucotricha	Morocco	12	3.6	21.1	61.6	El Kharrassi et al. (2020)
O. megacantha	Mexico, Morocco	0.3–12	0.5–3.5	13.2–20.8	62–79	Regalado-Rentería et al. (2020), El Kharrassi et al. (2020)
O. ficus-barbarica	Turkey	10.7–22.6	3.9–9.2	2–28.5	0.76–57.5	Al Juhaimi et al. (2020)
Opuntia sp.	Mexico, South Africa	9–16	0.7–4.01	12–17	61–77	Delgado and Pimienta-Barrios (1994) in: Pimienta-Barrios (1994), Labuschagne and Hugo (2010)

Note: Concentration ranges reported can indicate different cultivars for the same species, different sample collection sites, harvesting periods, and extraction methods conditions, and climate conditions influence the composition of fatty acids of *Opuntia* seeds oil (Matthaüs & Özcan, 2011; Ramadan & Mörsel, 2003). The fatty acid composition of seed oil from *O. ficus-indica*, Sanguigna (red) variety, and *O. ficus-indica*, Surfarina (yellow) variety of Italy is not affected by the extraction procedure used such as Soxhlet (*n*-hexane) and ultrasound-assisted maceration procedure (Loizzo et al., 2019). *O. megacantha* Salm-dyck seed oil has been reported to contain a higher linoleic acid content as compared to argan and olive oil (El Kharrassi et al., 2018). The eicosadienoic acid (C20:2, 1.7%), an *omega*-6 fatty acid, has been reported by Bhatt and Nagar (2013) to be contained in *O. elatior* (Mill.) from India. *O. ficus-indica* seed oil from Tunisia has been found (El Mannoubi et al., 2009) to contain 5% of vaccenic acid (18:1*n*-7).

5 Tocopherol and Sterol Composition

The most common species for which the tocopherol composition of *Opuntia*'s seed oil has been reported is *O. ficus-indica* from markets such as Germany, Tunisia, Turkey, Morocco, and Italy. At the same time, other species also include *O. dillenii* (Morocco), *O. megacantha* (Mexico), *O. albicarpa* (Mexico), *O. streptacantha*, *O. robusta* (Mexico), *O. matudae* (Mexico), *O. aequatorialis* (Morocco), and *O. leucotricha* (Morocco). Table 33.4 provides an overview of the tocopherol composition of the seed oil from various species of *Opuntia*. The reported dominant sterol is γ-tocopherol, while α, β, δ-tocopherol have been reported to be present in some *Opuntia* seed oils. Tocopherols such as α-tocopherol, ∝-tocopherol, δ-tocopherol, α-tocotrienol, ∝-tocotrienol, plastochromanol-8, γ-tocotrienol, and δ-tocotrienol were not detected in *O. ficus-indica* L. seed oil from Turkey (Matthaüs & Özcan, 2011). The geographical location affects the composition and concentration of tocopherol in *Opuntia* seed oil (Matthaüs & Özcan, 2011; Taoufik et al., 2015). The γ-tocopherol content of seed oil from *O. ficus-indica*, Sanguigna (red) variety and *O. ficus-indica*, Surfarina (yellow) variety of Italy is reported to be affected by the extraction procedure, wherein Soxhlet (*n*-hexane) extracted a higher content as compared to the ultrasound-assisted maceration procedure (Loizzo et al., 2019). *O. megacantha* Salm-dyck seed oil contains mainly β-tocopherol and γ-tocopherol (El Kharrassi et al., 2018). Various sterols are found in *Opuntia* seed oil, with ∝-sitosterol as the most dominant sterol (Table 33.5). The sterol, fucosterol, has been detected in the seed oil obtained from *O. dillenii* from Morocco (Ghazi et al., 2013). Stigmastanol (47 mg/100 g) has been found in the seed oil of *O. ficus-indica* from Algeria (Brahmi et al., 2020). Regalado-Rentería et al. (2020) reported the presence of the squalene in the seed oil of *O. megacantha*, *O. albicarpa*, *O. streptacantha*, *O. robusta,* and *O. matudae* from Mexico.

Table 33.4 Tocopherol of *Opuntia* seed oil (mg/100 g)[a]

Specie	Source	α-tocopherol	∝-tocopherol	γ-tocopherol	δ-tocopherol	References
O. ficus-indica	Germany, Tunisia, Turkey, Morocco, Italy	1–5.6	1.2	15.3–85.6	0.5–8.26	Ramadan and Mörsel (2003), El Mannoubi et al. (2009), Matthaüs and Özcan (2011), Zine et al. (2013), Ghazi et al. (2013), Ghazi et al. (2013), Taoufik et al. (2015), Loizzo et al. (2019), El Kharrassi et al. (2020), Gharby et al. (2020)
O. megacantha	Mexico			118–139		Regalado-Rentería et al. (2020), El Kharrassi et al. (2020)
O. albicarpa	Mexico			136–156		Regalado-Rentería et al. (2020)
O. streptacantha	Mexico			134–406		Regalado-Rentería et al. (2020)
O. robusta	Mexico			150–1386		Regalado-Rentería et al. (2020)
O. matudae	Mexico			119–373		Regalado-Rentería et al. (2020)
O. aequatorialis	Morocco	1.3%		98.3%	0.39%	El Kharrassi et al. (2020)
O. leucotricha	Morocco	0.96%		98.7%	0.38%	El Kharrassi et al. (2020)
O. dillenii	Morocco			0.29%		Ghazi et al. (2013)

Note: Concentration ranges reported can indicate cultivars for the same species, different sample collection sites, and extraction methods
[a]mg/100 g unless otherwise stated in the Table

6 Health and Cosmetic Applications

Opuntia seed oil has been reported to have a wide range of health applications (Table 33.6), which include antimicrobial and antifungal activities, analgesic and anti-inflammatory effects, *α*-glucosidase inhibitory activity and cytotoxicity against certain cancer cell lines from the human origin (Ramírez-Moreno et al., 2017; Villacís-Chiriboga et al., 2020). Table 33.5 provides a summary of the health benefits of *Opuntia* seed oil and their potential industrial applications. The seeds of prickly pear have been reported to have antioxidant activity towards lipid peroxidation (González-Stuart & Rivera, 2019). The seeds of *O. ficus-indica* are also reported to be used in traditional medicine (Boukeloua et al., 2012). The antioxidant ability and hypoglycemic effect of seed oils from *O. ficus-indica*, Sanguigna (red) variety, and *O. ficus-indica*, Surfarina (yellow) variety of Italy have been demonstrated by Loizzo et al. (2019). *O. albicarpa* and *O. ficus-indica* from Mexico are useful as antimicrobials and antioxidants (Ramírez-Moreno et al., 2017). The presence of phenolic compounds and tocopherols in the oil contributes to the good antioxidant activity because these compounds are capable of influencing cellular responses to various oxidative stresses *via* modulating signal-transduction pathways (Eckardt, 2008; Maeda et al., 2008). The consumption of oil has been associated with a reduced risk of developing cardiovascular, inflammatory, and autoimmune diseases (Chahdoura et al., 2017). *O. ficus-indica* seed oil was reported to have hypocholesterolemic and hypolipidemic activities (Ennouri et al., 2007). Cactus pear seed oil has also been reported to have the ability to prevent alloxan-induced-diabetes by quenching free radicals produced by alloxan and inhibiting tissue injuries in pancreatic β cells (Berraaouan et al., 2015). Cold pressed *Opuntia* seeds oil extracted from *O. ficus-indica* (Morocco) is useful in treating diabetes mellitus (Berraaouan et al., 2015). The *Opuntia* seed oil has been applied in encapsulating vitamin A towards the use as a topical delivery system of vitamin A (Al Zahabi et al., 2019). The dominant presence of linoleic acid at a high concentration in *Opuntia* seed oil (Table 33.3) also contributes to the oil's health benefits (Soel et al., 2007). The health benefits and antioxidant potential of phenolic compounds is well reported. Chbani et al. (2020) have suggested developing a phenolic compound composition fingerprint to detect adulteration and authenticity of the *Opuntia* seed oil. The dominant phenolic compounds in the seed oil of *O. ficus-indica* from Morocco are ferulaldehyde, vanillin, and syringaldehyde. Roasting of seeds before oil extraction resulted in differences in phenolic compounds' composition, except vanillin (Chbani et al., 2020).

Opuntia seed oil is a beneficial oil widely advertised for skincare applications (Argan Oil Direct, 2020). It is marketed as oil with good hydration potential, anti-aging and antioxidant potential, improved skin elasticity, and the ability to reduce skin redness and pigmentation (Joslin, 2017; Opuntia Luxury Oils, 2020; Argan Oil Direct, 2020). The oil has a ratio of 3:1 of linoleic to oleic acid, making it suitable for cosmetic applications (Opuntia Luxury oils). The oil's antimicrobial ability makes it suitable to develop skincare products to treat acne (Healthline, 2020). The oil is reported to contain vitamin K_1 (0.53 g/kg) that provides the oil with the ability

Table 33.5 Sterol compositions of *Opuntia* seed oil (mg/100 g)[a]

Specie	Source	Campesterol	Stigmasterol	∝-sitosterol	Squalene	Cholesterol	Δ^5-Avenasterol	Δ^7-Avenasterol	Δ^7-Stigmasterol	References
O. ficus-indica	Germany, Tunisia, Turkey, Morocco, Italy	11.6–21.7	3.3–11.3	76–387		1.5–1.8	4–4.4	2–2.17	1.8–2.2	Ramadan and Mörsel (2003), El Mannoubi et al. (2009), Matthaüs and Özcan (2011), Zine et al. (2013), Ghazi et al. (2013), Taoufik et al. (2015), Loizzo et al. (2019), El Kharrassi et al. (2020), Gharby et al. (2020), Brahmi et al. (2020)
O. megacantha	Mexico	10.3%[b]	1.48%[b]	456–721 74.6%[b]	245–1255	1%[b]	5.2%[b]	1%[b]	0.56%[b]	Regalado-Rentería et al. (2020), El Kharrassi et al. (2020)
O. albicarpa	Mexico			608–777						Regalado-Rentería et al. (2020)

Specie	Source	Campesterol	Stigmasterol	∝-sitosterol	Squalene	Cholesterol	Δ^5-Avenasterol	Δ^7-Avenasterol	Δ^7-Stigmasterol	References
O. streptacantha	Mexico			601–710						Regalado-Rentería et al. (2020)
O. robusta	Mexico			507–730						Regalado-Rentería et al. (2020)
O. matudae	Mexico			581–641						Regalado-Rentería et al. (2020)
O. aequatorialis	Morocco	10.2%	1.1%	76.2%		0.83%	5.4%	1.1%	0.89%	El Kharrassi et al. (2020)
O. leucotricha	Morocco	11.2%	1.6%	72.7%		1.01%	5.4%	1.3%	0.59%	El Kharrassi et al. (2020)
O. dillenii	Morocco	0.51%		2.8%						Ghazi et al. (2013)

Note: Concentration ranges reported can indicate cultivars for the same species, different sample collection sites, harvesting periods, and extraction methods
[a]mg/100 g unless otherwise stated in the Table; [b]El Kharrassi et al. (2020)

Table 33.6 Health applications of *Opuntia* seed oil

Opuntia specie	Health benefit	Industrial application(s)	Reference(s)
O. ficus-indica	Antimicrobial and antioxidant, decrease circulating cholesterol and LDL-cholesterol, lipid peroxidation, hypolipidemic effect, natural source of edible oil containing essential fatty acids, modulation of cholesterol metabolism inhibition of tissue injuries in pancreatic β-cells, hypoglycemic effect, hypolipidemic and hypocholesterolemic	Food, cosmetic, pharmaceutical, cosmeceuticals (Topical lipid delivery system), wound healing, nutraceutical, natural food colorants	Stintzing et al. (2005), Ennouri et al. (2005), Ennouri et al. (2006), Ennouri et al. (2007), Özcan and Al Juhaimi (2011), Chougui et al. (2013), Battermann and Thomas (2014), El Kharrassi et al. (2014), Berraaouan et al. (2014, 2015) Ramírez-Moreno et al. (2017), Ortega-Ortega et al. (2017b), R'bia et al. (2017), Khémiri et al. (2019), Al Zahabi et al. (2019), Belviranlı et al. (2019), Loizzo et al. (2019), Karabagias et al. (2020), Brahmi et al. (2020)
O. albicarpa	Antimicrobial and antioxidant, Anti-UV radiation	Food, cosmetic, pharmaceutical, cosmeceutical	Ramírez-Moreno et al. (2017), Regalado-Rentería et al. (2020)
O. macrorhiza	Antioxidant, cytotoxicity, α-glucosidase inhibition, antimicrobial, analgesic effect, and anti-inflammatory properties	Functional food	Chahdoura et al. (2017)
O. dillenii	Antioxidant activity, lowering cholesterol	Food, nutraceutical	Liu et al. (2009), Alsaad et al. (2019)
O. robusta	Antioxidant activity, anti-UV radiation	Natural food colorants, Cosmeceutical	Stintzing et al. (2005), Regalado-Rentería et al. (2020)
O. megacantha *O. matudae* *O. streptacantha*	Anti-UV radiation	Cosmeceutical	Regalado-Rentería et al. (2020)
O. aequatorialis *O. leucotricha*	Antioxidant activity	Functional foods	El Kharrassi et al. (2020)
Opuntia spp.	Antioxidant, hypoglycemic, antineoplastic, antibacterial, and antifungal activity, Positive effects on mitochondrial activity	Food, cosmetic, pharmaceutical	Ennouri et al. (2006, 2007), Badreddine et al. (2015), Aruwa et al. (2018)
O. stricta	antioxidant and antibacterial activities	Food and pharmaceutical	Koubaa et al. (2017)

to reduce dark/under-eye circles and spider veins (Ramadan & Mörsel, 2003; Argan Oil Direct, 2020; Daya, 2020). The oil is non-greasy and easily absorbed onto the skin. While the direct application of *Opuntia* seed oil on the skin is known, the oil is also used as a carrier oil to produce other cosmetic products (Healthline, 2020). *Opuntia* seed oil is also applied in hair products (Argan Oil Direct, 2020), with some treatments have been patented (Battermann & Thomas, 2014).

7 Conclusion

Opuntia seed oil can be obtained from a wide range of different species and cultivars of *Opuntia* worldwide. Harvesting times, geographical locations, and species type or cultivar affect the biochemistry of *Opuntia* seed oil. In terms of its chemical composition, it is considered safe with various health benefits. The oil is actively promoted in the cosmetics industry, but there is a great potential for developing cosmeceuticals and nutraceuticals from *Opuntia* seed oil.

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