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Evaluation of yield and fatty acid composition of seed oils from cactus varieties resistant to *Dactylopius opuntiae* (Hemiptera: Dactylopiidae) in Morocco

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Abstract. The Cactus *Opuntia spp.* plant is important to Morocco's arid and semi-arid regions. The edible and cosmetic oil from prickly pear fruit seeds is very prized. Since *Dactylopius Opuntiae* first appeared in Morocco in 2014, hundreds of hectares of cactus have been devastated, causing environmental and socio-economic costs. Eight *D. Opuntiae* resistant varieties were selected, multiplied and transplanted throughout Morocco, as part of the government's nationwide cactus rehabilitation program. This research evaluated the production and fatty acid composition of the seed oil of these varieties. Oil extraction was carried out with the Soxhlet method using hexane and by mechanical screw press. The crude seed oil content obtained by hexane extraction ranged from 9.54% to 16.44% (w/w). Mechanical screw extraction recovered half the seeds' oil. The fatty acid profiles showed that the oils were highly unsaturated; UFA fraction represented 76.31 to 82.63% of total FA and UFA/SFA ratio of 3.48 to 5.36. Linoleic acid was the dominant and represented 61.50% to 68.35% of total FA. These results highlight the importance of cochineal-resistant cactus varieties as oil sources and alternatives to those destroyed and still threatened by the harmful scale pest that appeared in more than 20 countries.

Keywords: prickly pear*,* seed soil, yield, fatty acids, *Dactylopius opuntiae*

Introduction

The *Opuntia* cactus is a xerophyte that grows mainly in arid and semi-arid areas, it can be found in various locations due to its ecological adaptability (Moßhammer *et al.,* 2006). Several authors confirm that it is native to North America, particularly in central and southern Mexico (Griffith, 2004) and South America (Majure *et al.,* 2012) from where it has been introduced into Europe, Africa, Asia and Oceania. Recently, it has gained worldwide interest due to the bioactive components of its fruits and edible young cladodes, such as betalains (betaxanthins and betacyanins), flavonoids and extractable phenolic compounds (Méndez-Gallegos and Bravo-Vinaja, 2022). It is also used in the cosmetic, pharmaceutical and food industries (Ciriminna *et al.,* 2019). In Morocco, prickly pear cactus plantations have been greatly encouraged by the Green Morocco Plan strategy as an alternative crop in less favorable regions of the country. The goal of this strategy was to increase the cultivated areas of prickly pear cactus, as well as the number of cooperatives and units for fruit conditioning, seed oil extraction, and valorization; this initiative aimed to improve the incomes of farmers, particularly women, and promote the socio-economic development of these regions through the production of sustainable and profitable alternative crops. In fact, the planted area has increased from 45,000 hectares in the early 1990s to over 150,000 ha (El Aalaoui *et al.,* 2019; El Aalaoui and Sbaghi, 2021c, 2021a, 2021b, 2021d, 2022; Ramdani *et al.,* 2021; Sbaghi *et al.,* 2019). More than 40% of these plantations were located in the southwestern part of the country. The size of prickly pear orchards is very variable, ranging from less than one ha to more than 100 ha. The average fruit production is eight tons per hectare and approximately one ton of fruits is required to produce one liter of prickly pear seed oil (Genin *et al.,* 2017). Furthermore, Barbera *et al.* (1994) reported that the weight of seeds typically accounts for 2 to 4% of the total fruit weight.

Unfortunately, the sustainability of cactus ecosystem has become seriously threatened by the recent invasion of *Dactylopius opuntiae* (Cockerell) (Hemiptera: Dactylopiidae), which is considered to be the most aggressive and harmful scale insect for *Opuntia* cactus *(Paterson et al.,* 2011) among the 11 *Dactylopius* species registered (Ramírez-Cruz *et al.,* 2020). It is currently distributed in at least 20 countries (Mazzeo *et al.,* 2019). It was first detected in Morocco in 2014. More recently, it has appeared in Lebanon (Moussa *et al.,* 2017), Cyprus (Ülgentürk *et al.,* 2019), Jordan (Bader and Abu-Alloush, 2019), Namibia (Paterson *et al.,* 2019), Syria (Bufaur *et al.,* 2020), and Algeria (El Bouhissi *et al.,* 2022) showing its rapid dissemination, whether induced or naturally occurring, and its wide distribution (Méndez-Gallegos and Bravo-Vinaja, 2022).

With the appearance for the first time of the wild cactus cochineal "*D. opuntiae*" in Morocco, the cactus sector was confronted with this harmful pest. As the spread of this scale pest is very fast and unpredictable, several basins of cactus production have seen their plantations infested, especially in Doukkala, Rhamna, Benguerir, Abda, Azilal, Benimellal, Taourirt, Haouz and Chaouia-Sous-Nord-Meknès-Gharb. As a result, several hectares of plantations and kilometres of cactus hedges around houses have been destroyed in these production basins by this insect, causing huge socio-economic and environmental losses (Sbaghi *et al.,* 2019). Similar cases were reported in Brazil where *D. opuntiae* attacks on a cactus forage species, *Opuntia ficus indica* (L.) Mill.1768, resulted in the loss of 100,000 ha, valued at US$ 25 million (Lopes *et al.,* 2009).

In order to fight against the spread of *D. opuntiae* in Morocco, the Ministry of Agriculture, Maritime Fishing, Rural Development and Water and Forests has put in place a major emergency plan to prevent the spread of this cochineal in 2016. This plan included, in addition to uprooting operations and chemical treatments of the infected cactus, a research program which was assigned to INRA (National Institute of Agricultural Research) and which is based on three lines of research: 1) Identifying and proposing biological control alternatives using natural enemies; 2) Identifying bio pesticides of plant or microbial origin for the treatment of infested orchards; and 3) Identification of varieties or clones resistant or tolerant to attacks by this pest. The research carried out to achieve the last point allowed the identification of eight *Opuntia* cactus resistant varieties that showed a very high degree of resistance against this scale pest (*D. opuntiae*) (Sbaghi *et al.,* 2019). These resistant varieties were recently registered in the Official Catalogue of species and varieties in Morocco (Sbaghi *et al.,* 2019). They are also multiplied and transplanted in different regions of Morocco with very different climatic

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conditions (El-Aalaoui and Sbaghi, 2022; Sbaghi *et al.,* 2019). They should be massively cultivated in order to provide a solid base for launching of the national emergency program for the rehabilitation of devastated cactus areas (Sbaghi *et al.,* 2019).

Prickly pear seed separated as a waste product in the valorization of the fruit pulp, are used to extract the oil fraction (Karabagias *et al.,* 2020). The obtained oil occupies an important market niche as an edible and cosmetic oil, known for its valuable properties (Labuschagne and Hugo, 2010). It is a lightweight and non-greasy oil that is abundant in antioxidants, essential fatty acids, and vitamin E; these components contribute to its anti-inflammatory, hydrating, brightening, and anti-aging benefits, making it suitable for all skin types. The oil content of *Opuntia* cactus seeds varies from 5.0 to 14.4% depending on the variety and climatic conditions (Kadda *et al.,* 2022; Matthäus and Özcan, 2011).

The aim of this study was to investigate the potential of the eight cochineal-resistant varieties in terms of seed oil production. The oil content of the different seeds as well as the extraction efficiency were evaluated. The fatty acid profiles of the extracted oils were established using Gas Chromatography-Mass Spectrometry (GC-MS) for the identification and quantification of the major fatty acids.

Material and Methods

Sample collection and preparation

Fruits batches of eight cochineal-resistant prickly pear varieties were collected during the harvest seasons of 2021 and 2022 from the platforms of *Opuntia* cactus resistant to *D. opuntiae* established by INRA (National Institute for Agricultural Research) in the localities of Khemis Zemamra (33°15' N, 8°30' W) and Khemis M'touh (32° 52' 48" N, 8° 10' 12" W). All the two localities belong to Mediterranean climates, with an average annual rainfall over the past 30 years of 330 mm; the temperature varies from -1 °C to 45 °C (El Aalaoui *et al.,* 2019).These platforms contain only the eight *Opuntia* cactus varieties [Marjana (INRA-1), Karama (INRA-2), Belara (INRA-3), Ghalia (INRA-4), Cherratia (INRA-5), Angad (INRA-6), Akria (INRA-7) and Melk Zhar (INRA-8)] identified as resistant to the *Opuntia* cactus cochineal (*D. opuntiae*) by INRA (Sbaghi *et al.,* 2019) (Table 1). A fruit batch of *O. ficus indica*, a non-resistant variety to the cochineal, was purchased from the market and used as a reference.

The fruits were manually peeled and their seeds were separated from the pulp using a plastic sieve, washed with water and sun-dried (36 °C) for one day. The seeds were stored in airtight bags at room temperature and in the dark for 3 weeks until use.

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Table 1: List of cactus varieties resistant to *D. opuntiae* and registered in the catalog officiel of cactus in Morocco (Sbaghi *et al.,* 2019).

Varieties	Origin	Characteristics of cladodes	Fruit characteristics
INRA-1	Dchira- Inezgane - Morocco	Intermec cladodes (without spines) for use as fodder	Fruit with light purple flesh, juicy and very sweet
INRA-2	Dchira - Inezgane - Morocco	Spiny cladodes with very good forage quality	Fruit with red flesh, very sweet and tasty
INRA-3	Dchira - Inezgane - Morocco	Intermec cladodes (without thorns) with good forage quality	Fruit with white flesh, juicy and very sweet
INRA-4	Dchira - Inezgane - Morocco	Thorny cladodes of good quality and very rich in nitrogen for livestock	Fruit with very good organoleptic quality, rich in vitamins and antioxidants, low in acidity, and very sweet
INRA-5	Bouznika-Morocco	Very thorny cladodes with good quality and very rich in nitrogen for livestock	Fruit with very good organoleptic quality, low acidity, rich in vitamins and antioxidants, and very sweet
INRA-6	Oujda - Morocco	Very thorny cladodes with good quality and very rich in nitrogen for livestock	Fruit with dark-purple flesh, sweet, tasty, and very rich in vitamin C and antioxidants
INRA-7	Bouknadel - Morocco	Thorny cladodes with good forage quality	Red fruit of small size, too acidulous, not very sweet, and appreciated in the off-season by diabetics mainly
INRA-8	Irradiation O. robusta - Morocco	Very thorny cladodes with good quality and very high nitrogen content for livestock	Fruit with very good organoleptic quality, rich in vitamins and antioxidants, low in acidity

Weight of 1000 grains

The weight of 1000 grains samples of each variety was determined after seeds drying for 4 h at 40 °C in an oven and cooling to room temperature.

Crude lipid content of seeds

Samples of analyzed seeds were first grounded using a Technoswiss model YT-999 blender. Exact amounts of approximately 20 g of ground seeds were then used to determine crude oil content using the Soxhlet method and hexane as the extraction solvent (Mohd-Setapar *et al.,* 2014). The crude oil content was calculated by dividing the mass of extracted oil by the total amount of plant material.

Mechanical press oil extraction

Press extraction trials of oil from the prickly pear seeds were carried out with a mechanical screw press (Ateliers Afyach, Morocco) equipped with perforated press cylinder and powered by a 1.5 kW electric motor. Trials were carried out in triplicate. The extraction process was followed by decantation of the collected oil for 6 hours in the dark followed by a filtration step using Whatman filter paper no. 42 to separate it from the powder sediments.

Oil extraction yield and oil extraction efficiency ware calculated. The oil extraction yield was calculated according to the mathematical equation reported by (Adeeko and Ajibola, 1990) and (Olaniyan and Oje, 2011) :

Oil Extraction Yield (OEY), % = 100 x (Extracted oil mass) / (Powder seed mass)

Extraction efficiency is the percentage of oil extracted in relation to the total amount of oil in the seed. The oil extraction efficiency was calculated by dividing the weight of press extracted oil by the oil content of the seed obtained by Soxhlet method as reported by Adeeko and Ajibola (1990) and Aniyan and Oje (2007):

Oil Extraction Efficiency (OEE), % = 100 x (Extracted oil mass) / (Total oil mass in the sample)

Preparation of fatty acid methyl esters (FAME)

Fatty acid profile and content were determined in the oils obtained by hexane extraction from the eight fruits seeds samples. Fatty acid analysis was performed in triplicate following two consecutive steps; preparation of fatty acid methyl ester (FAME) and chromatographic analysis.

The ISO 5509 (2000) method was followed to esterify the oil extract. 10 mg of seed oil was used with 0.2 ml of hexane and 0.5 ml of solution composed of 55% methanol, 20% hexane and 25% Boron Tri-fluoride (BF3) at 14%. The tubes containing the mixture were placed in a thermostatic water bath (Memmert WB 14, Schwabach, Germany) at 75 °C for 90 min. Then, 0.5 mL of saturated NaCl and 0.2 mL of 10% H_2SO_4 were added, after a vigorous stirring, they were diluted by 8 mL of hexane. The resulting upper phase obtained was taken and injected for gas chromatographic analysis. Fatty acid methyl esters were separated, identified, and quantified using GC-FID.

Fatty acid methyl ester (FAME) analysis by gas chromatography mass spectrometer (GC MS)

The Clarus© 580 Gaz (Perkin Elmer) chromatograph equipped with a 30m x 0.25mm x 0.25µm 5MS capillary column was used for sample analysis. The carrier gas used was helium at a flow rate of 1 mL min^{-1}. A volume of 0.5 µl of each extract was injected at a temperature of 250 °C in split mode; the total time of analysis was 53 min. The initial oven temperature was 50 °C, then increased at a rate of 10 °C min^{-1} until 200 °C was reached and maintained for 25 min, followed by an increase of 10 °C min^{-1} to 230 °C and maintained for 10 min. Detection was performed with Clarus© SQ8S Mass spectrometer (Perkin Elmer), the transfer line temperature was maintained at 250 °C and the source at 250 °C. The full scan was conducted in EI+ mode, within 10-600 m/z interval. The results are expressed as a percentage, after identification of the fatty acids by comparing the mass spectra with the mass spectral database.

Statistical analysis

Three repetitions were performed for each experiment. Statistical analysis was carried out using XLSTAT Version 2016.02. Analysis of variance (ANOVA) was performed with a significance level of $P < 0.05$.

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Results and discussion

1000 grain weight

Figure 1 shows samples of seeds obtained from of the prickly pear varieties used in this study. A difference in seed size and aspect between the studied varieties is observed. Results of 1000 grains weight are reported in Table 1. These results show a significant difference in weight and consequently in size between the varieties studied.

The 1000-seed weight varies between 6.14 g (INRA-3) and 15.90 g (INRA-7). These values are lower than those reported by other authors for other varieties. El Hachimi *et al.* (2015) reported an average 1000-grain weight of 15.81 g and Ennouri *et al.* (2005) found values of 13.80 g and 16.90 g for *Opuntia ficus indica* (L.) Mill., 1768 and *Opuntia stricta* (Haw.) Haw., 1812 seeds respectively.

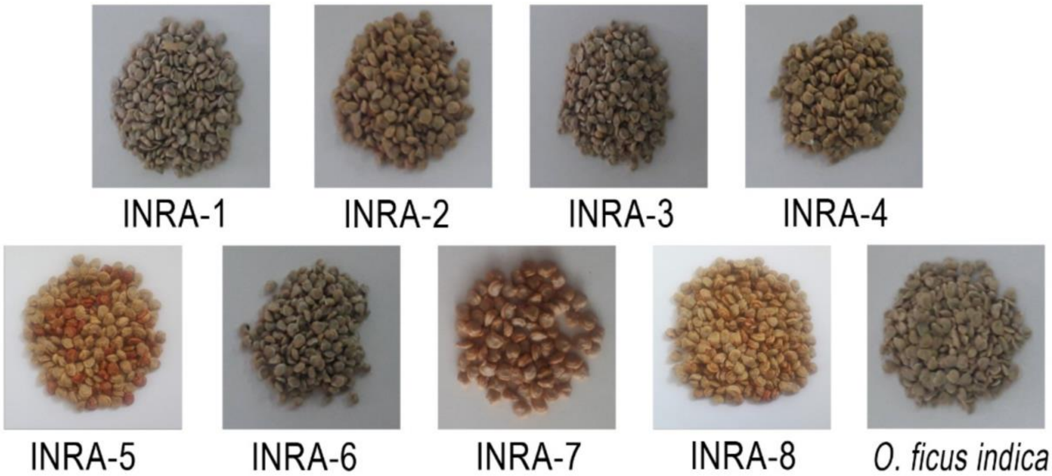

Figure 1. Photos of seeds from different cactus species (1 to 8: cochineal resistant varieties compared to a non-resistant variety (O. ficus indica) as reference).

Seed oil content

Prickly pear seed oil is fluid, relatively odorless and varies in color depending on variety, ranging from light yellow to greenish with a relatively low extraction yield (Lomanitz, 1920). Factors such as genotype and the presence of chlorophylls, carotenoids and betalains can explain the difference in colors between oils.

As depicted in Table 2, the eight cactus varieties exhibit distinct characteristics in terms of weight of 1000 grains, oil content, mechanical extraction yield, and mechanical extraction efficiency. Among them, INRA-8 displayed the highest oil percentage (16.44%), closely followed by INRA-4 (16.34%), while *O. ficus indica* showcased the lowest (9.06%). These findings hold significance in the selection of an ideal cactus variety for specific purposes, such as oil production, based on desired characteristics. The lowest oil content value observed for the cochineal-resistant prickly pear varieties studied was statistically similar to that of the reference variety (9.06%). These contents are slightly higher than the average (8.74%) reported by El Hachimi et al. (2015). Benattia *et al.* (2019) found lower oil contents (6.42%) in prickly pear seeds collected in the region of Relizane (Algeria). Other studies reported that the oil content of prickly pear seed ranged from 4.60 to 17.2% (Coşkuner and Tekin, 2003; Gharby *et al.,* 2020; Liu *et al.,* 2009). Ennouri *et al.* (2005) studied two *Opuntia* species from the Sfax region (Tunisia); they found an oil content of 10.90% and 11.05% for the seeds of *O. ficus-indica* and *O. strica* respectively. Other studies have shown that the yield percentage of extracted oil from *Opuntia dillenii* is about 6 to 7% (Alsaad *et al.,* 2019; Bouhrim *et al.,* 2021).

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The present findings indicates that, as for 1000-grain weight, seed oil content may depend on the species, genotypes, and region of origin (Belviranlı *et al.,* 2019). Also, differences in the oil content of cactus seeds from different origins can be explained by different climatic, environmental and growing conditions, as well as differences in research findings may be due to the difference in methods adopted and experimental conditions (Matthäus and Özcan, 2011).

Table 2: 1000-grain weight and extraction performance of the oils from the seeds of the Opuntia cactus varieties resistant to D. opuntiae in Morocco.

Coded cactus varieties	Weight of 1000 grains (g)	Oil content (%)	Mechanical extraction yield (%)	Mechanical extraction efficiency (%)
INRA-1	7.29 ± 0.00 [f]	13.29 ± 0.49 [abc]	7.10 ± 0.40 [abc]	53.39 ± 1.04 [a]
INRA-2	11.15 ± 0.15 [c]	13.78 ± 0.28 [abc]	7.30 ± 0.30 [ab]	52.97 ± 1.12 [a]
INRA-3	6.14 ± 0.04 [g]	13.22 ± 0.32 [bc]	7.05 ± 0.35 [abc]	53.32 ± 1.38 [a]
INRA-4	10.16 ± 0.01 [d]	16.34 ± 0.34 [ab]	8.20 ± 0.30 [ab]	50.17 ± 0.79 [a]
INRA-5	6.52 ± 0.02 [fg]	10.79 ± 1.09 [cd]	5.20 ± 0.70 [cde]	48.03 ± 1.64 [a]
INRA-6	6.83 ± 0.08 [fg]	13.22 ± 0.28 [bc]	6.35 ± 0.35 [bcd]	48.00 ± 1.63 [a]
INRA-7	15.90 ± 0.10 [a]	9.54 ± 0.06 [d]	4.75 ± 0.15 [de]	49.83 ± 1.91 [a]
INRA-8	14.60 ± 0.40 [b]	16.44 ± 1.06 [a]	8.51 ± 0.04 [a]	51.93 ± 3.07 [a]
*O. ficus indica**	8.57 ± 0.07 [e]	9.06 ± 0.05 [d]	4.30 ± 0.20 [e]	47.48 ± 1.92 [a]

*: Variety not resistant to cochineal. Results are expressed as mean ± standard deviation. Values in the same column with at least one letter in common are not significantly different at the 5% probability level.

Oil extraction yield

The results of seeds oil extraction by the mechanical press (oil extraction yield) are reported in Table 1. Oil extraction yield of the resistant varieties ranged between 4.75% (w/w) for variety INRA-7 and 8.20% (w/w) for variety INRA-4 and were all higher than the mechanical extraction yield of the reference *O. ficus indica* (4.30% (w/w)). The use of conventional extraction methods, including solvent extraction and mechanical processes, to extract prickly pear seed oil have been reported in previous studies (Al-Naqeb *et al.,* 2021; Ortega-Ortega *et al.,* 2017; Yeddes *et al.,* 2012). However, in comparison with the study reported by Regalado-Rentería *et al.* (2020), prickly pear seed oil was extracted using a cold mechanical press method that gave a lower yield ranging from 0.51 to 6.1%. These yields are supported by the results of De Wit et al. (2021), who found values between 2.51% and 5.96%.

The mechanical extraction yields obtained in this study confirmed the previous findings of the above research, with a slight improvement for some studied varieties, as shown in Table 1. In this context, it should be noted that the oil yield of the seeds depends primarily on the prickly pear variety used, and secondly on the extraction process (Karabagias *et al.,* 2020).

Oil extraction efficiency

Prickly pear seed oil is an oleaginous resource that is rich in essential fatty acids with high value applications in nutritional, cosmetic and medicinal fields. Mechanical screw pressing is an efficient method to extract prickly pear seed oil of virgin grade for health care with high nutritional value, which can also be easily implemented on an industrial scale. This method is widely used for the production of prickly pear oil that is generally used for cosmetic purposes. Indeed, it has several advantages in terms of quality of the oil extracted in an eco-friendly manner and without using solvents.

Results of table 2 show that the cactus seeds oil extraction by mechanical press allowed the extraction of only the half of their oil content. In fact, values of oil extraction efficiency for the resistant varieties were similar and ranged from 48.00 to 53.39% with an average of 50.56%. They were all higher but not significantly different ($p > 0.05$) than the reference variety oil extraction efficiency (47.48%). Similar results were obtained with supercritical CO_2 extraction technique by Koubaa et al. (2017) who reported an oil extraction efficiency of 49.9%.

Fatty Acid (FA) composition

The analysis carried out using gas chromatography allowed to establish the fatty acid profile of prickly pear seed oils of the varieties studied (Table 2). Results show that prickly pear oils were highly unsaturated, UFA fraction represented 76.31 to 82.63%, with an average of 79.57% of total FA and UFA/SFA ratio of 3.48 to 5.36. Ghazi et al. (2013) reported that this ratio was 4.63 and 4.91 for oils extracted from *Opuntia ficus indica* and *Opuntia dillenii* seeds, respectively. Linoleic acid was the dominant fatty acid and represented between 61.91 and 68.35% for the variety INRA-1 and INRA-7, respectively. The SFA fraction was composed of Palmitic and Stearic acids and represented between 15.43 and 21.90%.

The differences observed in the oil content and fatty acid composition of seed oils derived from the cochineal-resistant varieties of *D. opuntia* could potentially be attributed to the influence of habitat and/or the level of fruit ripeness (Coşkuner and Tekin, 2003). These variations might be influenced by various factors, including environmental conditions, genetic traits, plant stress levels, fruit development stages, varieties, and geographical origins (Belviranlı *et al.,* 2019), among others. However, all the seed oils of these varieties showed higher unsaturation degree and linoleic acid, and lower palmitic and linolenic acids contents than the oil of the non-resistant variety *O. ficus indica*, used as the reference.

Our results are in accordance with those found by Ali *et al.* (2022), they reported a content of 66.79%, 15.16% and 12.70% for linoleic acid, oleic acid and palmitic acid respectively, in the seed oil of *Opuntia ficus-indica L*. El Hachimi *et al.* (2015) reported that the unsaturated fatty acids represented more than 80% of the fatty acid composition of *Oputia ficus indica L*. seed oil, and 16.64% as average content of SFA.

The composition of the fatty acid profile of the oils studied demonstrate the importance of the new cactus varieties resistant to *D. opuntiae* seed oils as a natural source of PUFA and their potential as a functional food and a highly prized ingredient in cosmetic formulations, particularly because of their richness in linoleic acid (Ail El Cadi, 2001). Miller *et al.* (1991) reported that oils rich in linoleic acid are widely used in homeopathic preparations for dry inflamed skin. In particular, it has been found to be effective in treating dry and inflamed skin. Homeopathic preparations that contain linoleic acid, such as creams and oils, have been used for many years to help alleviate skin conditions like eczema, psoriasis, and dermatitis. Linoleic acid is present in various skincare products, such as moisturizers, serums, and face oils. It is a preferred ingredient in natural and organic skincare items because of its gentle and non-irritating properties, and most skin types can tolerate it well.

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Table 3: Main fatty acid composition of seed oils extracted from different Opuntia cactus varieties resistant to *D. opuntiae* in Morocco.

Coded cactus varieties	Palmitic acid (C16:0)	Palmitoleic acid (C16:1)	Stearic acid (C18:0)	Oleic acid (C18:1)	Linoleic acid (C18:2)	Linolenic acid (C18:3)	UFA	SFA	UFA/SFA
INRA-1	14.19 ± 0.02 c	0,65 ± 0,01b	5.94 ± 0.02 b	15.58 ± 0.07 b	58.61 ± 0.11 e	0.44 ± 0.01 bc	78.58 c	20.11 d	3.90 b
INRA-2	15.08 ± 0.02 b	0,46 ± 0,02a	5.62 ± 0.05 c	8.22 ± 0.02 e	66.42 ± 0.05 ab	0.36 ± 0.00 d	77.38 b	20.70 e	3.74 b
INRA-3	13.09 ± 0.05 d	0,62 ± 0,05ab	4.49 ± 0.02 e	12.00 ± 0.05 d	64.64 ± 0.05 bc	0.46 ± 0.01 b	80.48 d	17.58 c	4.58 c
INRA-4	13.85 ± 0.04 c	0,63 ± 0,03ab	6.28 ± 0.02 a	11.07 ± 0.02 d	64.27 ± 0.02 cd	0.35 ± 0.00 d	77.95 bc	20.12 d	3.87 b
INRA-5	11.67 ± 0.02 e	0,55 ± 0,02ab	4.48 ± 0.05 e	18.43 ± 0.15 a	59.95 ± 0.25 e	0.42 ± 0.01 c	81.89 e	16.15 b	5.07 d
INRA-6	13.15 ± 0.05 d	0,64 ± 0,01b	4.68 ± 0.02 d	13.28 ± 0.02 c	63.06 ± 0.01 cd	0.46 ± 0.01 b	80.36 d	17.83 c	4.51 c
INRA-7	11.37 ± 0.13 e	0,87 ± 0,07c	4.06 ± 0.04 f	13.20 ± 0.40 c	67.25 ± 0.35 a	0.21 ± 0.01 e	82.63 e	15.43 a	5.36 e
INRA-8	13.00 ± 0.10 d	0,64 ± 0,01b	4.68 ± 0.02 d	13.25 ± 0.05 c	62.53 ± 0.52 d	0.46 ± 0.01 b	80.55 d	17.68 c	4.56 c
*O. ficus indica**	16.09 ± 0.09 a	0,92 ± 0,02c	5.82 ± 0.02 b	13.35 ± 0.35 c	56.69 ± 0.69 f	0.54 ± 0.01 a	76.31 a	21.90 f	3.48 a

*: Variety not resistant to cochineal. Results are expressed as mean ± standard deviation. Values in the same column with at least one letter in common are not significantly different at the 5% probability level.

The Omega-3 essential fatty acids (EFA) have received a lot of attention recently even though it has been known since 1930 that linoleic and linolenic acids are necessary for normal growth and proper skin function. Holman (Holman, 1998) discovered the importance of linoleic acid and he demonstrated that this acid has an effect against hair loss and skin dryness. Also the richness of prickly pear seed oil in both oleic acid and palmitic acid gives it restructuring, regenerating and moisturizing properties (Boelsma *et al.,* 2001).

Cactus seeds oil is used in cosmetic formulations for the development of a range of products against skin aging for the Moroccan and international market. However, Genot *et al.* (2004) mentioned in a study that oils rich in long chain fatty acids are very sensitive to oxidation, which can alter its sensory, nutritional and functional properties (Boutakiout *et al.,* 2022). The composition of this oil (cactus oil) demonstrate that prickly pear can be an interesting natural source of edible oil as it contains high amounts of essential fatty acids. These fatty acids are known for their capacity to reduce the risk of heart disease and inflammation, improve brain function, and promote skin health (Matthäus and Özcan, 2011). To illustrate the commercial feasibility of producing prickly pear seed oil, there are about twenty valorization units in Morocco. This highly sought-after oil in the cosmetic industry is intended for both national and international markets, especially in Europe and the United States. In addition, its extraction uses an easy-to-use mechanical extraction method with a continuous screw press, typically carried out by women's cooperatives in rural areas, near the cactus fields.

Conclusions

This research evaluated seed oil content and oil extraction efficiency of eight *Opuntia spp.* resistant to *D. opuntiae* and are already registered in the official catalogue of species and varieties in Morocco. The seed oil content of the studied cactus varieties ranged from 9.54 to 16.44% (w/w). The mechanical press extraction allowed the recovery of half of the seed crude oil content; obtained extraction yield was between 4.75 and 8.51% (w/w) and a corresponding extraction efficiency ranging from 48.00 to 53.39% with an average of 50.56%. Analysis of the fatty acids profile of oils extracted from the seed of the cochineal-resistant varieties studied were found to be rich in unsaturated fatty acids, UFA percentage and UFA/SFA ratio ranged from 76.31 to 82.63% and 3.48 to 5.36, respectively. Linoleic acid was the dominant fatty acid and represented between 61.50 and 68.35% of the total FA. The SFA fraction was composed of Palmitic and Stearic acids and represented between 15.53 and 21.90 %.

The new cochineal resistant varieties (INRA varieties) studied for their seeds oil content and FA profile have an equivalent or even slightly better performance as a source of seeds oil, compared to the *Oputia ficus indica*, the *D. opuntiae* non-resistant variety used as a reference. Thus, the new cochineal-resistant varieties may be considered in Morocco, as alternatives to the usual *O. ficus indica* destroyed and still threatened by this harmful scale pest. Future research should investigate the flavonoids, phenols, sterols, and volatile components in these oils. Also, in light of its high value and low content in the seed, extraction methods should be optimized to take advantage of this oil and increase its application in food, cosmetics, and medicines.

Ethics statement

It is not applicable

Consent for publication

It is not applicable

Availability of supporting data

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Author contributions

Conceptualization, C.Y. and S.M.; methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, C.Y.; writing—review and editing, S.M. and E.M.; supervision, S.M. All the authors read and approved the manuscript.

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