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RESEARCH ARTICLES

Physicochemical, phytochemical and antioxidant properties of juice and seed oil of cactus pear *Opuntia aequatorialis and Opuntia leucotricha*

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Abstract

The present study aims to design for the first time the physicochemical properties, fatty acids, tocopherols and phytosterols of cactus juice and seed oil from *O. aequatorialis* (O.A) and *O. leucotricha* (O.L) than compared with two other species widely studied [*O. ficus indica* (O.F.I) and *O. megacantha* (O.M)]. Fatty acids and phytosterols were quantified by gas chromatography; whereas tocopherols were performed by HPLC. The physicochemical results showed that O.A exhibited the highest levels of acidity and proteins. The highest Vitamin C content was recorded in the juice of O.M species. Total phytosterols and tocopherols content are highest in the seed oil of O.A and O.F.I species with β-sitosterol and γ-tocopherol, the major isoforms detected. Oleic and linoleic acids were detected in fatty acids profile. The juice exhibits strong antioxidant activity. Fruits of O.A and O.L own substantial antioxidant ingredients offering add value for functional foods and contributing to the development of food and nutritional products.

Keywords Antioxidant · Chromatography · Fruit juice · *Opuntia* · Phytochemical · Seed oil

Introduction

Opuntia spp., commonly known as prickly cactus pear, nopal or barbary fig is a perennial native of Mexico, which belongs to the Cactaceae family. This species has a commercial value in the production of juices, jams and natural liquid sweeteners (Abdel-Hameed et al. 2014). Recently, scientists have focused their efforts toward *Opuntia ficus-indica*, the most cultivated species. However, *Opuntia* genus has over 200 species that could be more important for the bio-industries (Helsen et al. 2007). Besides that, *Opuntia* spp. is a good source of plant bioactive compounds and products (Chahdoura et al. 2015; Poudel et al. 2019), which change in term of species, cultivar, fruit parts, and climate conditions (Aragona et al. 2018). Indeed, the phytochemical diversity of Cactaceae family has been highlighted in several studies (Aragona et al. 2018). The compounds examined in cactus have nutritional benefits and are usually categorized into phenolic, non-phenolic compounds and pigments (Martins et al. 2011). According to studies conducted on this species, both *Opuntia* fruits and cladodes contain high values of important nutrients. The cactus fruit is a valuable source of vitamin C, flavonoids, phenolic acids,

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carotenoids and betalains (El Kharrassi et al. 2016), while cladodes are rich in mineral, amino acids, vitamins and sterol (Aragona et al. 2018). In addition, the cactus seed oil is commercially exploited by cooperatives and companies due to its nutritive value; and particularly to its richness in polyunsaturated fatty acids, phytosterols, tocopherols and phenolic content (Aragona et al. 2018; El Kharrassi et al. 2018). The food industry has widely used cactus species for their gelling properties and as a source of fibre and food colouring (Aragona et al. 2018). In fact, it is considered as a functional ingredient of nutraceutical, dietary and food supplement products suitable for the human and animal consumption (Ciriminna et al. 2017). Cactus plays an important position in Morocco's economy, allowing it to stand as the main producer in the Mediterranean country. Although, only *O. ficus indica* species was cultivated clonally (El Kharrassi et al. 2017). This species, botanically classified as a succulent plant, adapts well to extreme climate conditions, and it has a rapid growth in poor soils with low water requirement (Aragona et al. 2018). There is actually a need to expand the cactus genetic diversity used in cactus industry and to shed light on other *Opuntia* species that could be of high importance than the traditionally used *O. ficus indica*. The assessment of genetic diversity of Moroccan cactus species can be useful for plant breeding and hence the production of more efficient and nutritive cactus species (El Kharrassi et al. 2017). In this study, we have focused for the first time on the chemical profile and the biological activity of juice and seed oil extracts of *O. aequatorialis* Britton and Rose and *O. leucotricha* de Candolle to compare with two other species widely studied and cultivated in Morocco, *O. ficus indica* and *O. megacantha* Salm-Dyck. This investigation will provide new valued data on nutritional compositions and phytochemical properties of *Opuntia* spp. for better practical application in the food, beverage and nutraceutical industries.

Materials and methods

Plant material and sample preparation

Fruits of four species of *Opuntia* named *O. ficus indica* (O.F.I), *O. megacantha* (O.M), *O. aequatorialis* (O.A) *and O. leucotricha* (O.L) were collected in July and August 2017, from 7-year-old cactus pear plants growing at the experimental site "Ain Nzagh" of the National Institute of Agronomic Research INRA-CRRA (Settat, Morocco). Botanical description of plants studied was conducted as described by El Kharrassi et al. (2017). Cactus species were grown under similar edaphoclimatic conditions. After preparing the fruits samples at the Cooperative of Sabbar Rhamna (Skhour Rhamna, Morocco), seeds and juice were separated by an industrial prickly pear juice extract machine (Philips Viva HR1832/00, India). Juice was stored at – 20 °C after measuring their pH, whereas seeds were washed thoroughly with water, dried in the open air, then extracting seed oil by extraction machine (Longer machinery, LGYL-80A, Henan, China) and stored in the darkness.

Physicochemical analysis

Nutritional value of fruit juice in the four cactus species studied was assessed using different parameters. As described by El Kharrassi et al. (2016), the quantification of the total titratable acidity was performed using phenolphthalein as the color change indicator and reported as meq/l (Camara et al. 1994). Soluble solids content was measured using a refractometer (Erma, Tokyo, Japan), and reported in degree brix at 20 °C.Total protein content was determined by the Kjeldahl method (1883). Lipid content was estimated using the Association of Official Analytical method (AOAC 1990). Vitamin C or ascorbic acid content was measured according to the method described by Moussa-Ayoub et al. (2016) and reported in mg per liter. Sugar levels were determined according to the AOAC (1995), using high-performance liquid chromatography (HPLC) coupled to a refraction index detector (HPLC-RI, Knauer, Smart line system 1000, Berlin, Germany) following to the procedure developed previously by Pereira et al. (2011).

Phytochemical analysis

Quantification and determination of the phytosterol composition in the seed oil was conducted by gas chromatograph (GC, HP 6890, Agilent J&W, 19091J-413, Santa Clara, USA), using a flame ionization detector, on a HP-5: 5% phenyl methyl siloxane capillary column (30 m, 0.32 mm, 0.25 µm thickness, USA). Total phytosterol content was quantified as mg/kg of oil. Besides, each phytosterol was reported in percentage of total phytosterols (COI/T20/ doc no 26 Rev 4 2018). Total fatty acids (FAMEs) profile in seed oil samples, was identified according to their retention times to those of standards, using gas chromatography (GC; HP 6890, Agilent Technologies, Santa Clara, CA, USA) contained a flame ionization detector and a capillary column (70% Cyanopropyl polysilphenylen, 60 m × 0.25 mm, 0.25 µm thickness) (COI/T 20 / doc no 33 Rev 1 2017). Tocopherols profile in seed oil samples was quantified by high-performance liquid chromatography (HPLC, HP 1050, Hewlett–Packard, PA, USA) equipped with differential refractometer as detector on an octadecylsilane silica (C18) column (280 mm L, 4.6 mm ID, 5 µm particle size). The isooctane/ isopropanol (99:1, v/v) was the eluting solvent (ISO 9936 2006). All reagents used in this study were procured from Loretz GmbH (Hilden, Germany) and Sigma–Aldrich (St. Louis, MO, USA).

Antioxidant activity

The antioxidant potential was determined in seed oil and juice extracts from the four cactus species studied by different procedures, using various in vitro systems such as DPPH, ABTS+, FRAP, and BCB assays. DPPH (2,2 diphenyl1′ picryl hydrazyl) radical scavenging assay was done according to the procedures described by Zuraini et al. (2008) and ascorbic acid was used as a positive control. DPPH radical scavenging capacity was expressed as µmol Trolox equivalent per ml of cactus juice or seed oil (µmol TE/ml). For the ABTS radical cation depolarization assay, the method used was as described by Re et al. (1999). The absorbance was recorded on a spectrophotometer (ThermoElectron Corporation Helios Gamma, Hemel Hempstead, Hertfordshire, England) at 734 nm. The ABTS radical-scavenging activity of the extract was calculated from the calibration curve of Trolox and expressed as µmol Trolox equivalent per ml of cactus juice or seed oil (µmol TE/ml). Ferric reducing antioxidant power (FRAP) was performed based on the method described by Benzie and Strain (1996). Absorbance at 593 nm was determined against distilled water blank, and quercetin was used for calibration. The FRAP values were expressed as µmol Trolox equivalent per ml of cactus juice or seed oil (µmol TE/ml). The β-carotene bleaching (BCB) assay was evaluated by the method of Amin and Tan (2002). The absorbance was determined using a model EAR 400 microtiter reader (Lab systems Multi skan MS) at 470 nm. The results were expressed as IC50 values (µg/ml) of cactus juice or seed oil.

Statistical analysis

Measurements were conducted in triplicate. The mean and standard deviation were calculated for each analysis. Analysis of variance (ANOVA) was performed and means were compared using the Turkey test at a significance level of $p < 0.05$. The software SPSS version 10.0 was used to perform statistical analyses.

Results and discussion

Physicochemical composition

In our study, we were interested to characterizing the physicochemical propriety of fruits juice of *Opuntia* species studied (Table 1). The obtained results showed significant statistical differences between the four species regarding acidity, proteins and ascorbic acid content ($p < 0.05$). O.A species exhibited significantly highest acidity and proteins levels compared to other species studied. However, the highest ascorbic acid content was recorded by O.M ($p < 0.05$). O.A contain significantly the highest protein content with a value of 1.1% while the total protein contents in O.L and O.M was 0.6% ($p < 0.05$). The highest titratable acidity was found in O.A and the lowest one was in O.L (Table 1). In terms of species studied, there was no significant difference linkage between acidity and species. The results obtained presented a high concentration of titratable acidity, which does not support the previous works. These differences could be beneficial in fruit processing as they contribute to decrease the addition of the artificial acidic components (Cavalcante et al. 2012). But some cactus genotypes grown in other countries showed lower acidity levels (El-Razek and Hassan 2011). These variations can be related to genotype, species and environmental effect and to the shelf life of the juice. We did not point out any significant interspecies differences regarding the pH, brix, lipids, glucose and fructose levels ($p < 0.05$). Within Moroccan populations, the juice shows low pH values ranging from 3.3 to 4.8 and 3.8–4.8 in O.F.I and O.M respectively (El Kharrassi et al. 2016). Biologically, the low pH values can inhibit pathogens growth and consequently conserve food quality (Mert 2010) contrary to the Egyptian cultivars, which have high pH values of 7.1 (El-Razek and Hassan 2011). Ascorbic acid (Vitamin C) plays a major role in human food and nutrition due to its antioxidant properties. Today, it becomes well known that cactus pear fruits are rich in antioxidant vitamin C (20–40 mg/100 g) (El Kossori et al. 1998). According to our measurements, O.M showed the highest (24.6 mg/L)

Table 1 Results of certain physicochemical parameters in the fruit juice extracted from four *Opuntia* species from Morocco (*O. aequatorialis, O. leucotricha, O. ficus indica*, and *O. megacantha*)

Species	pH	Acidity (meq/l)	°Brix	Lipids (%)	Proteins (%)	Ascorbic Acid (mg/l)	Fructose (%)	Glucose (%)
O.A	5.73 ± 0.06a	17.40 ± 0.17a	16.20 ±2.54a	0.01 ± 0.00a	1.10 ± 0.10a	2.40 ± 0.87c	6.00 ± 0.62a	9.90 ± 1.32a
O.L	5.77 ± 0.06a	12.80 ± 0.40b	12.50 ±1.32a	0.01 ± 0.00a	0.60 ± 0.11b	5.50 ± 0.09b	4.80 ± 0.46a	7.40 ± 0.76a
O.F.I	5.77 ± 0.06a	13.83 ± 0.78b	14.10 ± 1.23a	0.01 ± 0.00a	0.77 ± 0.06b	6.20 ± 0.87b	5.00 ± 0.55a	8.80 ± 1.05a
O.M	5.73 ± 0.06a	13.27 ± 0.31b	14.20 ± 1.06a	0.01 ± 0.00a	0.60 ± 0.07b	24.60 ± 1.86a	5.20 ± 1.15a	8.80 ± 1.23a

Results expressed as mean ± standard deviation (n = 03). Different letters in the same line mean significant difference ($p < 0.05$) by the Tukey test concentrations (Table 1). However, no statistical difference was noted between O.L and O.F.I. Indeed, O.L showed a concentration of about 5.5 mg/L relatively close to that recorded in O.F.I (6.2 mg/l). Vitamin C concentrations were reported to change significantly between species and genotype, which is in accordance with El Kharrassi et al. (2016) who reported highest vitamin C concentration, 29.2 and 22.1 mg/L in O.F.I accessions from Guelmim and O.M accessions from Sidi Boumehdi, respectively. Vitamin C content in *O. robusta* from Mexico was assessed at 4 mg/100 g fresh weight and 121 µg/g fresh weight in *O. lindheimeri*, 815 µg/g fresh weight in *O. stricta* and *O. streptacantha* from Mexico (El Mostafa et al. 2014). The difference in the present results according to the literature could be related to the difference in the environmental and genotypic conditions influencing the ascorbic acid content.

In terms of fruit quality, the juices sugars are important components as they provide a good taste. Therefore, fructose and glucose were quantified using HPLC (Table 1). The glucose as the predominant sugar along with fructose was present in the same quantities in the four species juices with no significant differences. Both O.M and O.F.I showed almost the same glucose rate (8.8%). Those results supported previous finding reported on two prickly pear cactus cultivars *(O. ficus-indica* Mill.) (Abdel-Hameed et al. 2014). There was as well no significant difference in total soluble solid content among the four species. In Moroccan accessions, O.F.I and O.M, the average Brix value was previously determined at 12.6° (El Kharrassi et al. 2016). Other researchers reported brix range of 14.67° for O.F.I from Egypt (El-Razek and Hassan 2011). These reports corroborate with our obtained results.

Phytosterol composition

In our study, the analysis of phytosterols in the seed oil extracted from the four species allowed us to identify some major phytosterols that typically characterize vegetable oils (Table 2). The phytosterol content varied significantly depending on the species ($p < 0.05$). O.A hold the high total phytosterols content in comparison with the other species ($p < 0.05$). The total phytosterol content was 1219.50, 889.10, 832.90 and 760.30 mg/kg for O.A, O.L, O.F.I, O.M respectively (Table 2). Remarkably, the main phytosterol fraction exhibited was β-sitosterol in all the species, with the highest rate was recorded in O.A about 76.15%, followed by Campesterol with 10.20% in O.A and 11.20% in O.L (Table 2). These recorded rates agree with the previous results reported by Ghazi et al. (2013). The percentage of the seven identified phytosterols showed statistically significant differences among the four species, except for Δ5-Avenasterol. In terms of interspecies differences, the highest percentage was found in O.A, whereas the O.L showed the highest level of both Campesterol and Stigmasterol (11.20% and 1.64% respectively). Besides these identified phytosterols, other small phytosterols were found in small quantities notably Δ7-Stigmasterol, Δ7-Avenasterol and Cholesterol. The highest levels were recorded in O.F.I, of about 1.08% and 2.31% respectively, followed by O.M (1.04%) (Table 2). These results concord with other findings previously described by El Kharrassi et al. (2018). Cactus seems to be interesting to add to food matrices rather than fat spread including low-fat milk bakery products, cereal bars, low-fat and non-fat beverages and chocolate bars (Jones et al. 2009). Our result showed the richness of the cactus in phytosterols, which proves the possibility of using it in functional foods. Unlike the fatty acid ester forms, the administration of these active compounds, especially free phytosterols, in functional food may not induce malabsorption of fat-soluble vitamins and antioxidants (Jones et al. 2009).

Fatty acids composition

The lipid profile of the seed oil in the four species was studied and different categories of fatty acids were shown in

Table 2 Total phytosterols (mg/kg) and phytosterol composition (%) of cactus pear seed oil extracted from four different *Opuntia* species: *O. aequatorialis, O. leucotricha, O. ficus indica*, and *O. megacantha*

	O. aequatorialis	*O. leucotricha*	*O. ficus indica*	*O. megacantha*
Total phytosterol	1219.50 ± 47.70a	889.10 ± 33.20b	832.90 ± 29.50bc	760.30 ± 12.90c
Cholesterol	0.83 ±0.01c	1.01 ± 0.12ab	0.97 ± 0.03b	1.04 ± 0.02a
Campesterol	10.20 ± 0.12b	11.20 ± 0.14a	10.31 ± 0.13b	10.33 ± 0.16b
Stigmasterol	1.12 ± 0.02c	1.64 ± 0.02a	1.54 ± 0.04b	1.48 ±0.03b
β-Sitosterol	76.15 ± 0.19a	72.68 ± 1.02b	74.71 ± 1.22ab	74.62 ± 0.99ab
Δ5-Avenasterol	5.39 ± 0.16a	5.43 ± 0.07a	5.14 ± 0.24a	5.22 ± 0.07a
Δ7-Stigmasterol	0.89 ± 0.13b	0.59 ± 0.01c	1.08 ± 0.02a	0.56 ± 0.01c
Δ7-Avenasterol	1.05 ± 0.01c	1.29 ± 0.03b	2.31 ± 0.13a	1.08 ± 0.01c
Other phytosterols	4.36 ± 0.59a	6.15 ± 1.26a	3.95 ± 1.77a	5.68 ± 1.25a

Results expressed as mean ± standard deviation (n = 03). Different letters in the same line mean significant difference ($p < 0.05$) by the Tukey test

Table 3 Fatty acid composition (%) of cactus pear seed oil extracted from four different Moroccan *Opuntia* species (*O. aequatorialis, O. leucotricha, O. ficus indica*, and *O. megacantha*)

	O. aequatorialis	*O. leucotricha*	*O. ficus indica*	*O. megacantha*
C14:0 (myristic acid)	0.09 ± 0.00a	0.08 ± 0.01a	0.08 ± 0.01a	0.08 ± 0.02a
C16:0 (palmitic acid)	12.24 ± 0.11a	12.03 ± 0.01bc	12.17 ± 0.01ab	11.98 ± 0.02c
C16:1, ω-7 (palmitoleic acid)	0.71 ± 0.02a	0.71 ± 0.01a	0.72 ±0.01a	0.7 ± 0.01a
C17:0 (margaric acid)	0.05 ± 0.00a	0.05 ± 0.00a	0.04 ± 0.01a	0.05 ± 0.00a
C17:1 (margaroleic acid)	0.02 ± 0.00a	0.02 ± 0.00a	0.02 ± 0.00a	0.02 ± 0.00a
C18:0 (stearic acid)	3.53 ± 0.06a	3.59 ± 0.02a	3.42 ± 0.02b	3.54 ± 0.04a
C18:1, ω-9 (oleic acid)	21.52 ± 0.23a	21.09 ± 0.01b	20.91 ± 0.03bc	20.77 ± 0.03c
C18:2, ω-6 (linoleic acid)	60.93 ± 0.22c	61.55 ± 0.03b	61.81 ± 0.02ab	62.00 ± 0.00a
C18:3, ω-3 (linolenic acid)	0.29 ± 0.05a	0.23 ± 0.00ab	0.22 ± 0.01b	0.22 ± 0.01b
C 20:0 (arachidic acid)	0.33 ± 0.01a	0.34 ± 0.01a	0.32 ± 0.01a	0.33 ± 0.01a
C 20:1 (gondoic acid)	0.29 ± 0.01b	0.31 ± 0.01a	0.29 ± 0.00b	0.32 ± 0.01a
SFA	16.24 ± 0.05a	16.09 ± 0.02b	16.03 ± 0.01bc	15.98 ± 0.01c
MUFA	22.54 ± 0.22a	22.13 ± 0.01b	21.94 ± 0.03bc	21.81 ± 0.04c
PUFA	61.22 ± 0.18c	61.79 ± 0.02b	62.03 ± 0.03a	62.21 ± 0.03a

Results expressed as mean ± standard deviation (n = 03). Different letters in the same line mean significant difference ($p < 0.05$) by the Tukey test

SFA saturated fatty acids, *MUFA* monounsaturated fatty acids, *PUFA* polyunsaturated fatty acids

Table 3. Eleven fatty acids were identified in our samples, of which the linoleic acid (60.93−62%) followed by oleic acid and palmitic acid (20.77–21.52% and 11.98–12.24% respectively) are the most dominant in the lipid composition of seed oil in all studied species. The percentage of few fatty acids such as, palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid and gondoic acid were change significantly ($p < 0.05$) depending on species studied. Whereas other fatty acids were detected in low amounts. Previously, it is reported the *Opuntia* spp. richness in unsaturated fatty acids (El Kharrassi et al. 2018). Ghazi et al. (2013) proved the richness of O.F.I with fatty acids and indicated that linoleic acid was the dominating fatty acid; however, our results showed that O.M is the richest in this compound (62%) compared to other species. The O.F.I seeds could be used as nutraceutical agents (Aragona et al. 2018). Also, Ciriminna et al. (2017) reported that the seed oil of *O. ficus-indica* and *O. dillenii*, due to its important amount of unsaturated fatty acids, can offer significant potential as new ingredient in nutraceutical, food supplement, sport drink and food products. High rates (80 and 84%) of oleic acid and linoleic acid respectively, have been found in the seed oil of O.F.I (Taoufik et al. 2015). Palmitic, stearic, oleic, and linoleic acids were previously detected in O.F.I seed oil ranging between 11.22 and 11.77%, 2.97 and 3.23%, 13.61 and 15.46%, and 60.94 and 63.38%, respectively (Belviranli et al. 2019). In comparison with other *Opuntia* species oils, Ghazi et al. (2013) have reported that *O. dillenii* contain linoleic acid: 79.83%, and palmitic acid 13.52% as the main fatty acids. Ramírez-Moreno et al. (2017) reported that the palmitic, oleic and linoleic acids in *O. albicarpa* from Mexico, presented 12.327; 16.215 and 67.448% respectively. The three categories of fatty acids: saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) revealed significant differences between the four species ($p < 0.05$). In the four Moroccan *Opuntia* species, the PUFA are the most dominant with more than triple and quadruple, respectively, regarding MUFA and SFA. Regarding the species factor, the O.A showed highest SFA and MUFA level, while both O.F.I and O.M exhibited the highest PUFA level. Our results are in line with previous findings in similar and different *Cactus* species (Chahdoura et al. 2015; El Kharrassi et al. 2018).

Tocopherol profile

Tocopherols or Vitamin E are particularly abundant in the cactus fruit seed oil, in which α- and **γ**-tocopherol are among the main components, amounting to about 80% of the total vitamin E content (El Kharrassi et al. 2018). They have suitable properties for human body as an essential lipophilic nutrient (Hensley et al. 2004). In our study, tocopherols and their main forms were as well determined in particular α-tocopherol, γ-tocopherol and δ-tocopherol for all species (Table 4). The high total tocopherol content was recorded in O.F.I and O.M (815 and 791.67 mg/kg, respectively) ($p < 0.05$). Nonetheless, except for the α-tocopherols, the both other tocopherol forms were not significantly different in the four species. The high α-tocopherol percentage was noted in O.L (1.35%) compared to the other species which revealed rates of 0.96% in O.M, 1.09% in O.F.I and 1.30% in O.A ($p < 0.05$). Among the three forms of tocopherols, the γ-tocopherol was the major component (about 98%) in the four species, confirming also the results presented

Table 4 Total tocopherols (mg/kg) and tocopherol composition (%) of cactus pear seed oil extracted from different Moroccan *Opuntia* species: *O. aequatorialis, O. leucotricha, O. ficus indica* and *O. megacantha*

Species	Total tocopherols	α-Tocopherol	γ-Tocopherol	δ-Tocopherol
O. aequatorialis	671.41 ±9.50b	1.30 ± 0.12ab	98.32 ± 0.20a	0.39 ± 0.07a
O. leucotricha	709.44 ± 8.97b	1.35 ± 0.22a	98.23 ± 0.32a	0.41 ± 0.18a
O. ficus indica	815 ± 43.77a	1.09 ± 0.05ab	98.45 ± 0.11a	0.46 ± 0.09a
O. megacantha	791.67 ± 7.53a	0.96 ± 0.11b	98.66 ± 0.05a	0.38 ± 0.08a

Results expressed as mean ± standard deviation (n = 03). Different letters in the same line mean significant difference ($p < 0.05$) by Tukey test

by R'bia et al. (2017). This especial constituent was also reported as the major isoform in the seed oil of O.F.I and O.M (Chahdoura et al. 2017; El Kharrassi et al. 2018). It has been reported by Hensley et al. (2004) that γ-tocopherol has a good impact on nutrition and human health with its antioxidant potential. It is also involved in the prevention activity of PUFA and contributes to improve the quality of oil through the stability towards oxidation, by preserving it from rancidity and prolonging its shelf-life (Chahdoura et al. 2017). Like other many oil seeds (e.g. canola and sesame), our findings showed that the Cactus seed oil seems to be a good source of tocopherols. These bioactive components are free radical scavengers and natural anti-oxidants, which can be formulated and applied to develop functional juices (Poudel et al. 2019).

Antioxidant activity

Plant natural antioxidants are gaining more attention in the development of foods with added nutraceutical value due to restriction of the synthetic antioxidants for their toxicity and carcinogenicity, as well as the valuable nutritional value. As shown in Fig. 1, statistical analysis of parameters related to antioxidant activity namely DPPH, ABTS,

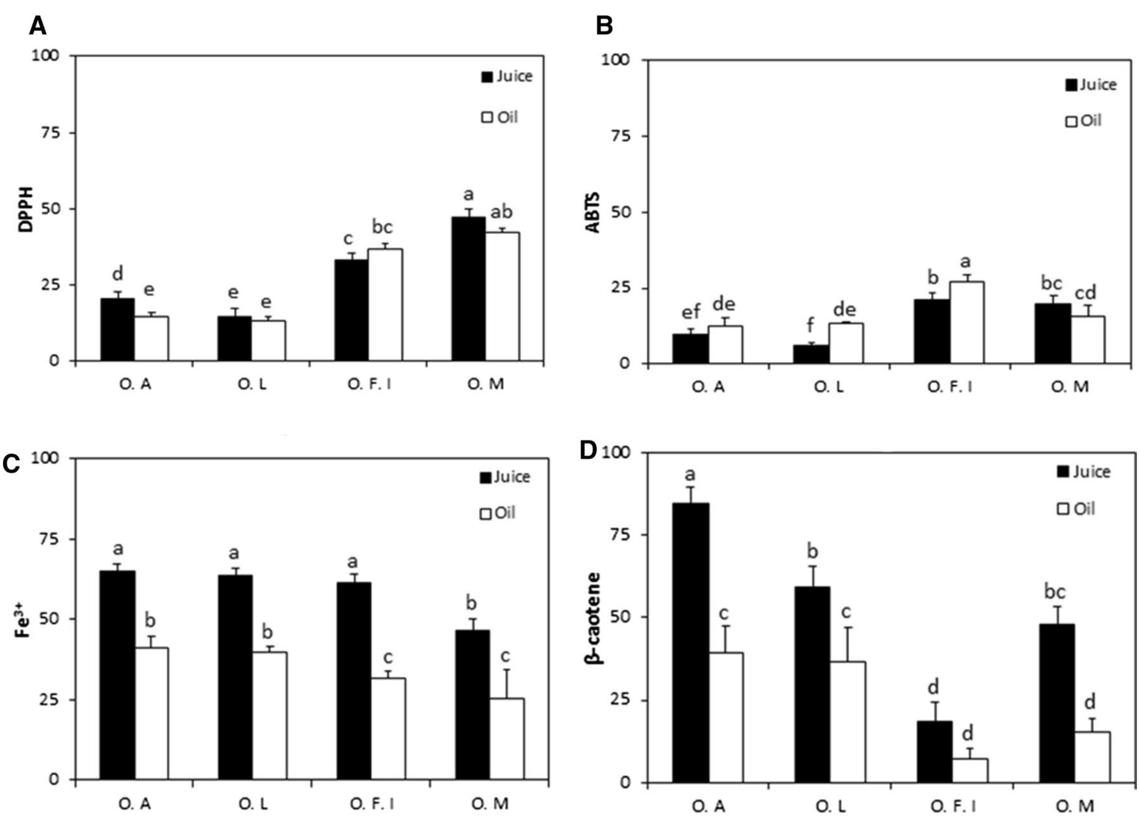

Fig. 1 Antioxidant activities in seed oil and juice extract of the four Moroccan *Opuntia* species (O. A, O. L, O. F. I, and O. M). **a** DPPH radical scavenging activity, **b** ABTS assay, and **c** ferric reducing antioxidant power (FRAP) (μmol (Trolox Equivalent)/ml, and **d** β-carotene bleaching (βCB) (IC50 values (μg/ml). Results are presented as mean ± standard deviation (n = 03). Different letters mean significant difference ($p < 0.05$) by the Tukey test

$Fe^{3+}$and β-carotene, in juice and seed oil from cactus species revealed significant interspecies differences ($p < 0.05$) (Fig. 1). For all studied species, the DPPH, Fe^{3+} and β-carotene activities were significantly highest in the juice extract compared to that of seed oils. However, the activity of ABTS in the oil extract in both O.L (13.20 µmol TE/ml) and O.F.I (26.91 µmol TE/ml) was significantly higher compared to the juice extracts. This result can be explained through the high content of γ-tocopherol (see Table 4) since it's involved to improve the activity of superoxide dismutase, thus taking part to different antioxidant effects Chahdoura et al. (2017). In terms of interspecies variation, the highest Fe^{3+} activity was recorded in O.A juice and in both O.A and O.L oil extracts ($p < 0.05$). Considering the DPPH, O.A showed the highest activity for both oil and juice extract, whereas O.F.I and both O.M and O.F.I exhibited the highest ABTS activity in oil and juice extract, respectively. Other antioxidants have been examined in oil and juice extracts from different *Opuntia* species from other countries (Chahdoura et al. 2017; Ramírez-Moreno et al. 2017; R'bia et al. 2017). Several studies have suggested that the antioxidant properties of the cactus are mainly due to its content of polyphenolics, flavonoids and ascorbic acid (Aragona et al. 2018; El Mostafa et al. 2014).

Conclusions

The present study illustrates the phytochemical profiles of Cactus juice and seed oil. Our results provided additional information on the nutritional characteristics, and antioxidants activities of other *Opuntia* species were not studied before. They showed that the fruit of the *Opuntia* spp. owns a source of natural antioxidants, considering their higher phenolic content and antioxidant capacity, which could be used for functional foods as prevention of oxidative stress-related diseases. In addition, the studied Cactus species appear a rich source of potentially important nutrients. Based on the chemical profile of the seed oil, further research trials are on its beneficial properties, and the isolation of the main constituents are required for food and nutraceutical industries. Present study provides useful data to nutritionists and food scientists that seek to develop the food industry as well as to support their nutritional value. Also, culture intensification could be one of the possible perspectives for marketing products of species with interesting nutritional traits like *O. aequatorialis*. This approach will be useful on the increase of economic incomes and have high benefit advantages for Moroccan farmer.

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Compliance with ethical standards

Conflict of interest All contributing authors have no conflicts of interest to declare regarding this article.

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