ELSEVIER

Food Chemistry 82 (2003) 339–345

Food Chemistry

www.elsevier.com/locate/foodchem

Oil cactus pear (*Opuntia ficus-indica* L.)

Mohamed Fawzy Ramadan*, Jörg-Thomas Mörsel

Institute of Food Chemistry, Technical University of Berlin, TIB 4/3-1, Gustav-Meyer-Allee 25, D-13355 Berlin, Germany

Received 5 August 2002; received in revised form 13 November 2002; accepted 13 November 2002

Abstract

Seeds and pulp of cactus pear (*Opuntia ficus-indica* L.) were compared in terms of fatty acids, lipid classes, sterols, fat-soluble vitamins and β-carotene. Total lipids (TL) in lyophilised seeds and pulp were 98.8 (dry weight) and 8.70 g/kg, respectively. High amounts of neutral lipids were found (87.0% of TL) in seed oil, while glycolipids and phospholipids occurred at high levels in pulp oil (52.9% of TL). In both oils, linoleic acid was the dominating fatty acid, followed by palmitic and oleic acids, respectively. Trienes, γ- and α-linolenic acids, were estimated in higher amounts in pulp oil, while α-linolenic acid was only detected at low levels in seed oil. Neutral lipids were characterised by higher unsaturation ratios, while saturates were higher levels in polar lipids. The sterol marker, β-sitosterol, accounted for 72% and 49% of the total sterol content in seed and pulp oils, respectively. Vitamin E level was higher in the pulp oil than in the seed oil, whereas γ-tocopherol was the predominant component in seed oil and δ-tocopherol was the main constituent in pulp oil. β-Carotene was also higher in pulp oil than in seed oil. Oils under investigation resembled each other in the level of vitamin K_1 (0.05% of TL). Information provided by the present work is of importance for further chemical investigation of cactus pear oil and industrial utilisation of the fruit as a raw material of oils and functional foods.

Keywords: Cactus pear; *Opuntia ficus-indica* L.; Seed oil; Pulp oil; Fatty acids; Lipid classes; Sterols; Tocopherols; β-carotene; Vitamin K_1.

1. Introduction

The potential supply of lipid from fruits and fruit by-products may be enormous and should to be investigated. Palm and coconut oils are good examples of commercially successful oils extracted from fruit flesh. Future edible oil supplies may depend on the discovery and development of similar types of plants. A listing of the lipid content and fatty acid composition of oils extracted from new plant sources would be an important first step in this search. Furthermore, a relatively untapped source of lipid and protein raw material is the by-product of fruit-processing plants. Millions of pounds of fruit seeds are discarded yearly, resulting in disposal problems, while proper utilisation of these waste products could lead to an important new source of oil and meal (Kamel & Kakuda, 2000). A multi-ingredient fruit, such as cactus or prickly pear (*Opuntia ficus-indica* L.) (Fig. 1), holds promising answers for tailor-made nutraceuticals and functional foods by embracing essential ingredients, such as taurine, amino acids, readily absorbable carbohydrates, minerals, vitamin C and soluble fibres (Stintzing, Schieber & Carle, 2000, 2001). Cactus pear grows wild in arid and semi-arid regions, where the production of more succulent food plants is severely limited; it is a delicacy in Mexico, United States, Mediterranean countries and South Africa (Gurbachan & Felker, 1998). Low water exigency and a high water-use efficiency ratio favour the extension of cactus production, as underlined by the Food and Agriculture Organisation (Barbera, Inglese, & Pimienta-Barrios, 1995). Under optimal conditions, annual production of cactus pear can reach 50 tons/hectare (Dominguez-Lopez, 1995; El-Kossori, Villaume, El-Boustani, Sauvaire, & Mejean, 1998). Therefore, it will be an important fruit for recovery in arid and semi-arid areas.

Both nopal and cactus pear fruit are consumed as fresh vegetables, added to casseroles, cooked, canned, or used in salads, syrups, alcoholic drinks, fruit juices and in cheese production (Gurbachan & Felker, 1998).

* Corresponding author. Tel.: +49-30-31472813; fax: +49-30-31472823.

E-mail address: hassanienmohamed@hotmail.com (M. F. Ramadan).

0308-8146/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0308-8146(02)00550-2

Juice obtained from the strained pulp is suggested to be a good source for natural sweeteners and colorants (Saenz, Estevez, Sepulveda, & Mecklenburg, 1998; Turker, Coskuner, Ekiz-Hi, Aksay, & Karababa, 2001). On the other hand, in most medicinal research involves the leaves rather than the fruit (El-Kossori et al., 1998). Experimental evidence showed that cactus pear could reduce glucose and cholesterol levels in human blood and modify low density lipoprotein (LDL) composition (Frati, 1992; Gurbachan & Felker, 1998; Stintzing et al., 2001).

The proximate composition of prickly pear cactus (*O. ficus-indica* L.) has been investigated (Dominguez-Lopez, 1995; El-Kossori et al., 1998; Stintzing et al., 2000, 2001). Seeds constitute about 10–15% of the edible pulp and are usually discarded as waste after extraction of the pulp. According to literature data (Sawaya & Kahn, 1982; Pimienta-Barrios, 1994; Stintzing et al., 2000), oil processed from the seeds constitutes 7–15% of whole seed weight and is characterised by a high degree of unsaturation wherein linoleic acid is the major fatty acid (56.1–77%). The sterols in seed oil are composed of β-sitosterol as the sterol marker, followed by campesterol, then stigmasterol. Information on the lipid composition of seed oil, however, is still inadequate and data available are incomplete. Moreover, no data about the lipid constitution in the seedless part of the pulp are yet available. In the present study, we analysed the seeds and soft parts, to obtain an informative profile of lipids in cactus pear which will serve as a basis for further detailed chemical investigation and nutritional evaluation. The results will be important as an indication of the potential nutraceutical and economic utility of cactus pear as a new source of fruit oils and to address stability issues and the potential for their delivery in functional foods.

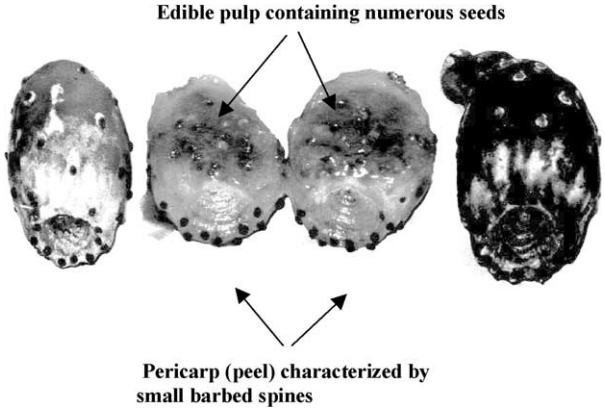

Fig. 1. Cactus pear (*Opuntia ficus-indica* L.) fruits are uniocular, polyspermic, egg-shaped fleshy berries and highly appealing because of their attractive colours. Fruit weights range from 100 to 150 g, depending on origin and cultivar. Small barbed spines on the pericarp, the glochids, consist of pure crystalline cellulose. The pericarp and the edible pulp from the ripe fruits have cherry-red or purple hues containing numerous small brown seeds.

2. Material and methods

2.1. Materials

Three kilogrammes of freshly harvested cactus pear (ca. 11 fruits per kilogramme) fruits were purchased from a local market, Berlin, Germany, in 2001. Standards used for sterols (ST) characterisation, cholesterol, β-sitosterol, stigmasterol, lanosterol, ergosterol, campesterol, Δ5-avenasterol and Δ7-avenasterol, were purchased from Supelco (Bellefonte, PA, USA). Standards used for characterisation of vitamin E (α-, β-, γ- and δ-tocopherol), β-carotene and vitamin K_1 (2-methyl-3-phytyl-1,4-naphthoquinone) were purchased from Merck (Darmstadt, Germany). Reagents and chemicals used were of the highest purity available.

2.2. Methods

2.2.1. Extraction of total lipids (TL)

Intact fruits were carefully selected according to the degree of ripeness measured by fruit colour (red to purple), the pH value of the pulp (pH 6.05) and the total titratable acidity (0.39%). Fruits were brushed under distilled water, air-dried and hand-peeled. Seeds were isolated by pressing the whole edible pulp and rinsing the residue with distilled water. The two fractions (pulp and seeds) were separately lyophilised (Alpha 1-5, Martin Christ, Osterode am Harz, Germany) to 10–25% of the original weight, depending on the fruit fraction and composition. Three samples (5 g each sample) of lyophilised seeds and pulp were ground (Analysenmühle A10, Janke & kunkel GmbH, Staufen Br., Germany), and the lipid was isolated using a chloroform/methanol extraction procedure (Yang & Kallio, 2001). The samples were homogenised in methanol (50 ml) for 1 min in a blender, chloroform (100 ml) was added and homogenisation was continued for a further 2 min. The mixture was filtered and the solid residue resuspended in chloroform/methanol (2:1, v/v, 150 ml) and homogenised for 3 min. The mixture was filtered again and washed with fresh solvent (2:1, v/v, 150 ml). The combined filtrates were cleaned with a repeat addition of 0.2 volumes of 0.75% aqueous sodium chloride solution. The samples were thoroughly mixed without shaking, the layers allowed to separate and the chloroform layer recovered. The purified lipids were collected in a flask and subsequently treated with sodium sulphate to remove traces of water; after filtration, the extract was taken to dryness on a rotary evaporator at 40 °C. Total lipids recovered were weighed and stored in chloroform at −20 °C until analysed.

2.2.2. Gas liquid chromatography analysis of fatty acid methyl esters

Fatty acids were transesterified into methyl esters (FAME) by heating in boron trifluoride (10% solution in methanol, Merck, Darmstadt, Germany) according to the procedure reported by Metcalfe, Schmitz, and Pleca (1966). FAME were identified on a Shimadzu GC-14A equipped with flame ionisation detector (FID) and C-R4AX chromatopac integrator (Kyoto, Japan). The flow rate of the carrier gas helium was 0.6 ml/min and the split value with a ratio of 1:40 was used. A sample of 1 μl was injected on a 30 m × 0.25 mm × 0.2 μm film thickness Supelco SP™-2380 (Bellefonte, PA, USA) capillary column. The injector and FID temperatures were set at 250 °C. The initial column temperature was 100 °C programmed by 5 °C/min until 175 °C and kept 10 min at 175 °C, then 8 °C/min until 220 °C and kept 10 min at 220 °C. A comparison of the retention times of the samples with those of authentic standard mixture (Sigma, St. Louis, MO, USA; 99% purity specific for GLC), run on the same column under the same conditions, was made to facilitate identification. The quantification of each fatty acid was carried out by comparing the peak of its methyl ester with that of methyl nonadecanoate without application of any correction factor.

2.2.3. Column chromatography fractionation of the main lipid classes

Total lipid (30 mg per g of adsorbent) in chloroform was separated into neutral lipids (NL), glycolipids (GL) and phospholipids (PL) by passing through a glass column (20 mm dia × 30 cm) packed with a slurry of activated silicic acid (70 to 230 mesh; Merck, Darmstadt, Germany) in chloroform (1:5, w/v) according to Rouser, Kritchevsky, Simon, and Nelson (1967). NL were eluted with three-times the column volume of chloroform; GL were eluted with 5-times the column volume of acetone and PL with four times the column volume of methanol. Solvents were evaporated by using a rotary evaporator and the percentage of each fraction was determined gravimetrically. The respective residue was dissolved in chloroform and stored at −20 °C as a lipid fraction.

2.2.4. High temperature gas liquid chromatography analysis of sterols (ST)

Separation of ST was performed after saponification of the oil samples without derivatization (Ramadan & Mörsel, 2002b). After the addition of cholesterol acetate (1.5 mg; Sigma, MO, USA) as an internal standard, lipids (250 mg) were refluxed with 5 ml ethanolic KOH solution (6%, w/v) and a few anti-bumping granules for 60 min. The unsaponifiables were first extracted three times with 10 ml of petroleum ether; the extracts were combined and washed three times with 10 ml of neutral ethanol/water (1:1, v/v), then dried overnight with anhydrous sodium sulphate. The extract was evaporated in a rotary evaporator at 25 °C under reduced pressure, then ether was completely evaporated under nitrogen. Gas chromatography analyses of unsaponifiables were carried out using a Mega Series (HRGC 5160, Carlo Erba Strumentazione; Milan, Italy) equipped with FID. The column was a ID phase DB 5, packed with 5% phenylmethylpolysiloxan (J&W scientific; Falsom, CA, USA), 30 m length, 0.25 mm i.d., 1.0 μm film thickness with carrier gas (helium) flow of 38 ml/min and split-splitless injection. The detector and injector were set at 280 °C. The oven temperature was kept constant at 310 °C and the injected volume was 2 μl. All ST homologues eluted within 45 min and total analysis was set at 60 min to assure the elution of all ST. The quantification of sterol compounds was carried out with a cholesterol acetate internal standard and calculated by applying the detector response of sitosterol. The repeatability of the analytical procedure was tested and the relative standard deviation of three repeated analyses of a single sample was $<5\%$. Quantitative analyses were performed with a Shimadzu (C-R6A Chromatopac; Kyoto, Japan) integrator.

2.2.5. Normal phase high performance liquid chromatography (NP-HPLC) separation, identification and quantification of fat-soluble vitamins (FSV) and β-carotene

2.2.5.1. Procedure. NP-HPLC was selected to avoid extra sample treatment (e.g. saponification). Analysis was performed with a solvent delivery LC-9A HPLC (Shimadzu, Kyoto, Japan). The chromatographic system included a model 87.00 variable wavelength detector and a 250 × 4 mm i.d. LiChrospher-Si 60, 5 μm, column (Knauer, Berlin, Germany). Separation of all components was based on isocratic elution where the solvent flow rate was maintained at 1 ml/min at a column back-pressure of about 65–70 bar. The solvent system selected for tocopherols elution was isooctane/ethylacetate (96:4, v/v) with detection at 295 nm. An isooctane/isopropanol (99:1, v/v) mixture was used to elute β-carotene (detection at 453 nm) and vitamin K_1 (detection at 244 nm). Twenty μl of the diluted solution of TL in the selected mobile phase were directly injected into the HPLC column. FSV and β-carotene were identified by comparing their retention times with those of authentic standards.

2.2.5.2. Preparation of standard curves. Standard solutions of vitamins were prepared by serial dilution to concentration of approximately 5 mg/ml of vitamin E, 0.7 mg/ml of β-carotene and, 1.4 mg/ml of vitamin K_1. Standard solutions were prepared daily from a stock solution which was stored in the dark at −20 °C. Twenty μl was injected and peaks areas were determined to generate standard curve data.

2.2.5.3. Quantification. All quantitation was by peak area using a Shimadzu C-R6A chromatopac integrator (Kyoto, Japan). Standard curves (concentration versus peak area) were calculated from six concentration levels by linear regression. Based on the established chromatographic conditions, repeated injections of different concentrations of the standard FSV and β-carotene were made three times onto the HPLC system. All work was carried out under subdued light conditions. All the experiments were repeated at least twice when the variation on any one was routinely less than 5% and mean values are given.

3. Results and discussion

3.1. General

For a plant to be suitable for oil production, it must meet the following two criteria: (i) the oil content must reach the minimum for commercially viable exploitation, and (ii) the plant must be suitable for high acreage cultivation. The only exceptions are plants that contain oils or fats unique in their composition or with properties that cannot be found elsewhere (Bockisch, 1998). Cactus pear pulp which resembles the edible part of the fruit can be divided into seeds (ca. 15%) and strained pulp (ca. 85%), the latter being the basis for fruit and juice products. It was found that seeds contain the maximum amount of oil (98.8 g/kg dry weight) while TL, recovered from lyophilised strained pulp, accounted for 8.70 g/kg. It is well known that the mesocarp, or pulp, of fruits generally contains very low levels of lipid materials (0.1–1.0%) and, as such, does not constitute an important source of edible or industrial oils (Kamel & Kakuda, 2000). Amounts of oil recovered from seeds which represent a potential source of oil, are in agreement with literature data (Pimienta-Barrios, 1994; Sawaya & Kahn, 1982). The levels of total lipids, however, may depend on fruit cultivar, degree of ripeness and fruit processing or storage conditions.

3.2. Lipid classes and their fatty acid composition

The levels of lipid classes in cactus pear seed and pulp oils and fatty acid profile of these classes are shown in Table 1. Among the TL present in the seeds, a significant amount of NL was found (87.0% of TL), while polar lipids were recovered at higher levels in pulp oil (52.9% of TL). In both oils, GL resemble PL in the low unsaturation ratios, whereas NL were characterised by high level of unsaturated fatty acids. Fatty acid profile of seed oil evinces the lipids as a good source of the nutritionally essential linoleic acid and unsaturated oleic acid, wherein the ratio of linoleic acid to oleic acid was about 3:1. In both seed and pulp oils, linoleic acid was the dominating fatty acid, followed by palmitic and oleic acids, respectively. Previous data on cactus pear seed oil showed a rather similar pattern in that linoleic acid was the fatty acid marker (Sawaya & Kahn, 1982). In the polar lipid classes of seed oil, unsaturated fatty acids were also predominant, while saturates (palmitic and stearic acids) ranged from 28.9 to 30.0%. The fatty acids identified in the pulp oil contained myristic and γ-linolenic acid (GLA, C18:3*n*-6) in addition to the fatty acids identified in the seed oil. Of the three saturates estimated in pulp oil, palmitic was the most predominant fatty acid (34.4% of total FAME). The majority of fatty acids detected in polar fractions in pulp oil were also saturated fatty acids that comprised more than 45%. Concerning the polyunsaturated fatty acids (PUFA), especially trienes, the two oils are distinctly different, wherein GLA and α-linolenic were estimated in higher amounts in pulp oil, while α-linolenic was only detected at low level in seed oil. Unlike seed oil, which contains very low levels of trienes, pulp oil could be a good source of this unique type of PUFA. Interest in the PUFA as health-promoting nutrients has expanded dramatically in recent years. Although GLA was identified at low level, a great deal of interest has been placed in the few oils that contain GLA. The sources of natural GLA are few and at present only borage (21–25%), evening primorse, hemp and hopseed oils are well known (Kamel & Kakuda, 2000). Furthermore, the need for ω-3 fatty acids relates to the formation of their long-chain polyunsaturated metabolites. These play a critical role, as structural lipids, but also as substrates for signalling molecules, such as prostaglandins and leukotrienes (O'Keefe, 1998; Riemersma, 2001). A rapidly growing literature illustrates the benefits of PUFA in alleviating cardiovascular complaints, inflammatory conditions, heart diseases, atherosclerosis, autoimmune disorder, diabetes and other diseases. In addition, presence of these fatty acids in human milk is associated with better performance of breast-fed infants than those on infant formula. Pregnant and lactating women, therefore, are encouraged to ensure their dietary intake of appropriate amounts of PUFA (Finley & Shahidi, 2001; Riemersma, 2001). The fatty acid composition (and high amounts of PUFA) makes the cactus pear a special fruit for nutritional applications.

3.3. Sterols composition

Sterols comprise the bulk of the unsaponifiables in many oils. They are of interest due to their impact on health. Recently, sterols have been added to vegetable oils as an example of a successful functional food (Ntanios, 2001). This type of product is now available and has been scientifically proven to lower blood LDL-cholesterol by around 10–15% as part of a healthy diet (Jones et al., 2000). The contents and compositions of

most of the sterols in the cactus pear seed and pulp oils are presented in Table 2. High levels of sterols were estimated in both oils, which made up 9.33 g/kg seed oil and 22.8 g/kg pulp oil. The latter were characterised by high amounts of unsaponifiables (87.2 g/kg TL), while unsaponifiable residues accounted for 20.1 g/kg seed oil. β-Sitosterol, campesterol, stigmasterol, lanosterol and Δ5-avenasterol were among the major components. In both oils, the sterol marker was β-sitosterol, which comprised ca. 72% and 49% of the total sterol content in seed and pulp oils, respectively. The next major component was campesterol and these two major components constituted ca. 90% of the total sterols. Other components, e.g., stigmasterol and lanosterol, were present is approximately equal amounts (3.0% of total sterols) in the both samples. Moreover, Δ5-avenasterol was present at levels of 3.1 and 6.2% of total sterols in seed and pulp oils, respectively. A small amount of Δ7-avenasterol (0.53%) was identified in the seed oil, but not detected in the unsaponifiable residues of pulp oil.

3.4. Fat-soluble vitamins (FSV) and β-carotene composition

Nutritionally important components, such as carotenes and tocopherols (vitamin E), improve stability of the oil. Carotenoids, as singlet oxygen quenchers, protect oils from photo-oxidation, whereas their role in auto-oxidation is associated with the presence of tocopherols (Psomiadou & Tsimidou, 2001). Data about the qualitative and quantitative composition of vitamins E, K_1 and β-carotene are summarised in Table 2. The NP-HPLC technique was used to eliminate column contamination problems and allow the use of a general lipid

Table 1
Levels of total lipids, lipid classes (g/kg) and fatty acid composition of cactus pear (*Opuntia ficus-indica* L.) seed and pulp oils

Lipid class	Seed oil				Pulp oil			
	TL	NL	GL	PL	TL	NL	GL	PL
	98.8[a]±6.26	870[b]±39.8	52.3[b]±3.13	70.7[b]±4.55	8.70[a]±0.89	462[b]±21.3	293[b]±11.5	236[b]±12-7
	Fatty acid relative content (%)							
C14:0	nd[c]	nd	nd	nd	1.13±0.09	0.89±0.06	1.00±0.08	1.20±0.10
C16:0	20.1±2.26	18.0±1.77	24.6±2.89	26.8±2.94	34.4±3.12	28.9±3.71	42.1±4.15	43.4±4.18
C16:1*n*-7	1.80±0.11	2.01±0.16	1.62±0.06	0.77±0.04	1.62±0.06	1.92±0.12	1.46±0.09	1.30±0.07
C18:0	2.72±0.13	2.07±0.08	4.32±0.27	3.23±0.21	2.37±0.10	2.14±0.08	2.29±0.08	2.85±0.07
C18:1*n*-9	18.3±1.58	19.3±1.66	17.7±1.49	15.6±1.23	10.8±0.98	10.2±1.03	11.5±1.09	10.4±1.12
C18:2*n*-6	53.5±4.89	56.1±4.95	50.2±4.56	49.7±4.35	37.0±3.87	45.9±4.26	28.0±3.12	27.7±3.08
C18:3*n*-6	nd	nd	nd	nd	0.68±0.05	0.45±0.06	0.79±0.09	0.65±0.08
C18:3*n*-3	2.58±0.16	2.52±0.12	1.56±0.09	3.90±0.28	12.0±1.05	9.60±0.86	12.9±0.98	12.5±0.99
Total saturates	22.8±2.36	20.0±2.25	28.9±2.58	30.0±2.67	37.9±3.09	31.9±2.96	45.4±4.23	47.4±4.36
Total monoenes	20.1±1.89	21.3±2.16	19.3±1.96	16.3±1.86	12.4±1.09	12.1±1.06	12.9±1.00	11.7±0.96
Total dienes	53.5±4.89	56.1±4.95	50.2±4.56	49.7±4.35	37.0±3.87	45.9±4.26	28.0±3.12	27.7±3.08
Total trienes	2.58±0.16	2.52±0.12	1.56±0.09	3.90±0.28	12.7±1.09	10.0±0.93	13.7±1.05	13.1±1.06
U/S[d]	3.38	4.00	2.46	2.33	1.63	2.13	1.20	1.10

Results are given as mean±SD from triplicate estimations.
[a] g/kg of seed or pulp dry weight.
[b] g/kg of total lipids.
[c] Not detected.
[d] Unsaturation ratio = (16:1 + 18:1 + 18:2 + 18:3)/(14:0 + 16:0 + 18:0).

Table 2
Sterols and fat-soluble vitamin profile (g/kg) of cactus pear (*Opuntia ficus-indica* L.) seed and pulp oils

Compound	Seed oil	Pulp oil	Compound	Seed oil	Pulp oil
Cholesterol	nd[a]	nd	α-Tocopherol	0.056±0.003	0.849±0.09
Ergosterol	nd	nd	β-Tocopherol	0.012±0.002	0.126±0.01
Campesterol	1.66±0.21	8.74±0.75	γ-Tocopherol	0.330±0.03	0.079±0.006
Stigmasterol	0.30±0.04	0.73±0.08	δ-Tocopherol	0.005±0.001	4.220±0.17
Lanosterol	0.28±0.05	0.76±0.07	Total vitamin E	0.403±0.04	5.274±0.36
β-Sitosterol	6.75±0.89	11.2±1.21			
Δ5-Avenasterol	0.29±0.03	1.43±0.13	β-Carotene	0.047±0.008	0.420±0.05
Δ7-Avenasterol	0.05±0.006	nd	Vitamin K_1	0.525±0.06	0.532±0.08

Results are given as mean±S.D. from triplicate estimations.
[a] Not detected.

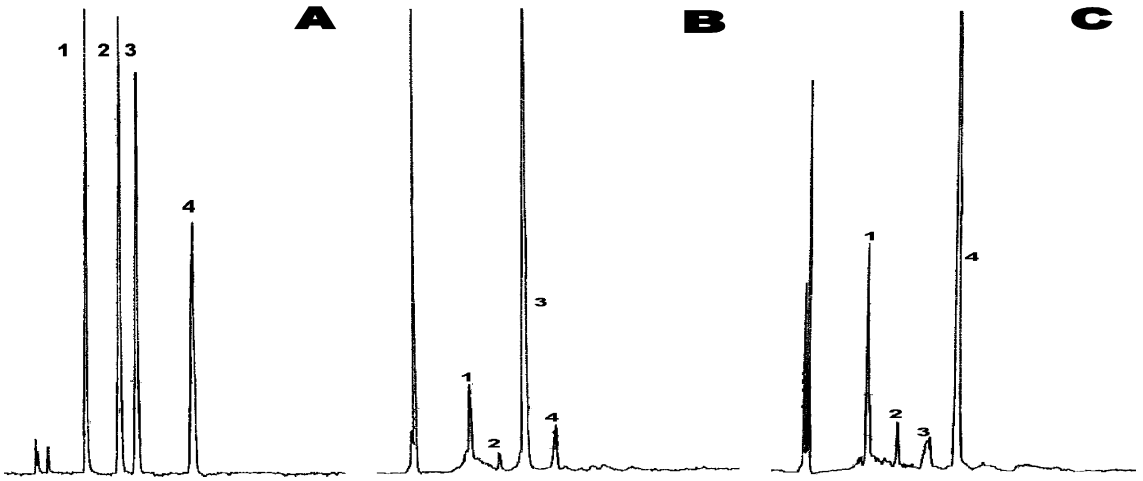

Fig. 2. Simultaneous isocratic NP-HPLC chromatograms of tocopherols in standard mixture (A), seeds (B) and pulp (C) of cactus pear (*Opuntia ficus-indica* L.). Detection was at 295 nm using isooctane/ethylacetate (96:4, v/v) as a mobile phase and elution was performed by direct injection onto the HPLC system. 1. α-Tocopherol (R_t = 9 min); 2. β- Tocopherol (R_t = 13 min); 3. γ- Tocopherol (R_t = 15 min); 4. δ-Tocopherol (R_t = 21 min).

extraction for FSV as well as β-carotene isolation (Ramadan & Mörsel, 2002a). In our study, saponification of oil samples was not required, which allowed shorter analysis time and greater vitamin stability during analysis. All tocopherol derivatives were identified in both samples (Fig. 2). Vitamin E levels were extremely high in the pulp oil (ca. 0.52% of TL), but only 0.04% of TL in the seed oil. Although, there are certain differences in the levels of the separated individual tocopherols, γ-tocopherol seems to be the major component in seed oil, while δ-tocopherol was the main constituent in pulp oil. Both tocopherol markers comprised more than 80% of total vitamin E content in both oils. α-Tocopherol was the second major component in both oils, accounting for 14–16% of the total vitamin E content. High levels of vitamin E, detected in the oils, may contribute to great stability toward oxidation. Evaluation of carotenoid levels was restricted to β-carotene, which accounted for 0.42 g/kg in pulp oil, but less than this in the seed oil. Carotenoids may be the reason of the dark orange hues of cactus pear pulp oil, while seed oil is characterised by light yellow hues. The level of pigments, however, depends on the stage of fruit ripeness, the extraction process and storage conditions. Thus, oils extracted from older fruits may contain more carotene pigments and oils from younger fruits more chlorophyll pigments. The vitamin K_1 (phylloquinone) profile involves 2-methyl-3-phytyl-1,4-naphthoquinone in the plant. The phylloquinone requirement of the adult human is extremely low. However, relatively few values for dietary items are available (Suttie, 1985). Oils under investigation resemble each other in the levels of phylloquinone (Table 2), which accounted for more than 0.05% of TL in each oil. Addition of phylloquinone-rich oils in the processing of foods that are otherwise poor sources of vitamin (for example, peanut and corn oils) could make them potentially important dietary sources of the vitamin.

4. Conclusions

The trend towards natural ingredients and products promoting health is likely to increase. The data obtained will be important as an indication of the potentially nutraceutical and economic utility of cactus pear as a new source of fruit oils and functional foods. Moreover, these results provide useful information for the industrial application of cactus pear fruits. Evidently fruit pulp provides low yields of oil, but is a rich source of essential fatty acids, sterols, carotenes and fat-soluble vitamins. Utilisation of the entire pulp makes commercialisation of oil more economic, reduces wastes from seeds and procures hitherto neglected substances for technological and nutritional purposes. Addition of cactus pear oil to mixed dishes and desserts could have an impact on the amount of essential ingredients in diet. Furthermore, it can be assumed that deoiled pulp will yield a more stable juice.

References

Barbera, G., Inglese, P., & Pimienta-Barrios, E. (1995). Agro-ecology, cultivation and uses of cactus pear. *FAO Plant Production and Protection Paper* 132.

Bockisch, M. (1998). Vegetable fats and oils. In M. Bockisch (Ed.), *Fats and oils handbook* (pp. 174–344). Champaign: AOCS Press.

Dominguez-Lopez, A. (1995). Use of the fruits and stems of the prickly pear cactus (*Opuntia* spp.) into human food. *Food Science and Technology International*, *1*(2/3), 65–69.

El-Kossori, R. L., Villaume, C., El-Boustani, E., Sauvaire, Y., & Mejean, L. (1998). Composition of pulp, skin and seeds of prickly pears fruit (*Opuntia ficus-indica* sp.). *Plant Foods for Human Nutrition*, *52*(3), 263–270.

Finley, J. W., & Shahidi, F. (2001). The chemistry, processing, and health benefits of highly unsaturated fatty acids: an overview. In W. J. John, & F. Shahidi (Eds.), *Omega-3 fatty acids, chemistry, nutrition and health effects* (pp. 1–13). Washington DC: American Chemical Society.

Frati, A. (1992). Medical implication of prickly pear cactus. In P. Felkar, & L. R. Moss, *Proc. 3rd Annual Texas prickly pear council*, 24–25 July, Kingsville, Texas, (pp. 29-34).

Gurbachan, S., & Felker, P. (1998). Cactus: new world foods. *Indian Horticulture*, *43*(1), 29–31.

Jones, P., Raeini-Sarjaz, M., Ntanios, F., Vanstone, C., Feng, J., & Parsons, W. (2000). Modulation of plasma lipid levels and cholesterol kinetics by phytosterol versus phytostanol esters. *Journal of Lipid Research*, *41*, 697–705.

Kamel, B. S., & Kakuda, Y. (2000). Fatty acids in fruits and fruit products. In C. K. Chow (Ed.), *Fatty acids in foods and their health implications* (2nd ed.) (pp. 239–270). New York: Marcel Dekker.

Metcalfe, L. C., Schmitz, A. A., & Pleca, I. R. (1966). Rapid preparation of acid esters from lipids for gas chromatographic analysis. *Analytical Chemistry*, *38*, 514–515.

Ntanios, F. (2001). Plant sterol-ester-enriched spreads as an example of a new functional food. *European Journal of Lipid Science and Technology*, *103*, 102–106.

O'Keefe, S. F. (1998). Nomenclature and classification of lipids. In C. C. Akoh, & B. M. David (Eds.), *Food lipids, chemistry, nutrition, and biotechnology* (pp. 8). New York: Marcel Dekker.

Pimienta-Barrios, X. (1994). Prickly pear (*Opuntia* spp.): a valuable fruit crop for semi-arid lands of Mexico. *Journal of Arid Environments*, *28*, 1–11.

Psomiadou, E., & Tsimidou, M. (2001). Pigments in Greek virgin olive oils: occurrence and levels. *Journal of The Science of Food and Agriculture*, *81*, 640–647.

Ramadan, M. F., & Mörsel, J. T. (2002a). Direct isocratic normal phase assay of fat-soluble vitamins and β-carotene in oilseeds. *European Food Research and Technology*, *214*(6), 521–527.

Ramadan, M. F., & Mörsel, J. T. (2002b). Oil composition of coriander (*Coriandrum sativum* L.) fruit-seeds. *European Food Research and Technology*, *215*(3), 204–209.

Riemersma, R. A. (2001). The demise of the n-6 to n-3 fatty acid ratio? a dossier. *European Journal of Lipid Science and Technology*, *103*, 372–373.

Rouser, G., Kritchevsky, D., Simon, G., & Nelson, G. J. (1967). Quantitative analysis of brain and spinach leaf lipids employing silicic acid column chromatography and acetone for elution of glycolipids. *Lipids*, *2*, 37–42.

Saenz, C., Estevez, A. M., Sepulveda, E., & Mecklenburg, P. (1998). Cactus pear fruit: a new source of natural sweetener. *Plant Foods for Human Nutrition*, *52*(2), 141–149.

Sawaya, W. N., & Khan, P. (1982). Chemical characrterization of prickly pear seed oil, *Opuntia ficus-indica*. *Journal of Food Science*, *47*, 2060–2061.

Stintzing, F. C., Schieber, A., & Carle, R. (2000). Cactus pear, a promising component of functional food. *Obst, Gemüse und Kartoffelverarbeitung*, *85*(1), 40–47.

Stintzing, F. C., Schieber, A., & Carle, R. (2001). Phytochemical and nutritional significance of cactus pear. *European Food Research and Technology*, *212*(4), 396–407.

Suttie, J. W. (1985). Vitamin K. In A. T. Diplock (Ed.), *Fat-soluble vitamins, their biochemistry and applications* (pp. 225–311). Lancaster, Pennsylvania: Technomic Publishing Co.

Turker, N., Coskuner, Y., Ekiz-Hi Aksay, S., & Karababa, E. (2001). The effect of fermentation on the thermostability of the yellow-orange pigments extracted from cactus pear (*Opuntia ficus-indica*). *European Food Research and Technology*, *212*(2), 213–216.

Yang, B., & Kallio, H. (2001). Fatty acid composition of lipids in sea buckthorn (*Hippophaë rhamnoides* L.) berries of different origins. *Journal of Agricultural and Food Chemistry*, *49*, 1939–1947.