Cactus Pear: A Fruit of Nutraceutical and Functional Importance♦

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ABSTRACT

The constantly increasing demand for nutraceuticals is paralleled by a more pronounced request for natural ingredients and health-promoting foods. The multiple functional properties of cactus pear fit well this trend. Recent data revealed the high content of some chemical constituents, which can give added value to this fruit on a nutritional and technological functionality basis. High levels of betalains, taurine, calcium, magnesium, and antioxidants are noteworthy.

Key words: cactus pear, mucilage, food colorant, nutraceutical

INTRODUCTION

Cactus pear or prickly pear, a member of the *Cactaceae* family, is widely distributed in Mexico and in all American hemispheres and grows in many other parts of the world, such as Africa, Australia and the Mediterranean basin. The fruit is a fleshy berry, varying in shape, size, and colour and has a consistent number of hard seeds. The fairly high sugar content and low acidity of the fruit (Joubert, 1993; Munoz de Chàvez *et al*., 1995; Sepúlveda and Sáenz, 1990) make it very sweet and delicious.

Cactus pear was largely ignored by the scientific world until the beginning of 1980, when there was a multiplication of research and symposia, resulting in a large number of publications, including books and book chapters. This renewed interest is to be ascribed in part to the multi-functionality of cactus-pear fruits. Recent data has, in fact, revealed the high content of some chemical constituents, which can give added value to this fruit on a nutritional and technological functionality basis. High levels of betalains, taurine, calcium, magnesium, and antioxidants are noteworthy. Additionally, some of the constituents show promising characteristics in terms of functionality. This short review will summarize the up to date knowledge on chemical composition, with particular emphasis on nutraceuticals, and on functionality of cactus-pear fruits.

COMPOSITION AND MAIN NUTRACEUTICALS

The cactus-pear fruit is an oval, elongated berry, with a thick pericarp and a juicy pulp and, in general, many hard seeds. The pericarp of commercially ripe fruits of *Opuntia ficus-indica* (L.) Mill. accounts for 33% to 55%, while the pulp is 45% to 67%, the latter containing seeds (2% to 10%). The large variability in percentages depends on cultivar, cultural practices, fecundated- and aborted-seed number, fruit load, lighting period, climate, and harvesting season (Barbera *et al.*, 1994; Inglese *et al*., 1995; Lakshminarayana *et al*., 1979; Mondragon-Jacobo and Perez-Gonzalez, 1996; Nerd *et al*., 1991; Nieddu

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et al., 1997; Sawaya *et al*., 1983; Sepúlveda and Sáenz, 1990). Weight of fruits may range from 67 g to 216 g at the best stage of ripening, for the same reasons mentioned above.

The main technological and chemical parameters of the pulp are listed in Table 1. The pulp is the edible part of the fruit and is composed of water (84% to 90%) and reducing sugars (10% to 15%). First of all, mention should be made of the high pH value (5.3 to 7.1) and the very low acidity (0.05% to 0.18% in citric acid) of the pulp, which strongly influences the processing operations (Sepúlveda, 1998; Sáenz, 2000). Sugars range from 10°Brix to 17°Brix and are mainly of the reducing type, with glucose being the predominant sugar and fructose being the second sugar, thus the fruit pulp is very sweet (Russel and Felker, 1987; Sepúlveda and Sáenz, 1990; Stintzing *et al*., 2003).

Significant amounts of ascorbic acid may be present, within the broad range of 10 to 410 $mg{\cdot}kg^{-1}$ found in different *Opuntia* spp. (Kuti, 1992; Sawaya *et al*., 1983*). Opuntia ficus-indica* (L) Mill., shows a vitamin C content ranging from 180 to 300 $mg{\cdot}kg^{-1}$ (Cantwell, 1995; Piga *et al*., 1996; Sáenz, 1995). Cactus pear is higher in vitamin C than other common fruits, such as apple, pear, grape, and banana (Cheftel and Cheftel, 1983), while other vitamins, such as carotenoids, thiamin, riboflavin, and niacin are in trace amounts (Sawaya *et al*., 1983; Sepúlveda and Sáenz, 1990).

Other components, such as lipids, protein, minerals, and fiber, do not differ significantly from other tropical fruits (Cantwell, 1995; Sáenz, 1995). When the whole peeled fruit is ingested, the large quantity of insoluble fibre in the seeds (El Kossori *et al*., 1998) provides the major source of fibre in cactus fruits. Lipids are present in the peel, pulp and seeds. Peel, which is a by-product, gives a oil with appreciable amounts of polyunsaturated fatty acids, mainly linoleic acid, α-tocopherol, sterols, β-carotene and vitamin K_1 (Ramadan and Mörsel, 2003a). Linoleic acid also was the predominant polyunsaturated acid both in pulp and seed oil, while pulp oil predominates in terms of γ- and α-linolenic acids, the latter being detected only at very low levels in seed oil (Ramadan and Mörsel, 2003b; Ramadan and Mörsel, 2003c). The same works report that the main sterol is b-sitosterol, while vitamin E and β-carotene are higher in pulp oil, with respect to seed oil. The fruit has a high content of free amino acids, particularly proline and glutamine, the highest level being that of nutraceutical taurine, up to 572.1 mg/L (Stintzing *et al*., 2001).

The mineral pattern is characterised by high amounts of calcium (up to 59 $mg{\cdot}100\ g^{-1}$) and magnesium (98.4 $mg{\cdot}100\ g^{-1}$), while other minerals are in the normal range for fruits (Dominguez-Lopez, 1995; Wills *et al*., 1986). The literature reports also that cactus-pear fruit is a good source of fibre, which gives the juice a favourable mouth feel and helps to reduce blood sugar and plasma cholesterol levels (Fernandez *et al.*, 1992; Munoz de Chavez *et al*., 1995; Trejo *et al*., 1995).

The nutritional importance of cactus-pear fruits appears clear, therefore. Another important compositional factor is the presence of pigments, which give particular attractiveness to fruit and products. Chlorophylls and betalains are present in green and purple fruits, respectively. The particular flavour of cactus pear, on the other hand, is due to volatile components. Sixty-one aroma volatiles have been found in a white-flesh cultivar of *Opuntia ficus-indica* (L.) Mill. (Flath and Takahashi, 1978), most of them are alcohols. In other varieties (yellow fruits) some unsaturated aldehydes, such as 2,6 nonadienal and 2-nonenal, were predominant (Di Cesare *et al*., 1993). Arena *et al*. (2001) showed that the most important aroma contributors of yellow, red, and white Italian cultivars of *O. ficus-indica* were (E,Z)-2,6-nonadien-1-ol and 2-methyl-acid methyl ester, which accounted for almost 97% of the total aroma value, the former giving the typical odour of the fruit, the latter contributing to the fresh fruit odour.

Recently, an increased interest in antioxidant activity and health-improving capacity of cactus pear has been registered. The antioxidant capacity of cactus-pear fruits has been recently assessed. Butera *et al*. (2002) determined the antioxidant activity of methanolic extracts of yellow, red, and white fruits, as well as of betalains pigments. They found that, although the purified betanin (which gives the red colour) has a more than tenfold higher Trolox Equivalent Antioxidant Capacity (TEAC) value than the purified indicaxanthin (yellow colour), the methanolic extracts from yellow fruits had a significantly higher TEAC value, if compared to red ones. They also found that ascorbic acid accounted only for 30% to 40% of the total antioxidant capacity, despite its predominance. The radical scavenging activity of betalains has also been assessed on other plant species, such as in red beet (Escribano *et al*., 1998; Wettasinghe *et al*., 2002a; Wettasinghe *et al*., 2002b) and in *ex-vivo* studies (Tesoriere *et al*., 2003). In another study made at our laboratory, the antioxidant activity was assessed on the whole fruit pulp (Piga *et al*., 2003). In particular, the evolution of antioxidant capacity was related to the decrease in ascorbic acid (AA) and polyphenols during nine days of cold storage of minimally processed fruits; results revealed no significant decrease of TEAC and AA, which probably were protected by polyphenols that significantly decreased by an ascorbate-sparing effect. These two studies give contrasting results, thus it could be that other factors than the mere amount in single compounds influence the antioxidant capacity. The work of Piga *et al*. (2003) reports a substantially higher TEAC value than that of Butera *et al*. (2002). Galati *et al*., 2003, on the other hand, attributed the antioxidant capacity also to ferulic acid and rutin and isorhamnetin flavonol glycosides. In particular, they showed that only an aqueous fraction had radical scavenging activity, while the organic one had not. Results of this study, moreover, revealed that cactus-pear juice exerted a beneficial effect in preventing stomach ulcers in rats treated with ethanol. They concluded that antiulcer activity was promoted by flavonoids through stimulation of prostaglandins. Dok-Go *et al.* (2003) worked with *Opuntia ficus-indica*, cv. saboten, and revealed the protective effect of (+)-dihydroquercetin, quercetin, and quercetin 3-methyl ether, in order of importance, against oxidative neuronal injuries of cultured cortical rat cells, as well as the antioxidant activity. The principals were able to inhibit lipid peroxidation and scavenge 1,1-diphenyl-2-picrylhydrazil (DPPH). Quercetin and quercetin 3-methyl ether also were able to inhibit xanthine oxidase activity *in vitro*. Wolfram *et al*. (2003), showed that daily consumption of 250 g of cactus pear (*O. robusta*?) in patients and volunteers significantly decreased platelet proteins, platelet aggregation, and improved platelet sensitivity to prostaglandins (PGI_2 and PGE_1).

The latter two references illustrate considerable taxonomic confusion or simplification about cactus pear. *Opuntia ficus-indica*, cv. saboten, does not appear in the taxonomic studies of Scheinvar (1995) or Pimienta-Barros and Muñoz-Urias (1995). More recently, Kuti (2004) investigated the antioxidant compounds in extracts from *O. ficus-indica*, *O. lindheimeri*, *O. streptacantha*, and *O. stricta* var. *stricta*. The author measured the antioxidant activity by the oxygen radical absorbance capacity (ORAC) assay (Cao *et al*., 1996) and found a positive highly significant ($P \leq 0.01$) correlation coefficient between the ORAC value and the total flavonoid content in the red-purple skinned *O. lindheimeri* fruits, while no correlation was observed between ORAC and total ascorbic acid or carotenoid content.

FUNCTIONAL PROPERTIES OF FRUITS

Cactus-pear fruits are consumed mainly in the fresh state. Increased knowledge of their nutritional value, the possibility of using *Opuntia spp*. to colonise marginal lands, and the relatively limited shelf life, even in cold storage, has stimulated interest in obtaining processed items, which can satisfy the need for diversification, increased shelf life, and more convenience. As noted previously, cactus-pear fruits have a similar composition to other fruits (Cacioppo, 1992; Ewaidah and Hassan, 1992; Rodriguez *et al*., 1996; Sáenz, 1995; Sawaya *et al*., 1983), but technological parameters play an important role and are a great challenge during processing. The pH values (5.3 to 7.1) are in the range of nonacid foods (Saenz, 1996; Piga *et al*., 1997), thus sterilisation treatment is required to avoid growth of pathogenic microorganisms. Moreover, the high content of soluble solids makes cactus pear very susceptible to microbial invasion. The stabilisation procedure may have detrimental effects on some sensory parameters of fresh fruits, such as colour and flavour.

Research on the functional properties of cactus-pear fruits has also been carried out. Some constituents, in fact, may be extracted and used as additives in food preparations or in the pharmaceutical and cosmetic sectors. In particular, possible uses of food colorants have been assessed. Cactus pear is very particular for the presence of betalain, a widely used natural colorant in the food industry. Betalains are found only in 10 families of the *Caryophyllaleae*. Betalains are nitrogenous chromoalcaloids and their presence excludes that of anthocyanins (Mabry, 1970; Piattelli, 1981; Clement and Mabry, 1996). Betalains importance has been considered since the 1970s (Von Elbe and Maing., 1973; Von Elbe *et al*., 1974; Pasch *et al*., 1975). They are stable in a pH range of 4 to 7, thus they are particularly indicated as colorants of low-acidic foods. Betalains found in cactus pear are both betacyanins (red-violet colour) and betaxanthins (yellow colour), in amounts comparable to the most betalain rich red beet hybrids, taking the whole fruit into consideration (Fernández-López and Almela, 2001; Fernández-López *et al*., 2002; Odoux and Dominguez-Lopez, 1995; Sobkowska *et al*., 1991; Stintzing *et al*., 2002). Nowadays, betalains for food use are extracted from red beet (*Beta vulgaris* (L.) subsp. *vulgaris* cv. rubra), which contains up to 50mg/100g of betanin, a betacyanin. Montefiori (1990) found 26 mg of betanin per 100 g of fresh pulp of purple-coloured *O. ficus-indica* (L.) Mill fruits, while Krifa *et al*. (1994) extracted and characterised a pigment from *Opuntia stricta*, which was found to be composed of betanin (59%), isobetanin (37%) and neobetanin (traces up to 12.7% in very ripe fruits). Odoux and Dominguez-López (1996) found up to 100.8 mg of betacyanins per 100 g. Sáenz *et al*. (1999) detected 100 mg of betanin per 100 g of fresh weight of purple-cactus-pear juice, which was added as a colorant to a yogurt with promising results. Recently, Castellar *et al.* (2003) found up to 80 mg of betacyanin per 100 g of fresh weight in *O. stricta* fruits. Previously, other sources of betalaines have been used, although some of them have not been permitted, like, for example, the amaranthin, which can be used in China (Cai and Corke, 1999).

Cactus-pear fruits could, therefore, be an even better source of betalains than red beet, which has some technological and sensory problems due to high levels of the earth-like flavour geosmin (Acree *et al*., 1976; Henry, 1996). Moreover, the contemporary presence of betacyanins and betaxanthins allows a more wide chromatic interval. Research on cactus-pear betalains has been focused mainly on fruits with red or purple peel and pulp, although most of the varieties are red or orange.

Table 2 shows the betalains found in different cactus-pear species. Researchers have detected three betacyanins (betanin and phyllocactin, plus C_{15} isomers and corresponding aglicons, and neobetanin) and five betaxanthins (indicaxanthin, miraxanthin II, and vulgaxanthin I, II, and IV) (Stintzing *et al*., 2001; Stintzing *et al*., 2002).

Moreover, five new betaxanthins have been found in cactus-pear fruits grown in Italy (Stintzing *et al*., 2002). These new molecules are conjugated forms of betalamic acid and an aminocid (γ-aminobutyric acid, phenylalanine, isoleucine, serine, and valine). Free betalamic acid also has been detected. Technological advantages of using cactus-pear betalains, instead of red-beet ones, already have been reported. Cactus-pear fruits do not contain geosmin or 3-sec-butyl-methoxypyrazine, which confer a heart-like flavor to betalains extracted from red beet (Acree *et al*., 1976; Murray and Whitfield, 1975), as well as high levels of nitrates and microbial contamination (Henry, 1996).

Castellar *et al*. (2003) studied the stability of the red pigment extracted from three cactus-pear species (*O. ficus-indica*, *O. stricta*, and *O. undulata*) subjected to changes of pH and temperature and found that the stability was pH dependent and showed a maximum at pH 5. It is interesting to note that pigments extracted from *O. stricta*, apart from the very high amount, were only betanin and isobetanin that are the compounds found in the red beet dye (E-162). Problems to solve, in order to compete with red beet betalains, are stability of blend, yields, and pricks removal.

Besides use as colorants, cactus-pear fruits may be utilised for other applications in food. Forni *et al*. (1994) extracted pectins from *O. ficus-indica* (L.) Mill fruits and their characterisation revealed enough galacturonic acid content for use as a food or cosmetic additive, and a very low degree of methoxylation (10%), suggesting a possible use as a low methoxyl pectin (LMP), and thus as a gelling agent for low caloric foods.

Different authors have conducted studies on cactus-pear mucilages, which are complex polysaccharides, mainly composed of arabinose, galactose, rhamnose, and galacturonic acid (Lee *et al*. 1998; Paulsen and Lund, 1979; Sáenz *et al*., 1992). Although they have negative technological characteristics, mucilages possess important functional properties. Cactus-pear mucilages, in fact, have a high water-holding capacity, so they could serve as thickening or emulsifying agents and form viscous or gelatinous colloids.

Recently, Teixeira *et al*. (2000) and Pintado *et al.* (2001) extracted and characterised enzymes from unripe fruits of *O. ficus-indica* (L.) Mill fruits and concluded that these extracts could be a good source of milk-clot enzymes for the dairy industry owing to their pleasant smell and structural properties and because they do not appreciably delay clotting times, unlike other plant rennets. In fact, caseinolitic activity on α_s- and β-caseins in sodium caseinate obtained from bovine, caprine and ovine milk was very similar to that of animal rennet.

Lamghari *et al*. (2000) showed that cactus-pear fruit pulp fibres reduced the digestibility of a casein-based diet at the higher extent, compared to arabic gum, carragenan alginic acid, locust bean, and citrus pectin fibres.

Hassan *et al*. (1995) obtained a cocoa butter equivalent as a metabolic product of *Cryptococcus curvatus* growth on cactus-pear juice, while Flores *et al*. (1994) were able to obtain economically feasible production of citric acid by solid-state fermentation of cactus-pear peel by *Aspergillus niger*.

CONCLUSIONS

The increasing interest in cactus-pear cultivation in the last decades, has keenly stimulated the work of scientists to overcome the lack of knowledge about all aspects. If we consider that a number of uses and application of cactus-pear fruits are possible, we realize the importance of this crop to human food, in all its aspects. In this context the agro-industrial working group CACTUSNET is making great efforts to find and divulgate new ways of exploiting processed products. However, much more knowledge is needed to have a realistic possibility of extensive development of this crop. We have to solve problems such as breeding for higher fruit-pulp content and lower number and size of seeds, improving postharvest technologies (harvest and processing), selecting cultivars for higher nutritional and functional properties (colorants and fibres), and optimising current processing technologies, as well as exploring new ones. We have, in particular, to solve the particular technological problems of cactus pear. These, in fact, make some of the "conventional" indispensable unit operations, such as thermal sterilisation or evaporation, unsuitable to obtain, for example, a high-quality fruit juice. However, the multiple-ingredient characteristics of cactus pear should encourage research to obtain different fruit products with emerging technologies. In fact, although some of them (pulsed-electrical-field processing) have been developed only at the laboratory level and capital costs are higher than with conventional equipment, products that combine added value with a fresher taste might be obtained. Moreover, product diversification may increase. The health-promoting capacity of cactus pear, although not yet confirmed clinically, might be very attractive to the growing market for "nutraceutical foods". The importance of extractable colorants from some cactus-pear varieties should not be forgotten. The increasing demand for natural rather than synthetic colorants for drinks and dairy products could benefit cactus pear, provided further studies on increased yield, extractability, and stability are carried out.

An anecdote says that people from some countries of North Africa call cactus pear "the bridge of life", because it is the only feeding and watering resource for animals during drought seasons, but the hope is that this very attractive crop will substantially reward human exploitation in all the depicted ways and in all parts of the world.

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Table 1. Main Technological Parameters: Chemical and Mineral Composition of Cactus-pear Pulp*

Technological Parameters	**Range**
Pulp (%)	43-57
Seeds (%)	2-10
Peel (%)	33-55
pH	5.3-7.1
Acidity (% of citric acid)	0.05-0.18
°Brix	12-17
Total solids	10-16.20
Chemical Composition of the Pulp	**Range**
Moisture (%)	84-90
Protein (%)	0.2 – 1.6
Fat (%)	0.09-0.7
Fibre (%)	0.02-3.1
Ash (%)	0.3-1
Total sugars (%)	10-17
Vitamin C ($mg \cdot 100g^{-1}$)	1-41
Minerals	**Range**
Ca ($mg \cdot 100g^{-1}$)	12.8-59
Mg ($mg \cdot 100g^{-1}$)	16.1-98.4
Fe ($mg \cdot 100g^{-1}$)	0.4-1.5
Na ($mg \cdot 100g^{-1}$)	0.6-1.1
K ($mg \cdot 100g^{-1}$)	90-217
P as PO_4 ($mg \cdot 100g^{-1}$)	15-32.8
Aminoacids	**Maximum Content (mg/L)**
Proline	1768.7
Glutamine	574.6
Taurine	572.1
Serine	217.5
Alanine	96.6
Glutamic acid	83.0
Methionine	76.9
Lysine	53.3

* Source (see references): Askar and El-Samahy (1981), Barbera *et al*. (1992), Nieddu *et al.* (1997), Paredes and Rojo (1973), Piga *et al*. (1996, 1997) Sawaya *et al.* (1983), Sepúlveda and Sáenz (1990), Stintzing *et al*. (1999, 2001, 2003).

Table 2. Betacyanins and Betaxanthins in *Opuntia* spp.

Species*	Betacyanins	Betaxantins
O. bergeriana	betanidin betanin phyllocactin	indicaxanthin miraxanthin II vulgaxanthin I vulgaxanthin II
O. decumbens	betanin	-
O. dillenii	betanin	-
O. engelmannii	betanin phyllocactin	-
O. ficus-indica†	betanin isobetanin neobetanin	indicaxanthin miraxanthin II vulgaxanthin I vulgaxanthin II vulgaxanthin IV adducts of betalamic acid with γ-aminobutyric acid, phenylalanine, isoleucine, serine, and valine
O. guatemalensis	betanin	
O. monacantha†	betanidin betanin phyllocactin	indicaxanthin vulgaxanthin I
O. paraguensis	betanin phyllocactin	-
O. polyacantha	betanidin betanin	-
O. ritteri	betanin phyllocactin	-
O. robusta	betanin	-
O. streptacantha	betanin phyllocactin	-
O. stricta	betanin neobetanin	-
O. tomentella	betanin phyllocactin	-
O. tomentosa	betanin phyllocactin	-
O. vulgaris†	betanin	indicaxanthin vulgaxanthin I

* Adapted from: Stintzing *et al*., 2001; Stintzing *et al*., 2002

† Presence of free betalamic acid