



## Processing technologies: an alternative for cactus pear (*Opuntia* spp.) fruits and cladodes

Carmen Saenz

*Departamento de Agroindustria y Enología, Facultad de Ciencias Agronómicas, Universidad de Chile, Casilla 1004, Santiago, Chile*

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The cactus pear has become an important fruit crop in many semi-arid lands of the world. The fruit and the young cladodes ('nopalitos') have commonly been consumed fresh, but the last decade's research studies on cactus pear processing have produced another alternative which prevents damage to the fruit and, in spite of technological characteristics that make processing a challenge (high soluble solids content, low acidity and high pH), adds value to this crop. The cladodes of the plant are a good source of fibre, an important element for the human diet and of considerable potential for medical use. The results of several of these research studies involving the production of juices, marmalades, gels, liquid sweeteners, dehydrated foods and other products are discussed.

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### Introduction

The cactus pear fruit (*Opuntia ficus indica*) is associated with the semi-arid zones of the world; it is one of the few crops that can be cultivated in areas which offer very little growth possibility for common fruits and vegetables (Han & Felker, 1997). Commonly eaten fresh, it is known in some areas of the world as the 'bridge of life' because, during periods of little rain, it is one of the only crops that can be used as both human food and cattle feed. Recently, several authors have published research about the post-harvest of the fruit, as well as its 'nopalitos' (Chiessa & Barbera, 1984; Chiessa & Agabbio, 1987; Rodriguez-Felix & Cantwell, 1988; Piga *et al.*, 1996; Schirra *et al.*, 1996, 1997a, 1997b; Rodriguez-Felix & Villegas-Ochoa, 1998; Schirra, 1998). Consequently, as knowledge of its nutritive value grows, interest in expanding its possibilities is also raised, lending it even greater value through its transformation into attractive products of longer shelf-life.

Interesting studies on the cactus pear have been and continue to be made in an attempt to better use this species, which for centuries has been considered an attractive and rich food.

### Technological characteristics of the cactus pear fruit

Several research studies have been carried out on the chemical composition of cactus pear fruit, also known as prickly pear (Sawaya *et al.*, 1983a; Sáenz, 1990; Cacioppo, 1992; Ewaidah & Hassan, 1992; Sáenz *et al.*, 1995c; Rodriguez *et al.*, 1996; Parish

& Felker, 1997). As fresh fruit the cactus pear has a similar composition to other fruits and vegetables but the exact knowledge of composition is the basis for any successful technological process.

The chemical and mineral composition described by different authors shows that cactus pears have a similar nutritive value to other fruits. However, its soluble solids content reaches values greater than 16%, a value greater than that present in other fruits, such as prune, apricot, and peach (Pimienta, 1990; Schmidt-Hebbel *et al.*, 1990; Sepúlveda & Sáenz, 1990). As such, it is a very useful component for processing the fruit into concentrated juices or dehydrated products, or for other technologies that use sucrose content or low  $a_w$  to preserve the product.

In regard to sugars, the fruit pulp is about 53% glucose, and the remaining 47% fructose (Sawaya *et al.*, 1983a; Russel & Felker, 1987; Sepúlveda & Sáenz, 1990; Kuti & Galloway, 1994). This amount of glucose is notable, as this sugar is the sole energetic metabolite for the brain and nerve cells and is present in the prickly pear as free sugar, directly absorbable by the body. Also easily absorbed, fructose enhances flavour, as it is sweeter than either glucose or sucrose (Cheftel *et al.*, 1983).

The caloric value of the pulp according to Sawaya *et al.* (1983a) and Schmidt-Hebbel *et al.* (1990), is about 50 Kcal 100 g<sup>-1</sup>, comparable to that of other fruits such as pear, apricot and orange.

The other components present in cactus pear pulp are protein (0.21–1.6%), fat (0.09–0.7%), fibre (0.02–3.15%) and ash (0.4–1%), all of which are similar to other fruits (Paredes & Rojo, 1973; Askar & El Samahy, 1981; Sawaya *et al.*, 1983a; Pimienta, 1990; Sepúlveda & Sáenz, 1990; Rodriguez *et al.*, 1996). The total content of free amino acids (257.24 mg 100 g<sup>-1</sup>) is of a value found only in citrus and grape, and is above average in other fruits. Also characteristic of prickly pear, in comparison with other fruits, is their high content of serine,  $\gamma$ -amino butyric acid, glutamine, proline, arginine and histidine, and the presence of methionine (Askar & El-Samahy, 1981). Cactus pears show a high level of ascorbic acid, which can reach levels near 40 mg 100 g<sup>-1</sup> (Pimienta, 1990; Sepúlveda & Sáenz, 1990; Rodriguez *et al.*, 1996); such a concentration of vitamin C is higher than that of apple, pear, grape and banana (Cheftel *et al.*, 1983; Sáenz, 1985). Sodium and potassium content in cactus pear pulp shows a good source of potassium (217 mg 100 g<sup>-1</sup>) and a low level of sodium (0.6–1.19 mg 100 g<sup>-1</sup>) which is an advantage for people with renal and blood pressure problems (Sepúlveda & Sáenz, 1990; Rodriguez *et al.*, 1996). Calcium and phosphorus represent three-quarters of the minerals of the body and are found fundamentally in bones, which serve as an important reservoir. Prickly pears are rich in calcium and phosphorus, 15.4–32.8 mg 100 g<sup>-1</sup> and 12.8–27.6 mg 100 g<sup>-1</sup>, respectively (Sawaya *et al.*, 1983a; Sepúlveda & Saenz, 1990). Although they are one of the fruits to contribute a large content of calcium to the diet, its availability must be further studied, as some researchers (Lecaros, 1997) doubt the real possibility of this calcium being used by the body, due to its common presence in the plant as calcium oxalate component, which has a low assimilation by the body. The contribution of phosphorus is similar to that of cherry, apricot, melon and raspberry. Chemical composition and nutritive value are not the only characteristics that play an important role in prickly pear processing (Table 1); in this aspect, the cactus pear is a great challenge. The high pH value (5.3–7.1) (Pimienta, 1990; Sepúlveda & Sáenz, 1990; Sáenz, 1996b) classifies this fruit within the low acid group, (pH > 4.5) requiring a thermal treatment of 115.5°C or greater to obtain good control of micro-organisms. The pH value, together with low acidity and a high content of soluble solids, make prickly pear pulp a very attractive medium for micro-organism growth (Sepúlveda & Sáenz, 1990; Sáenz, 1995). Barbagallo *et al.* (1998b) studied the organic acids present in the cactus pear juices of three Italian varieties: 'Gialla', 'Rossa' and 'Bianca'. They found that citric acid is the prevalent acid (about 17 mg 100 g<sup>-1</sup>) followed by oxalic, malic and succinic acids, in different proportions in the cited varieties.

**Table 1.** *Technological characteristics of purple and green cactus pear pulp*

Parameters	Green pulp*	Purple pulp†
pH	5.3–7.1	5.9–6.2
Acidity (% citric acid)	0.01–0.18	0.03–0.04
Soluble solids (°Brix)	12–17	12.8–14.5
Pectin (g/100 g <sup>-1</sup> )	0.17–0.19	—
Vitamin C (mg 100 g <sup>-1</sup> )	4.6–41.0	20.0–31.5
Calcium (mg 100 g <sup>-1</sup> )	12.8–27.6	—
Colour parameters		
L* (lightness)	18.2–26.7	22.4–33.4
a* (red-green)	– 4.2– – 5.5	10.0–18.4
b* (yellow)	4.0–6.5	1.1–4.3
C* (chroma)	5.8–8.5	10.1–18.9
H* (hue)	130.2–136.4	6.2–13.2
Viscosity (mPa s)	73.9	119.2

Source: \*Askar & El-Samahy (1981); Sawaya *et al.* (1983); Pimienta (1990); Sepúlveda & Sáenz (1990); Sáenz (1995); Sáenz (1996a).

†Sáenz *et al.* (1995c); Sáenz & Sepúlveda (1999).

Pectin, partially responsible for the viscosity of the pulp, is a positive element towards the production of juices, marmalades and jams. However, the content in cactus pear pulp (0.17–0.21%) is not sufficient to produce gels (Sepúlveda & Saenz, 1990; Rodriguez *et al.*, 1996).

The fruit has a range of colours varying from green to orange to red to purple, and this is an attractive quality parameter for consumers. Colours, such as those produced by the presence of the pigments chlorophyll and betalain in the green and purple fruits respectively, are certainly a parameter that makes the fruit and its products attractive; nevertheless, their stability in prickly pear products is still being studied (Merin *et al.*, 1987; Montefiori, 1990; Sáenz *et al.*, 1993). The presence of these different pigments affects the stability of the products obtained. Betalains, for example, are more stable than chlorophylls under thermal treatment and pH variation. Therefore, it could be expected that the products from purple cactus pear would be more stable than those from green cactus pear, as is discussed later.

The volatile components are minor, but nonetheless important constituents. They give the flavour to prickly pear fruits and their products. Among these, alcohol comprises by far the major proportion, most of which is ethanol (76.33%). More characteristic of prickly pear in the de Castilla variety is some unsaturated alcohol, such as trans-2-hexen-1-ol (Flath & Takahashi, 1978); 1-hexanol is the major alcohol present in the Fructa sanguineo variety; some unsaturated aldehydes, including 2,6 nonadienal and 2-nonenal, are found in green and purple varieties, and in the latter, according to Di Cesare & Nani (1992), 2-hexenal prevails over ethanol. Many of the components found in these studies have been previously reported in other fruits and cannot be considered unique to cactus pear. However, the presence of 1-nonanol, several nonon-1-ols, the nonadien-1-ols, and 2-nonenal, along with the light melon-like flavour that is characteristic of the fruit, invite comparison with published findings on cucumber and melon volatiles (Flath & Takahashi, 1978). It will be very interesting in the future to study the changes that occur in the volatile compounds of the fruit when it is processed, as some long thermal treatments can cause a hay-like taste and an unattractive aroma in the products (Carrandi, 1995).

### Food products from the fruits and cladodes

One of the oldest ways to preserve vegetables which are highly perishable is through different processing systems; Table 2 shows different products and by-products that can be obtained from cactus pear and cladodes. Due to the previously mentioned technological characteristics, the cactus pear is a true challenge, and it is necessary to do more research in this area to offer the people of the arid and semi-arid zones different ways to preserve and use this fruit out of the harvest period.

Several products are obtained from the fruit; some of them are commonly known, and others have been recently developed or are in a research stage. The research concerning products from the plant cladodes has presented a very interesting composition quite different from the fruit, and recently there have been some very stimulating results.

#### *Juice, pulp and puree technologies*

Two of the most common domestic uses of cactus pear are juices and pulps. One of the first research studies on prickly pear juices was done by Paredes & Rojo (1973) on prickly pear cv. Cardona (*Opuntia ficus indica*). These authors used citric acid to reduce the pH value to 4.3, sodium benzoate (500 p.p.m.) and a thermal treatment for 5 min at 90°C; the juice was vacuum canned in enamelled tin. The results showed that the product had a pleasant flavour and taste, and was without microbiological problems.

Espinosa *et al.* (1973) studied the *Opuntia ficus indica* juice, and found several difficulties in its preservation. In spite of reducing the pH value to 4.0 with lemon juice and carrying out a mild thermal treatment (20 min at 80°C), the acetic fermentation continued and the juice could not be preserved.

Another possibility related to cactus pear juices was concentrated juice production (Almendares, 1992). The lower  $a_w$  of the concentrates relative to the natural juices is a clear protection against the growth of micro-organisms and can extend the shelf-life of the juice. The study showed that concentrated juices could be obtained with 63–67 °Brix; the juice was prepared in an  $\alpha$ -Laval centrifuge vacuum evaporator, at approximately 40°C; the stability of the juice against micro-organism growth was good, but the sensorial analyses found the acceptability was only 5.0 (1–9 points scale). This unsatisfactory ranking was due to damage to the colour and the herbaceous aroma that appeared after the concentration process (Sáenz *et al.*, 1993; Sáenz, 1996a).

**Table 2.** *Some products and by-products from cactus pear fruit and cladodes*

Products		By-products
Cactus pear	Cladodes	Cactus pear and cladodes
Juices and nectars	Pickles and brine	Oil from seeds
Marmalades, gels and jams	Candy	Mucilage from cladodes
Dehydrated sheets	Marmalades and jam	Pigments from the peel
Sweeteners	Flour	Dietary fibre from cladodes
Alcohol and wines	Sauce	
Canned fruit	Alcohol	
Frozen fruit		

Source: Sáenz (1998); Corrales-García (1998).

Colour changes were observed during thermal treatment in pasteurized and concentrated juices of green cactus pear (Sáenz *et al.*, 1993), where chlorophyll plays an important role; the colour was determined by the Hunter colour parameters, corresponding to lightness ( $L^*$ ), red-green dimension ( $a^*$ ) and yellow-blue dimension ( $b^*$ ). The decrease of  $L^*$  with the thermal treatment resulted in a loss of brilliant green hue, turning drabber and paler, without the initial appearance of brown colours. Nevertheless, studies done at different storage temperatures (2, 10, 20 and 27°C) of concentrated cactus pear juices showed that at room temperature the juice turned dark, as reflected by the increase of  $a^*$  (from  $-2.84$  to  $-0.57$ ) and a marked modification of the hue angle  $H^*$ , with time and temperature. Sáenz *et al.* (1997a) also studied the effect of different pH (5.2 and 4.0) and thermal treatment (80°C during 10 min) in the colour of purple cactus pear juice and concluded that it presented a high stability to the pH changes and also to the thermal treatment: a clear advantage over the green cactus pear juice. The authors tested three treatments: (1) a natural juice, without modification of pH (pH = 5.2) and without thermal treatment; (2) another natural juice, without modification of pH (pH = 5.2) and with thermal treatment; and (3) a third with modification of pH (pH = 4.0) and thermal treatment (80°C for 10 min). They concluded that the  $a^*$  and  $b^*$  parameters value would influence the juice tone. Although the three treatments gave rise to a red-purple colour, some appeared more reddish. The acidification of the juice and the thermal treatment applied for its conservation and microbiological stability caused a visual change in the colour, but the purple-reddish colour characteristic of this fruit juice remained.

In relation to microbiological stability, Carrandi (1995) observed in pasteurized juice (98–100°C during 20 s) a marked colour and flavour change and the presence of microorganisms that caused damage to the juice. To prevent the action of bacteria and fungi, the same author modified the pH of the juice by lowering it to 5.2, but this change was not enough to prevent the spoilage of lactic bacterial growth such as *Lactobacillus*. In the same study the use of additives such as sodium sorbate or sodium propyl p-hydroxybenzoate (200 p.p.m.) was also not enough to preserve the juice. Other more drastic thermal treatments, such as bottle juice treatment (100°C during 20 min), produced good results for microbiological stability, but the final product did not resemble the original fresh juice due to changes in colour and flavour. Bunch (1996) reported the production of a frozen puree in the U.S.A. as the most versatile and stable product. It was made from purple cactus pear and had some percentage of pineapple juice; it could be used in a number of beverages and food dishes. Recently, Thomas (1998) described, in detail, a flow diagram for the production of red cactus pear puree. The author reported  $<3\text{cfu g}^{-1}$  coliforms, lactic acid bacteria and *E. coli*, as well as  $<10\text{cfu g}^{-1}$  aerobics, yeast and molds. The same author reported obtaining a cactus pear puree concentrate, a 65°Brix, vacuum-dehydrated product used as a flavouring ingredient for ice cream, confections, pastries and desert toppings. Mixed drink flavourings using this cactus pear puree are now available through a national restaurant wholesaler's organization, in a 28-pound (12.6 kg) frozen pail.

Sáenz & Sepúlveda (1999) prepared several blends of purple cactus pear juice and pineapple juice, with good results. However, although the pineapple juice helped to improve the acidity of the blend, its aroma and taste affected the delicate aroma and taste of the cactus pear juice. Another alternative would be the use of only citric acid to improve the acidity of the blends.

Barbagallo *et al.* (1998b) obtained a concentrated puree (37%) from the cactus pear cv. 'Giulla' and compared the product with the natural pulp; the colour, aroma and flavour of the product were similar to those of the natural pulp; the acidity was modified with citric acid to pH = 4.0; they concluded that the concentrated puree could be a good ingredient for the candy industry as a semi-processed product.

A very important property of the juice is its rheological behaviour in terms of the industry's pump design, and also of the sensory quality of the products. The rheological

properties of different concentrated cactus pear juices were studied by Sáenz & Costell (1990), finding most of them to be pseudoplastic and to fit well within the Ostwald model ( $r^2 = 0.981$ ). Nevertheless, depending on the type of juice, pulped or pressed, and the degree of concentration, the rheological behaviour changed; for example, pressed juices changed to Newtonian in 40°Brix or less.

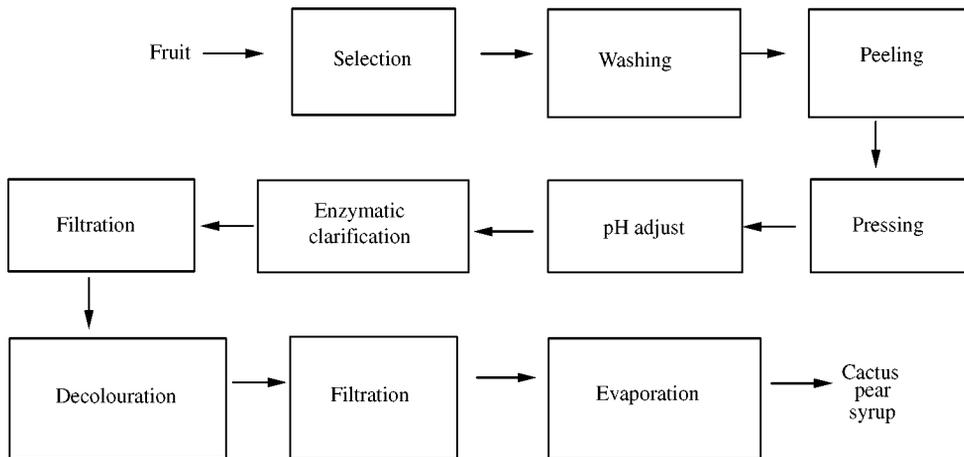
Other researchers have attempted to obtain clarified juices. It is known that the juices without pulp can be concentrated to a higher degree of solids content, with advantages in terms of both their conservation and the reduction of transport and storage space. The use of pectinolytic enzymes has been tested for this purpose with a treatment at 40°C for 48 h, and with the addition of citric acid. The juice packaged in cans receives a different thermal treatment from the juice packaged in glass bottles. Both treatments show colour changes due to pasteurization, which is then corrected by artificial colourants (Yagnam & Osorio, 1991). Using a NOVO prepared with a mix of pectolitic enzymes and a high activity of arabanase, Sáenz *et al.* (1996b) have clarified cactus pear juice with success.

#### *Liquid sweetener preparation*

The transformation of the juice into a liquid sweetener, using pectinolytic enzyme with a high arabanase activity, has been recently studied. Sáenz *et al.* (1996b, 1998) developed a process (Fig. 1) to obtain a natural liquid sweetener from cactus pear juice; the product had 60°Brix (56% of glucose, 44% of fructose), a density of 1.2900 g ml<sup>-1</sup>, an  $a_w$  of 0.83, similar to that of honey or marmalades; a light golden-yellow colour and a viscosity of 27.1 cps. The sweetness is 67 compared with sucrose. These characteristics are similar to those of other liquid sweeteners currently marketed.

#### *Gel, jam and candy technologies*

The use of cactus pear pulp to prepare gels, such as the apple or quince gels common to many countries' markets, opens another possibility for this fruit. Sáenz *et al.* (1996a) added a gelling agent and sugar to the pulp (35–40%); two pH levels were tested, 3.5 to



**Figure 1.** Processing scheme for cactus pear syrup. Source: Sáenz *et al.* (1998).

prevent microbiological growth and 6.1 (the original of the cactus pear pulp); a marked colour change was observed with pH 3.5 due to the transformation of chlorophyll into pheophytin, but the product maintained its chemical, physical and sensory characteristics for 14 more days at refrigeration temperatures (4–6°C).

Several studies have been carried out in different countries on other cactus pear products. Sawaya *et al.* (1983a) manufactured prickly pear jam, with and without blanching the fruit; sensory evaluation tests resulted in non-significant differences. The proportion was a prickly pear pulp:sugar ratio of 60:40; 1.25% pectin; citric acid or citric and tartaric 1:1. Flavours such as cloves, grapefruit extract, orange extract and almond flavour gave better results than other flavours tasted. In addition, the jam contained 20% date pulp.

Tirado (1986) made a jam with cladodes (cactus stems or pads) by, instead of the fruit, adding orange juice, orange peel, and sugar to the ratio 1:1.5:0.8:0.08. The jam had no microbial growth after 40 days of storage. This product showed no difference from other jams in the Mexican market (fig and orange) in aroma, colour, taste, texture and appearance.

Badillo (1987) made a jam with cladodes, sugar and citric acid in the proportion 1:0.6:0.01, obtaining a product with good sensory quality and microbiological stability. Sáenz *et al.* (1995a) made a marmalade from cladodes using a previous treatment plus a 2% solution of Ca(OH)<sub>2</sub> to lower the mucilage content, which damages texture and acceptability. The final formulation used lemon juice and lemon peel. The first lowered the pH and the second contributed pectin to the gelling of the product.

Vignoni *et al.* (1997) compared two cactus pear jams: one with lemon juice and lemon peel added, and the other without. They did not have significant differences, according to a Karlsruhe scale for sensory analysis.

Villarreal (1996) studied the manufacturing of candies from the cladodes. The author tested several proportions of sugar syrups (sucrose and glucose) and also tested sweet and bitter chocolate coatings; the products presented very good characteristics and sensory quality, with  $a_w$  of 0.53–0.63. The energy value differed (306.3–340.4 Kcal 100 g<sup>-1</sup>), depending on whether the products were covered with chocolate or not. The acceptability was higher in the products covered with chocolate (7.6) compared to the non-chocolate covered products (6.3).

### *Canned and frozen products*

Cactus pears have been canned experimentally, both in tin and glass. In the latter case, the addition of 45°Brix syrup was tested with a thermal treatment for 15 min at 100°C. Some of the results were contradictory and changes in colour and fruit texture could possibly be lessened (Yagnam, 1986; Sáenz, 1995). Joubert (1993) studied the canning of different cultivars of *Opuntia ficus indica* from South Africa; she studied the differences in cultivar firmness while hand-peeled fruit was canned in acidified sucrose syrup (20°Brix) at 100°C for 15 min. With increasing processing time, fruit firmness decreased; however, it increased with the addition of 0.25% CaCl<sub>2</sub> to the syrup. The processing of the fruit resulted in loss of texture, colour and flavour.

As another alternative to preserving the fruit, Sáenz *et al.* (1988) manufactured frozen fruit, using slices of 0.625 mm thickness and quarters of peeled and unpeeled fruit. The freezing process was done in a fluid bed tunnel at –40°C, and samples were stored at –20°C. The results achieved were not satisfactory due to the high drip, mainly from the slices during defrosting. This fact, together with a significant loss of texture, caused the low acceptance of all three alternatives tested. Possibly, the use of protective substances such as syrup or solid sugar could improve the results of this preservation process.

*Dehydrated products*

Dehydration is an age-old process of preserving food. Russel & Felker (1987) mentioned dried prickly pear as another edible form of the product. In a slightly modified preservation procedure, Ewaidah & Hassan (1992) tested prickly pear sheets using a Taifi cultivar. The optimum formulation was obtained by adding 10% sucrose, 1.1% citric acid, 0.15% sodium metabisulphite and 0.5% olive oil to the fruit pulp. Sodium metabisulphite improved the colour, and citric acid produced an acid taste similar to that of the traditional apricot sheets. A small tasting panel found the sheets extremely acceptable, rating them with a score of 8 out of 9.

Sepúlveda *et al.* (1996) developed a fruit leather made with cactus pear pulp and quince pulp. The authors tested different proportions of pulps and found the best blend to be 75:25, cactus pear: quince pulp. The blend was dehydrated in a forced air tunnel in thin layers until moisture content was approximately 15–16%. The product had a pleasant texture, and the components of the fruit gave it a moistness that permitted immediate consumption. This kind of product is well-liked by children and can be considered an energy food, with caloric values of about 319–327 cal 100 g<sup>-1</sup>.

*Alcoholic beverages and other products*

Another alternative use of cactus pears is in the cottage industry preparation of alcoholic beverages such as 'colonche'. 'Colonche' is obtained through fermentation of the juice and pulp in wooden barrels, a procedure with certain imperfections that, following this study, could be overcome. For example, the use of *Sacharomyces cerevisiae* would resolve the lack of selection of yeast. 'Colonche' is a low-alcohol drink and is best when freshly fermented, as it quickly turns acidic (Sáenz, 1995).

Other studies made to obtain alcoholic beverages from cactus pears show the use of *Sacharomyces cerevisiae* Montrachet whit SO<sub>2</sub> (10 ml l<sup>-1</sup>) and citric acid to decrease the pH to 3.3 (Bustos, 1981). Flores (1992) carried out experiments in order to obtain wine and alcohol from prickly pears, the first of 11.16°GL and the second of 56.2°GL. Of the varieties used for wine, *O. streptacantha* and *O. robusta*, both had similar, delicately pleasant, fruit-like characteristics. The alcohol, in turn, had fruit-like characteristics and a pleasant taste, with an initial and prevailing wine aroma. Blaisten (1968) obtained cactus pear alcohol from different varieties of the *Opuntia* genus, producing a distillate of 43°GL with unique and defined organoleptic characteristics. Retamal *et al.* (1987), using both cladodes and fruits to obtain alcohol with different yeast strains of the *Saccharomyces* genus, found a sugar conversion of over 90% in the fruit and approximately 60% in cladodes.

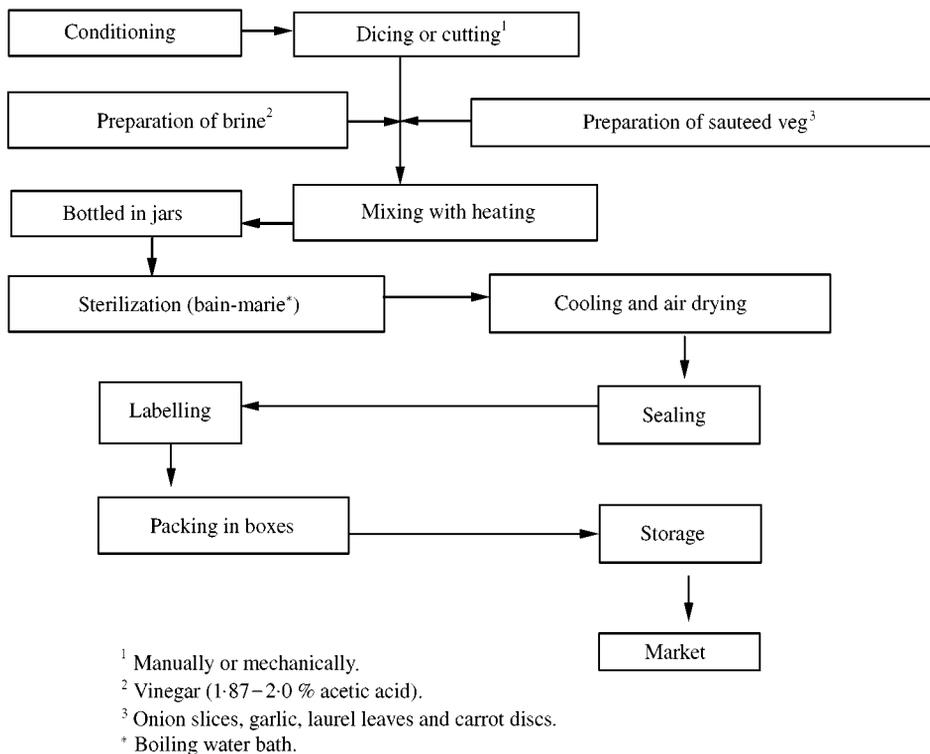
Other older preservation procedures with a large application today, although mostly in Mexico, are the ones developed for wild varieties (*Opuntia streptacantha* and *Opuntia robusta*); among them appears the 'tuna cheese', prepared with cottage industry procedures, based on the boiling of the pulp and juice until a certain viscosity is obtained ('melcocha'). The juice, highly concentrated and beaten, is then placed in rectangular recipients, usually of 1 kg, which are sold once the 'cheese' has dried. Raisins, nuts and pine nuts can be added to enrich its flavour (Sáenz, 1995; López *et al.*, 1997).

Another potential product that can be obtained during fruit processing is seed oil. This oil is edible and has a yield range between 5.8 and 13.6 (Sawaya & Khan, 1982; Sepúlveda & Sáenz, 1988; Becerril, 1997). The oil shows a high grade of non-saturated acids, with a high content of linoleic acid (57.7 to 73.4%). These and other physical and chemical characteristics, including the refractive index, iodine number, and saponification number, make it similar to other edible vegetable oils such as corn or grape seed oil. In another study, Sawaya *et al.* (1983b) found interesting contributions of protein

(16.6%), fat (17.2%) and fibre (49.6%) in the seeds, the latter being considerably higher than that of other oleaginous seeds.

### *Other products from the cladodes*

'Nopalitos' have been a traditional fresh green vegetable in the Mexican diet for centuries (Rodríguez-Félix & Villegas-Ochoa, 1998), and for many years have been used and prepared by Mexicans in various ways. In fact, the tender cactus pear pads are an ingredient in a diversity of dishes including sauces, salads, soups, stews, snacks, beverages and desserts (Rodríguez-Félix & Villegas-Ochoa, 1998). Cantwell (1995) mentioned that 'nopalitos' are also a traditional vegetable in some areas of the United States. Good quality cactus stems or 'nopalitos' are thin, fresh-looking, turgid, and a brilliant green. After trimming and chopping, the cactus stems may be eaten as a fresh or cooked vegetable, and resemble green beans in flavour (Rodríguez-Félix & Cantwell, 1988). A study developed by Rodríguez-Félix *et al.* (1997) showed that consumers eat 'nopalitos' because they like them and also because they consider them healthy. 'Nopalitos' are a highly perishable vegetable crop when handled and marketed fresh, but with industrial transformation they can be conserved for a long time. Two of the main processed products are 'nopalitos' in brine and pickled 'nopalitos' (Corrales-García, 1998). For both products, there are common steps that involve dethorning, washing, dicing or cutting, scalding or cooking; after this conditioning, the nopalitos can follow different methods of processing. As seen in Fig. 2, the nopalitos in brine are prepared



**Figure 2.** Flow diagram of the production process for pickled 'nopalitos'. Source: Corrales-García (1998).

with a pickling mixture, which is a combination of vinegar (1.87–2.0% acetic acid) with spices, aromatic herbs, and olive oil. The vinegar is heated to boiling, and the spices are then added, either directly or in a cloth bag. Onion slices, garlic cloves, laurel leaves and carrot discs are lightly fried, separately, in vegetable oil. Then the nopalitos, vinegar and sautéed vegetables are mixed, and bottled in jars that have been sterilized in boiling water.

Yet other possibilities for cactus cladode processing have been investigated in recent years. Changing life styles in developed countries over the past years have led consumers to prefer ready-to-eat foods and a low-calorie, low-cholesterol, low-fat diet that is fibre enriched. Interest in natural sources of fibre has increased. Consumers know the relationship between fibre consumption and cholesterol control, and the role of fibre in the prevention of some illnesses such as diabetes and obesity. One potential source of natural dietary fibre is the cladodes of the *Opuntias* (Sáenz, 1998). Pimienta (1990) said that the age of the cladodes influences its chemical composition; that is, the crude fibre (only a portion of the dietary fibre) increases with the age of the cladodes. In recent years Sepúlveda *et al.* (1995), Sáenz *et al.* (1995*b*) and Sáenz *et al.* (1997*b*) have studied methods for obtaining cladode flour from mature cladodes (2–3 years) as a concentrated fibre source to be added to other flour products. The authors tested different times and temperatures for drying the cladodes and obtained a concentration of 43% dietary fibre, where 28.5% was insoluble fibre and 14.5% soluble fibre, with a low moisture and  $a_w$  (Table 3). Different proportions for mixing cladodes and wheat flour were tested, and the rheological behaviour of the dough was analysed. The flour was tested by substituting it for some portion of the wheat flour in biscuits, and it was observed that it could be added in replacement portions of nearly 10–15%. Albornoz (1998) and Vallejos (1999) tested the substitution in a vegetable soup and in a flan (a dessert), respectively; they observed that in the soup the maximum level of addition was 15% and in the dessert it was 16%. Higher proportions affected the rheological properties as well as the taste and aroma of the products. Nevertheless, those substituted proportions made a great difference in these products, compared to the commercial ones, because the contribution to the fibre intake was significantly higher than before it was added.

Gallardo *et al.* (1997) and Zambrano *et al.* (1998) studied some properties of crude young 'nopal' as a source of fibre. The dried product had 20.4% of dietary fibre as well as other interesting physico-chemical characteristics: water absorption (5.8), water retention (4.7), organic molecules absorption (0.69), and cationic exchange (0.49), which could explain the role of 'nopal' in the intestine. Hernández *et al.* (1997, 1998) tested rats' consumption of crude and scalded 'nopal' and observed that the greater the amount of fibre in the diet the greater the production of faeces in both cases but the last one shows a better result. The authors concluded that if rats lose weight and show signs of malnutrition, the consumption of crude 'nopal' must be carefully examined in humans.

**Table 3.** Chemical and physical characteristics of nopal flour

Parameters	Average
Water activity ( $a_w$ )	0.53
Moisture (%)	7.14
Protein ( $\times 6.25$ ) (%)	3.9
Total dietary fibre (%)	43.0
Insoluble dietary fibre (%)	28.5
Soluble dietary fibre (%)	14.5

Sáenz *et al.* (1997).

Pure mucilage, obtained from the cladodes as well as from the peel, is another interesting possibility for alimentary, medical and cosmetic use. The mucilage, a complex polysaccharide, is part of dietary fibre and has the capacity to absorb large amounts of water, dissolving and dispersing itself and forming viscous or gelatinous colloids. Several authors have studied the extraction of the prickly pear mucilage (McGarvie & Parolis, 1979; Paulsen & Lund, 1979; Trachtenberg & Mayer, 1981; Sáenz *et al.* 1992). The mucilage is composed of arabinose, galactose, rhamnose and galacturonic acid, the latter being in proportions of 17.6 to 24.7%, depending on whether it comes from fruit or cladodes (Sáenz, 1995). Sáenz *et al.* (1992) observed a clear effect of pH over viscosity in a water dispersion of the mucilage (0.44% p/v) reaching values of 58.1 cps at pH 6.6. Cárdenas & Gooicolea (1997) and Cárdenas *et al.* (1997) studied several aspects of mucilage and obtained a yield of 0.07%, showing that the polymer had a weight average molecular mass ( $M_w$ ) of  $3 \times 10^6$  and an average molecular mass ( $M_n$ ) of  $2.4 \times 10^6$ , with a polydispersity index ( $M_w/M_n$ ) of 1.4. Both  $M_w$  and  $M_n$  values exceeded those previously reported for the polysaccharide from *Opuntia ficus indica*. This overestimation of molecular mass may indicate the extensive formation of large macromolecular aggregates in solution. Regarding the rheological properties of mucilage solutions with different concentrations of NaCl 0.1 M, the same authors reported that the rheological behaviour was similar to that of polysaccharide chains when little deformation was used. The mechanical response observed was characteristic of an entangled network of disordered polymer coils.

Nobel *et al.* (1992) reported that the mucilage content of cactus cladodes could be influenced by some probable effects associated with the management of this crop. The authors stated that climate temperature could influence the mucilage content. It is possible that irrigation and rain were also influences. These effects are important if we look at the cladodes as a source of mucilage.

Gardiner *et al.* (1999) reported quantitative benefits from cactus mucilage in a physical process to improve water infiltration in soils.

An important area to develop would be some sort of simple, fast, standardized mucilage test to rank the varieties of mucilage.

Cactus mucilage may find applications in food, cosmetics, pharmaceuticals, and other industries. A method known in some countries for clarifying drinking water uses cactus mucilage as an agent and has been used for many years by small farmers in Chile. Cardenas *et al.* (1997) also mentioned its culinary properties as a fat substitute and as a flavour binder.

### *Food additives*

In another area, the constant search for natural additives as pharmaceutical, cosmetic, and food colourants suggests that the research carried out on the purple cactus pear is on the right track. Well known and widely used in the food industry as powder or concentrated juice is the pigment obtained from the red beet, whose colour is due to the presence of betalain (the same pigment present in the red prickly pear). Montefiori (1990) carried out studies on extraction, identification and stability of the pigments of the purple prickly pear, finding yields of 16 mg of betanin per 100 g of fresh product. Odoux & Dominguez-López (1996) reported different quantities of betacyanines for several species of *Opuntia*, where *Opuntia* sp. had 100.8 mg 100 g<sup>-1</sup>. Strack *et al.* (1987) pointed out the presence of neobetainin in the fruit pulp and found a betanin-neobetainin ratio of about 1:2.5 in *Opuntia ficus indica*. Sáenz *et al.* (2000) determined 100 mg 100 g<sup>-1</sup> of betanin in a concentrated juice of purple cactus pear juice with colour parameters of  $L^* = 22.8$ ,  $a^* = 3.8$ ,  $b^* = 0.3$ ,  $C^* = 3.8$  and  $H^* = 5.1$  (Table 4); they tested the addition as a colourant in yogurt with good results, and no changes in the aroma or taste of this product were observed.

**Table 4.** Chemical and physical characteristics of the colour extracts of *Opuntia*

Parameter	Average
Soluble solids (°Brix)	61.5
Acidity (% citric acid)	0.81
pH	4.3
Betanin (mg 100 g <sup>-1</sup> )	100
Colour parameters	
L* (lightness)	22.8
a* (red)	3.8
b* (yellow)	0.34
C* (chroma)	3.82
H* (hue)	5.11

Sáenz *et al.* (2000).

#### Medical uses

There is an extensive variety of diseases that popular medicine (mainly Mexican) claims can be fought and cured with the 'nopal', or cactus pear, or other parts of the plants or their flowers (Pimienta, 1990; Barbera, 1991; Mulas, 1993). Few of these applications have any degree of scientific basis, although their effect can be cited in cases of diabetes mellitus, hyperlipidemy (excess of lipids in the blood), and obesity (Gulías & Robles, 1989). To this effect, Frati-Munari *et al.* (1990) studied the hypoglycemic effect of *Opuntia ficus indica* stems, and found that glycemia decreased in all patients tested following ingestion of *Opuntia ficus indica*, and reached statistically significant levels after 120 and 180 min. In another study, Ibañez-Camacho *et al.* (1983) confirmed this hypoglycemic action. Ramírez & Aguilar (1995) presented a review of evidence on the reduction effect of *Opuntia* in the serum glucose, and with access to eight different reports they concluded that this meta-analysis suggested *Opuntia* had a strong glucose reduction effect. They further indicated that these findings, however exciting, were preliminary at best. Trejo *et al.* (1995) evaluated the hypoglycemic activity of a purified extract from prickly pear cactus (*Opuntia* sp.) on STZ-induced diabetic rats. They concluded that, although the mechanism of action was unknown, the magnitude of the glucose control by the small amount of *Opuntia* extract required (1 mg kg<sup>-1</sup> body weight per day) precluded a predominant role for dietary fibre for hypoglycemic activity.

Frati-Munari *et al.* (1992) evaluated its role in the management of diabetes mellitus using commercial capsules of dried nopal. The experiment involved giving a dosage of 30 capsules, each containing 335 mg of dried nopal cladodes, to diabetic subjects, with serum glucose levels measured intermittently every 60 min for 3 h; a control test was also performed with 30 placebo capsules. It was concluded that nopal capsules did not show acute hypoglycemic effect and did not influence the glucose tolerance test. In diabetic patients serum glucose, cholesterol and tryglycerides levels did not change with *Opuntia*, but they increased with placebo. In healthy individuals glycemia did not change with nopal, while cholesterol and triacylglycerides decreased.

The effect of the prickly pear over the metabolism of the low-density lipoproteins has been studied by Fernández *et al.* (1990), suggesting, through its results, that the extract of prickly pear would act in a similar way to that of other compounds used to decrease cholesterol levels.

In conclusion, the numerous possibilities of obtaining different products and by-products from cactus pear and nopal open new hopes for the semi-arid regions.

Nevertheless, many aspects related to the processing of cactus pear and the uses of cladodes require further research. This crop has much to contribute to human food, and can be a hope for human medicine, a source of natural additives to the food industry, and mainly, more than a 'bridge of life' for low-income inhabitants of different parts of the world.

## References

- Albornoz, N. (1998). *Elaboración y evaluación de una crema de verduras con adición de fibra dietética de nopal*. Memoria de Título, Facultad de Ciencias Agrarias y Forestales, Universidad de Chile. 53 p.
- Almendares, L. (1992). *Elaboración y conservación de jugo concentrado de tuna (*Opuntia ficus indica* (L.) Mill) obtenido a partir de fruta fresca y con almacenaje refrigerado*. MSc. Thesis, Universidad de Chile, Facultad de Ciencias Agrarias y Forestales, Santiago, Chile. 90 pp.
- Askar, A. & El-Samahy, S.K. (1981). Chemical composition of prickly pear fruits. *Deutsche Lebensmittel-Rundschau*, **77**: 279–281.
- Badillo, J.R. (1987). *Elaboración de una jalea de nopal*. Tesis. Escuela de Ciencias Químicas, Universidad Autónoma de Puebla, México. 46 pp.
- Barbagallo, R., Papalardo, P. & Tornatore, G. (1998a). Valutazione chimica e sensoriale di una purea concentrata di fichi d'india. *Industria Alimentari*, **XXXVII**: 745–749.
- Barbagallo, R., Papalardo, P. & Tornatore, G. (1998b). Confronto varietale dei succhi di *Opuntia ficus indica* mediante dosaggio degli acidi organici per HPLC. *Industria delle Bevande*, **XXVII**(6): 273–275.
- Barbera, G. (1991). Utilizzazione economica delle opunzie in Messico. *Frutticoltura*, **2**: 41–48.
- Becerril, A. (1997). *Porcentaje de aceite en semillas de nopal (*Opuntia ficus indica*)*. Memorias VII Congreso nacional y V Internacional sobre conocimiento y aprovechamiento del nopal. Monterrey, México. 212 pp.
- Blaisten, R. (1968). Obtención de un aguardiente de la tuna del nopal. *Tecnología de Alimentos*, **3**: 26–30.
- Bustos, O. (1981). Alcoholic beverage from Chilean *Opuntia ficus indica*. *American Journal of Enology and Viticulture*, **32**: 228–229.
- Bunch, R. (1996). New developments in breeding and cactus pear products at D'Arrigo Bros. *Journal of the Professional Association for Cactus Development*, **1**: 100–102.
- Cacioppo, O. (1992). Il fico d'India: sviluppo produttivo, costi e commercializzazione. *L'informatore Agrario*, **33**: 1–7.
- Cantwell, M. (1995). Post-harvest management of fruits and vegetable stems. In: Barbera, G., Inglese, P. & Pimienta Barrios, E. (Eds), *Agro-ecology, cultivation and uses of cactus pear*, pp. 120–136. FAO Plant Production and Protection Paper No 132. 216 pp.
- Cárdenas, A. & Goicoolea, F. (1997). *Reología en solución del mucilago del nopal (*Opuntia ficus indica*)*. Memorias VII Congreso nacional y V Internacional sobre conocimiento y aprovechamiento del nopal. Monterrey, México. pp. 171–172.
- Cárdenas, A., Higuera-Ciapara, I. & Goycoolea, F. (1997). Rheology and aggregation of cactus (*Opuntia ficus indica*) mucilage in solution. *Journal of the Professional Association for Cactus Development*, **2**: 152–159.
- Carrandi, L. (1995). *Efecto de conservantes en la estabilidad de jugo de tuna pasteurizado*. Memoria de Título. Ing. Agrónomo. Facultad de Ciencias Agrarias y Forestales Universidad de Chile. 61 pp.
- Cheftel, J.C., Cheftel, H. & Besançon, P. (1983). *Introducción a la bioquímica y tecnología de los alimentos* (1st Edn), Vol II. Acirbia, Zaragoza, España. 404 pp.
- Chiessa, I. & Barbera, G. (1984). Indagine sulla frigoconservazione dei frutti della cv "Gialla" di Ficodindia. *Frutticoltura*, **8**: 57–61.
- Chiessa, I. & Agabbio, M. (1987). *Prospettive di sviluppo della coltura delle Opunzie: tecnologie di valorizzazione della produzione*. Progetto Finalizzato MAF Sviluppo e miglioramento della frutticoltura da industria, della frutticoltura da consumo fresco e dell'agrumicoltura Sottoprogetto 5. Pubblicazione No **277**: 273–287.
- Corrales-García, J. (1998). Industrialization of prickly pear pads (nopalitos). In: *Proceedings. International Symposium Cactus pear and nopalitos processing and uses*. Sáenz, C. (Ed.), Santiago, Chile. pp. 25–32.
- Di Cesare, L.F. & Nani, R. (1992). Analysis of volatile constituents of prickly pear juice (*Opuntia ficus indica* var. *Fructa sanguinea*). *Fruit Process*, **2**: 6–8.

- Espinosa, J., Borrocal, R., Jara, M., Zorrilla, C., Zanabria, C. & Medina, J. (1973). Quelques propriétés et essais préliminaires de conservation des fruits et du jus de figue de barbarie (*Opuntia ficus indica*). *Fruits*, **28**: 285–289.
- Ewaidah, E.H. & Hassan, B.H. (1992). Prickly pear sheets: a new fruit product. *International Journal of Food Science and Technology*, **27**: 353–358.
- Fernández, M.L., Trejo, A. & McNamara, D. (1990). Pectin Isolated from prickly pear (*Opuntia* sp.) modifies low density lipoprotein metabolism in cholesterol-fed guinea pigs. *Journal of Nutrition*, **120**: 1283–1290.
- Flath, R.A. & Takahashi, J.M. (1978). Volatile constituents of prickly pear (*Opuntia ficus indica* Mill.), de Castilla variety. *Journal of Agriculture and Food Chemistry*, **26**: 835–837.
- Flores, A. (1992). Producción de vino y aguardiente de tuna, alternativa en el aprovechamiento del nopal. *Ciencia y Desarrollo*, **17**: 56–68.
- Frati-Munari, A., Jiménez, E. & Ariza, C.R. (1990). Hypoglycemic effect of *Opuntia ficus indica* in non insulin-dependent diabetes mellitus patients. *Phytotherapy research*, **40**(5): 195–197.
- Frati-Munari, A., Vera Lastras, O. & Ariza Andraca, C.R. (1992). Evaluación de cápsulas de nopal en Diabetes Mellitus. *Gaceta Médica de México*, **128**(4): 431–436.
- Gallardo, Y., Zambrano, M.L. & Hernandez, A.D. (1997). *Determinación de las propiedades fisicoquímicas del nopal verdura*. Memorias VII Congreso Nacional y V Internacional sobre conocimiento y aprovechamiento del nopal. Monterrey, México. pp. 277–278.
- Gardiner, D., Felker, P. & Carr, T. (1999). Cactus extract increases water infiltration rates in two soils. *Communications in Soil Science and Plant Analysis*, **30**(1&2): 1707–1712.
- Gullías, A. & Robles, G. (1989). El nopal en su justa medida. *Cuadernos de Nutrición*, **12**: 42–43.
- Han, H. & Felker, P. (1997). Field validation of water-use efficiency of a CAM plant *Opuntia ellisiana* in south Texas. *Journal of Arid Environments*, **36**: 133–148.
- Hernández, A.D., Chamorro, G. & Gallardo, Y. (1997). *Efecto fisiológico de la ingesta de nopal sobre la producción de heces fecales*. Memorias: VII Congreso Nacional y V Internacional sobre conocimiento y aprovechamiento del nopal. Monterrey, México. pp. 289–290.
- Hernández, A.D., Gallardo, Y. & Chamorro, G. (1998). Caracterización de la fibra de nopal por medio de su respuesta fisiológica. In: Lajolo F. & Wenzel, E. CYTED. (Eds), *Temas en tecnología de alimentos*, Vol 2. Fibra dietética. Programa Iberoamericano de Ciencia y Tecnología de Alimentos — Instituto Politécnico Nacional de México. pp. 215–230.
- Ibañez-Camacho, R., Meckes-Lozoya, M. & Mellado-Campos, V. (1983). The hypoglycemic effect of *Opuntia Streptacantha* studied in different animal experimental models. *Journal of Ethnopharmacol*, **7**: 175–181.
- Joubert, E. (1993). Processing of the fruit of five prickly pear cultivars grown in South Africa. *International Journal of Food Science and Technology*, **28**: 377–387.
- Kuti, J.O. & Galloway, C.M. (1994). Sugar composition and invertase activity in prickly pear. *Journal of Food Science*, **59**(2): 387–393.
- Lecaros, M. (1997). *Caracterización de harina de cladodio de nopal (Opuntia ficus indica)*. Memoria de Título. Ing. Agrónomo. Facultad de Ciencias Agrarias y Forestales. Universidad de Chile. Santiago, Chile. 53 pp.
- López, J.J., Fuentes, J. & Rodríguez, A. (1997). Prickly pear fruit industrialization (*Opuntia streptacantha*). *Journal of the Professional Association for Cactus Development*, 169–174.
- McGarvie, D. & Parolis, H. (1979). The mucilage of *Opuntia ficus indica*. *Carbohydrate Research*, **69**: 171–179.
- Mulas, M. (1993). Medicinal properties and yield possibilities of the prickly pear (*Opuntia* spp.) in the Mediterranean Environment. *Acta Horticulturae*, **331**: 79–84.
- Merin, U., Gagel, S., Popel, G., Bernstein, S. & Rosenthal, I. (1987). Thermal degradation kinetics of prickly-pear-fruit red pigment. *Journal of Food Sciences*, **52**: 485–486.
- Montefiori, D. (1990). Ricerche sull' estrazione, la stabilità e l' impiego dei pigmenti del fico d' india sanguigno. Tesi di Laurea. Università degli Studi di Milano, Italia. 94 pp.
- Nobel, P., Cavelier, J. & Andrade, J.L. (1992). Mucilage in cacti: its apoplastic capacitance, associated solutes, and influence on tissue water relations. *Journal of Experimental Botany*, **43**(250): 641–648.
- Odox, E. & Dominguez-Lopez, A. (1996). Le Figuier de Barbarie: une source industrielle de Oetalaines? *Fruits*, **51**: 61–78.
- Paredes, O. & Rojo, R. (1973). Estudio para el enlatado del jugo de tuna. *Tecnología de Alimentos*, **8**: 237–240.

- Parish, J. & Felker, P. (1997). Fruit quality and production of cactus pear (*Opuntia* spp) clones selected for increased frost hardiness. *Journal of Arid Environments*, **37**: 123–143.
- Paulsen, B.S. & Lund, P.S. (1979). Water-soluble polysaccharides of *Opuntia ficus indica* cv 'Burbank's spineless'. *Phytochemistry*, **18**: 569–571.
- Pimienta, E. (1990). *El Nopal tunero* (1st Edn). Jalisco, México: Universidad de Guadalajara. 246 pp.
- Piga, A., D'Aquino, S., Agabbio, M. & Schirra, M. (1996). Storage life and quality attributes of cactus pears cv. 'Gialla' as affected by packaging. *Agricoltura Mediterranea*, **126**: 423–427.
- Ramirez, G. & Aguilar, C. (1995). The effect of *Opuntia* in lowering serum glucose among NIDDM patients. A systematic review – Preliminary Findings. *Proceedings: I Conference of the Professional Association for Cactus Development*, pp. 71–78.
- Retamal, N., Durán, J.M. & Fernández, J. (1987). Ethanol production by fermentation of fruits and cladodes of prickly pear cactus (*Opuntia ficus indica* (L.) Miller). *Journal of the Science of Food Agriculture*, **40**: 213–218.
- Rodriguez, S., Orphee, C., Macias, S., Generoso, S. & Gomes García, L. (1996). Tuna: Propiedades físico-químicas de dos variedades. *La Alimentación Latinoamericana*, **210**: 34–37.
- Rodriguez-Felix, A. & Villegas-Ochoa, M. (1998). Postharvest handling of cactus leaves (nopalitos). In: *Proceedings of the International Symposium: Cactus pear and nopalitos processing and uses*. Sáenz, C. (Ed.), Santiago, Chile. pp. 7–16.
- Rodriguez-Félix, A. & Cantwell, M. (1988). Developmental changes in the composition and quality of prickly pear cactus cladodes (nopalitos). *Plant Foods for Human Nutrition*, **38**: 83–93.
- Rodriguez-Félix, A., Cano-Ochoa, M.D., Villegas-Ochoa, M. & Santos-Becerril, V. (1997). Calidad sensorial y formas de consumo de nopal verdura. *Memorias: VII Congreso Nacional y V Internacional sobre Conocimiento y Aprovechamiento del nopal*. Monterrey, México. pp. 208–209.
- Russel, C. & Felker, P. (1987). The prickly-pears (*Opuntia* spp., Cactaceae): A source of human and animal food in semi-arid regions. *Economic Botany*, **41**: 433–445.
- Sáenz, C. (1985). The prickly pear (*Opuntia ficus indica*) a cultivar with prospects. *Alimentos*, **10**: 47–49.
- Sáenz, C. (1995). Food Manufacture and by-products. In: Barbera, G., Inglese, P. & Pimienta-Barrios, E. (Eds), *Agro-ecology, cultivation and uses of cactus pear*, pp. 137–143. FAO Plant Production and Protection Paper No. 132. 216 pp.
- Sáenz, C. (1996a). Foods products from cladodes and cactus pear. *Journal of the Professional Association for Cactus Development*, **1**: 89–97.
- Sáenz, C. (1996b). Food products from cactus pear (*Opuntia ficus indica*). *Food Chain*, **18**: 10–11.
- Sáenz, C. (1998). Cladodes: A source of dietary fiber. *Journal of the Professional Association for Cactus Development*, **2**: 117–123.
- Sáenz, C. (1998). Alternatives to process cactus pear. Cactusnet Newsletter. *FAO International Cooperation Network on Cactus Pear*, **4**: 8–10.
- Sáenz, C. & Costell, E. (1990). Rheology of prickly pear (*Opuntia ficus indica*) concentrated juices. In: Spies, W.E.L. & Schubert, H. (Eds), *Engineering and Food*, Vol. I, pp. 133–137. England: Elsevier Applied Science. 944 pp.
- Sáenz, C. & Sepúlveda, E. (1999). Physical, chemical and sensory characteristics of juices from pomegranate and purple cactus pear fruit. *Annals of the 22nd IFU Symposium*, Paris. pp. 91–100.
- Sáenz, C., Sepúlveda, E. & Araya, E. (1988). Ensayos preliminares de obtención de tuna (*Opuntia ficus indica*) congelada. *Resúmenes: VI Seminario Latinoamericano de Ciencia y Tecnología de Alimentos*. Bogotá, Colombia.
- Sáenz, C., Vásquez, M., Trumper, S. & Fluxá, C. (1992). Extracción y composición química de mucilago de tuna (*Opuntia ficus indica*). *Actas: II Congreso Internacional de la tuna y cochinilla*. Santiago, Chile. pp. 93–96.
- Sáenz, C., Sepúlveda, E., Araya, E. & Calvo, C. (1993). Colour changes in concentrated juices of prickly pear (*Opuntia ficus indica*) during storage at different temperatures. *Lebensmittel-Wissenschaft und Technologie*, **26**: 417–421.
- Sáenz, C., Sepúlveda, E. & Moreno, M. (1995a). Estudio de formulaciones para la obtención de mermelada de nopal (*Opuntia ficus indica*). *Resúmenes: XI Congreso Nacional de Ciencia y Tecnología de Alimentos*. Viña del Mar, Chile. p. 163.
- Sáenz, C., Sepúlveda, E., Moreno, M., Granger, D. & Pak, N. (1995b). Características funcionales de harina de nopal (*Opuntia ficus indica*) y su utilización en la formulación de galletas. *Actas: VI Congreso Nacional y IV Congreso Internacional sobre Conocimiento y Aprovechamiento del nopal*. Guadalajara. México. pp. 24–27.

- Sáenz, C., Sepúlveda, E. & Moreno, M. (1995c). Características tecnológicas de pulpa de tuna roja. *Resúmenes: XI Congreso Nacional de Ciencia y Tecnología de Alimentos*. Viña del Mar, Chile. p. 159.
- Sáenz, C., Arriagada, S., Fizsman, S. & Calvo, C. (1996a). Influence of pH and contents of carrageenan during the storage of cactus pear gels. *Acta Horticulturae*, **438**: 131–134.
- Sáenz, C., Mecklenburg, P., Estévez, A.M. & Sepúlveda, E. (1996b). Natural liquid sweetener from cactus pear: obtention and characteristics. *Acta Horticulturae*, **438**: 135–138.
- Sáenz, C., Sepúlveda, E., Calvo, C. & Costell, E. (1997a). Influencia del pH y la temperatura sobre los parámetros de color de jugo de tuna púrpura. *Resúmenes: X Seminario Latinoamericano y del Caribe de Ciencia y Tecnología de Alimentos*. Buenos Aires, Argentina. pp. 10–54.
- Sáenz, C., Pak, N., Sepúlveda, E. & Lecaros, M. (1997b). Caracterización de harina de cladodio de nopal. *Memorias: VII Congreso Nacional y V Internacional sobre Conocimiento y Aprovechamiento del nopal*. Monterrey, México. pp. 302–303.
- Sáenz, C., Estévez, A.M., Sepúlveda, E. & Mecklenburg, P. (1998). Cactus pear fruit: a new source for natural sweetener. *Plant Foods for Human Nutrition*, **52**: 141–149.
- Sáenz, C., Sepúlveda, E. & Idalsoaga, M. (2000). Extracto colorante de tuna púrpura: obtención, características y uso en alimentos. *Libro de Resúmenes: XI Seminario Latinoamericano y del Caribe de Ciencia y Tecnología de Alimentos*. Santiago, Chile. p. 166.
- Sawaya, W.N. & Khan, P. (1982). Chemical characterization of prickly pear seed oil, *Opuntia ficus indica*. *Journal of Food Science*, **47**: 2060–2061.
- Sawaya, W.N., Khatchadourian, H.A., Safi, W.M. & Al-Hammad, H.M. (1983a). Chemical characterization of prickly pear pulp, *Opuntia ficus indica*, and the manufacturing of prickly pear jam. *Journal of Food Technology*, **18**: 183–193.
- Sawaya, W.N., Khalil, J.K. & Al-Mohammad, M.M. (1983b). Nutritive value of prickly pear seeds, *Opuntia ficus indica*. *Plant Foods For Human Nutrition*, **33**: 91–97.
- Schirra, M. (1998). Storage Trials of cactus pear (*Opuntia ficus indica* Miller (L.) fruit with 'non-conventional' methods. In: Sáenz, C. (Ed.), *Proceedings of the International Symposium: Cactus pear and nopalitos processing and uses*. Santiago, Chile. pp. 17–21.
- Schirra, M., Barbera, G., D'Aquino, S., La Mantia, T. & McDonald, R.E. (1996). Hot dips and high-temperature conditioning to improve shelf quality of late-crop cactus pear fruit. *Tropical Science*, **36**: 159–165.
- Schirra, M., Barbera, G., D'Hallewin, G. Inglese, P. & La Mantia, T. (1997a). Storage response of cactus pear fruit to CaCl<sub>2</sub> preharvest spray and postharvest heat treatment. *Journal of Horticultural Science*, **72**: 371–377.
- Schirra, M., Agabbio, M., D'Aquino, S. & McCollum, T.G. (1997b). Postharvest Heat Conditioning Effects on Early Ripening Gialla Cactus Pear Fruit. *HortScience*, **32**(4): 702–704.
- Schmidt-Hebbel, H., Pennacchiotti, I., Masson, L. & Mella, M.A. (1990). *Tabla de composición química de alimentos chilenos* (8th Edn). Facultad de Ciencias Químicas y Farmacéuticas, Universidad de Chile. Santiago, Chile. 62 pp.
- Sepúlveda, E. & Sáenz, C. (1988). Prickly pear processing (*Opuntia ficus indica*). I. Seed oil. *Alimentos*, **13**: 35–38.
- Sepúlveda, E. & Sáenz, C. (1990). Chemical and physical characteristics of prickly pear (*Opuntia ficus indica*) pulp. *Revista de Agroquímica y Tecnología de Alimentos*, **30**: 551–555.
- Sepúlveda, E., Sáenz, C. & Moreno, M. (1995). Obtención y caracterización de harina de nopal (*Opuntia ficus indica*). *Actas: VI Congreso Nacional y IV Congreso Internacional sobre Conocimiento y Aprovechamiento del nopal*. Guadalajara. México. pp. 28–31.
- Sepúlveda, E., Sáenz, C. & Alvarez, M. (1996). Elaboración de láminas de fruta: tuna (*Opuntia ficus indica* (L) Mill) y membrillo (*Cydonia oblonga* Mill). *Textos Completos. CICTA-5. IX Seminario Latinoamericano y del Caribe de Ciencia y Tec. de Alimentos*. PSM Publicaciones Soporite Magnético. La Habana, Cuba. pp. 1–6.
- Strack, D., Engel, U. & Wray, V. (1987). Neobetanin: a new natural plant constituent. *Phytochemistry*, **26**: 2399–2400.
- Thomas, M. (1998). D'Arrigo Brothers cactus pear production. Cactusnet, FAO International Cooperation Network on cactus pear. *Newsletter*, **4**: 5–7.
- Trachtenberg, S. & Mayer, A.M. (1981). Composition and properties of *Opuntia ficus indica* mucilage. *Phytochemistry*, **20**: 2665–2668.
- Tirado, L.E. (1986). Elaboración de una mermelada a base de nopal. Tesis. Escuela de Ciencias Químicas. Universidad Autónoma de Puebla. Puebla, México. 29 pp.

- Trejo, A., Ortiz, G.G., Puebla, A.M., Huizar, M.D., Munguía, M.R., Mejía, S. & Calva, E. (1995). A purified extract from prickly pear cactus (*Opuntia* sp.) controls experimentally induced diabetes in rats. *Actas: VI Congreso Nacional y IV Congreso Internacional sobre conocimiento y aprovechamiento del nopal*. Guadalajara. México. pp. 300–305.
- Vallejos, X. (1999). *Elaboración y evaluación de la calidad de un flan con adición de fibra dietética de nopal*. Memoria de Título. Facultad de Ciencias Agronómicas. Universidad de Chile. 74 p.
- Villarreal, P. (1996). *Obtención de confitados a base de cladodios de nopal*. Memoria de Título. Ing. Agrónomo. Facultad de Ciencias Agrarias y Forestales. Universidad de Chile. Santiago, Chile. 68 pp.
- Vignoni, L., Bauzá, M., Bautista, P. & Germano, C. (1997). Elaboración de pulpa y mermelada de tuna (*Opuntia ficus indica*) preferencia y aceptabilidad. *Resúmenes: X Seminario Latinoamericano y del Caribe de Ciencia y Tecnología de Alimentos*. Buenos Aires, Argentina. pp. 10–22.
- Yagnam, F. & Osorio, F. (1991). Clarificación y pasteurización de jugos de tuna (*Opuntia ficus indica*). *Resúmenes: IX Congreso Nacional de Ciencia y Tecnología de Alimentos*. Santiago, Chile. pp. 36–37.
- Yagnam, F. (1986). La tuna y sus posibilidades agroindustriales. *Próxima Década*, **52**: 6–11.
- Zambrano, M.L., Hernández, A.D. & Gallardo, Y. (1998). Caracterización fisicoquímica de nopal. In: Lajolo, F. & Wenzel, E. (Eds), *Temas en tecnología de alimentos*, Vol 2. Fibra dietética. pp. 29–42. CYTED. Programa Iberoamericano de Ciencia y Tecnología de Alimentos — Instituto Politécnico Nacional de México.