

# Chemical and Rheological Characteristics of Orange-Yellow Cactus-Pear Pulp from Egypt<sup>♦</sup>

S. K. El-Samahy, E. A. Abd El-Hady, R. A. Habiba, and T. E. Moussa\*  
Department of Food Technology, Faculty of Agriculture, Suez Canal University  
41522, Ismailia, Egypt

\*Corresponding author  
e-mail: [tamer1375@yahoo.com](mailto:tamer1375@yahoo.com)

## ABSTRACT

Orange-yellow cactus-pear fruits from Egypt, called shameia variety, were collected at the same ripening stage from different regions to evaluate selected chemical properties and to study the rheological behavior of their pulps. The results obtained showed that there were differences between the pulp characteristics, which may be due to environmental effects. The fruits showed pulp ratios between 41.53% to 49.63%. All pulps had low acidity and high pH values ranging between 0.049% to 0.057% and 6.00 to 6.20, respectively. The rheological data obtained indicated that the flow behavior of all pulps was non-Newtonian besides exerting pseudoplastic behavior. Thixotropy values were 4.13 to 19.30 Pa s<sup>-1</sup>; yield stress reached 2.26 N m<sup>-2</sup> at 20°C.

**Key words:** Cactus pear, *Opuntia*, pulp properties, Egypt

## INTRODUCTION

*Opuntia* represents the largest and the most impressive member of the *Cactaceae* family. The genus *Opuntia* originates from Mexico and includes approximately 300 to 400 species and great number of varieties (Anaya-Perez, 2001; Benson, 1982; Odoux and Dominguez-Lopez, 1996; Stintzing and Carle, 2005). Prickly pear or cactus pear (*Opuntia spp*) is the most cultivated edible cactus crop in the world and is widely distributed in Mexico and the South American continent. It is also grown in many other regions of the world such as Africa, Australia, and the Mediterranean basin (Inglese et al., 2002; Mizrahi et al., 1997; Nobel, 1995; Piga, 2004). On the other hand, *Opuntia ficus indica* (L.) Miller is the most commonly known cactus that is grown for fruits, vegetable forage, and fodder (Pimienta-Barrios and Munoz-Urias, 1995; Rodriguez-Felix, 2002; Russell and Felker, 1987). Cactus-pear plants have two edible parts. First, there is the fleshy stem also known as cladode, cactus pad, cactus stem, nopalito (young pad), vegetable cactus, or cactus leaf (Rodriguez-Felix, 2002). Second, the fruits are highly appealing and nutritious.

Cactus-pear fruits are fleshy berries varying in shape, size, and color, and consisting of a thick peel hosting a delicately flavored juicy edible pulp with many hard seeds. The attractive color of both pericarp and pulp varies from a soft green, greenish-white, canary-yellow, orange-yellow, lemon- yellow, red, cherry-red to purple hues (Gurrieri et al., 2000; Munoz De Chavez et al., 1995; Saenz and Sepulveda, 2001). These attractive colors are due to the betalains comprising the red-violet betacyanins and the yellow-orange betaxanthins (Fernandez-Lopez and Almela, 2001; Odoux and Dominguez-Lopez, 1996; Saenz, 2002; Stintzing et al., 1999b, 2002). In contrast to anthocyanins, these colorants maintain their appearance over a wide pH range from 4 to 7, which makes them ideal pigments for coloring especially

---

<sup>♦</sup> Received 9 November 2006

low-acid foods such as dairy products (Forni *et al.*, 1992; Krifa *et al.*, 1994; Montefiori, 1990; Saenz, 2000; Saenz *et al.*, 1997; Stintzing *et al.*, 2000).

The fruit pulp exhibits a high pH value (5.3 to 7.1), low acidity (0.01% to 0.18% as citric acid equivalents) and total soluble solids content ranging from 10.7° to 17°Brix, mainly due to reducing sugars (Abdel-Nabey, 2001; Askar and EL-Samahy, 1981; Barbagallo *et al.*, 1998; Barbera *et al.*, 1992; Gurrieri *et al.*, 2000; Kuti, 1992; Parish and Felker, 1997; Piga *et al.*, 2003; Russell and Felker, 1987; Saenz-Hernandez, 1995; Sawaya *et al.*, 1983; Saenz and Sepulveda, 1999; Sepulveda and Saenz, 1999; Sepulveda *et al.*, 2000). These characteristics make the pulp a very good medium for microbial spoilage (Saenz, 2000; Saenz and Sepulveda, 2001; Sepulveda and Saenz, 1990), but on other hand, very suitable to be added to low-acid foods such as ice cream and other dairy products. Sugar, protein, dietary fibers, and ash contents are similar to those of other fruits (Cantwell, 1995; Saenz-Hernandez, 1995 and Stintzing *et al.*, 2001), but their high total amino acid contents, dominated by proline and taurine is a special feature of cactus fruits (Stintzing *et al.*, 1999a, 2001). The pulp is a good source of vitamin C, calcium, and magnesium, in addition to pectin and mucilaginous components (complex polysaccharides, mainly composed of arabinose, galactose, rhamnose, and galacturonic acid) that influence the pleasant flavor of pulp and could serve as thickening agents and form viscous colloids (Piga, 2004; Saenz *et al.*, 1992; Stintzing, *et al* 2001).

Recent data indicate that cactus-pear pulp has multiple functional properties and could be a good natural source of nutraceuticals (Saenz, 2002 and Stintzing *et al.*, 2000, 2001), such as vitamin C, betalains, phenolics, and taurine (Kuti, 2004; Piga *et al.*, 2003; Piga, 2004). Moreover, cactus-pear pulp is rich in taurine, a conditional essential nonproteinogenic amino acid widely distributed in many animal food sources, except cow milk, but virtually absent in higher plants, especially fruits (AACE, 2003; Kindler, 1989; Parcell, 2002; Stintzing *et al.*, 1999a).

Prickly pear fruits usually eaten fresh after peeling could be processed into many different products such as juices, nectars, dehydrated sheets, marmalades, jellies, jams, natural sweeteners, wines and other alcoholic beverages, candies, canned and frozen fruit, etc. (Abdel-Nabey, 2001; Barbera, 1995; Gurrieri *et al.*, 2000; Hoffmann, 1995; Saenz, 2000; Saenz-Hernandez, 1995; Saenz and Sepulveda, 2001; Saenz *et al.*, 1998).

Notably, the rheological properties of cactus-pear pulp are virtually unknown except in data presented by Saenz (2000) who indicated that the viscosity of green and purple cactus-pear pulps amounted to 73.9 and 110.2 mPa s, respectively, and El-Samahy *et al.* (2006b) who showed that the flow behavior of cactus-pear pulp is non-Newtonian, beside being pseudoplastic in behavior with the presence of thixotropy. Thixotropic materials can be defined as those that exhibit decreasing shear stress and apparent viscosity over time at a fixed rate of shear, this action may be irreversible, reversible, or partially reversible (Steffe, 1996). Knowledge of the rheological properties of fruit pulps is essential for the design of food processing equipment as well as for application of such products in foods (El-samahy *et al.*, 2003, 2004a, 2004b).

In Egypt, prickly pears have been grown for many years, especially in arid areas. The *Opuntia* plants are grown not only for fruit production but also as defensive hedges or for erosion control in reclaimed areas. In recent years, the production of prickly-pear fruits increased as a result of an increase in producing area. The producing area increased from about 617.82 hectares in 1994 to 1115.52 hectares in 2004 with a corresponding production increase from 10233 to 29610 Tons (MALR, 1994, 2004).

## MATERIALS AND METHODS

### Plant Material

#### *Prickly-Pear Fruit Samples*

Representative fruits of orange-yellow prickly-pear cactus fruits, called shameia variety, were collected from three different specialized orchards at the same ripening stage (half ripening) at the end of July. Figures 1 through 5 show examples of the cladode form, fruits, and plantations. The orchards were located in three different regions: Al Sharqiyah, Al Qalyubiyah, and Al Isma'iliyah. For each orchard three samples (80 fruits for every sample) were selected randomly from 240 representative fruits. All selected fruits were washed, manually peeled, and blended for 5 seconds in a blender (Moulinex, type 241, code 222, France) just to facilitate the separation of the seeds, and then the full pulps were sieved to separate only the seeds. The resultant pulp samples contained all their components and were tested freshly for all analyses.

#### *Environmental Conditions of the Orchard Regions*

The most effective difference between the orchards regions is the nature of the soil. Whereas the orchard of Al Sharqiyah region has a loamy soil, the other orchards (Al Qalyubiyah, and Al Isma'iliyah regions) have a sandy soil.

#### *Climatic Conditions of the Regions*

The annual average precipitation is about 40 mm for the Al Sharqiyah and Al Isma'iliyah regions and is about 20 mm for the Al Qalyubiyah region. The rainy season extends from December to February for all regions. The three fields are irrigated by flood from the same water source, a grand water canal branched from the Nile River. The averages of maximum and minimum temperatures and maximum and minimum relative humidity values of air during July are at Al Sharqiyah region (33.8°, 23.8°, 79% and 41%), Al Qalyubiyah region (33.6°, 21.8°, 91% and 40%), and Al Isma'iliyah region (30°, 22.1°, 83% and 30%), respectively (according to data of the Agricultural Researches Center, Ministry of Agriculture and Land Reclamation, Egypt).

### Assessment of Chemical Quality Parameters

Chemical analyses were carried out according to AOAC (1990). Color attributes ( $L^*$ ,  $a^*$  and  $b^*$ ) were evaluated using a Minolta Color Reader CR-10 (Minolta Co. Ltd., Tokyo, Japan).

### Rheology

Rheological properties of all pulps were determined at different temperatures within the range of 5 to 90°C by a Brookfield Digital Rheometer model DV-III+ (Brookfield, Middleboro, USA). The Brookfield small sample adapter and Sc<sub>4</sub>-14 spindle were used. The data were analyzed by using the Bingham plastic, IPC paste and Power Law mathematical models to provide a numerical and graphical analysis of the behavior of data sets (Hegedusic *et al.*, 1995). These models are:

$$\tau = \tau_0 + \eta\dot{\gamma}, \quad \eta = KR^n, \quad \tau = K\dot{\gamma}^n, \text{ respectively.}$$

Where:

$$\tau = \text{shear stress (N m}^{-2}\text{)}$$

$$\tau_0 = \text{yield stress, shear stress at zero shear rate (N m}^{-2}\text{)}$$

$$\eta = \text{plastic viscosity (mPa s) for Bingham and 10 rpm viscosity (mPa s) for IPC paste}$$

$\gamma$  = shear rate ( $s^{-1}$ )  
K = consistency multiplier (mPa s) for IPC paste and  
K = consistency index (mPa s) for Power Law  
R = rotational speed (rpm)  
n = shear sensitivity factor for IPC paste and flow index for Power Law.

Calculation of thixotropy was based on measuring, according to spindle type and rotational speeds, the shear rate (up curve) and also registering the same parameter using the reverse direction (down curve), the area between the ascending and descending curves, i.e., hysteresis was quantified using a planimeter according to Lozano and Ibarz (1994), this area is given in  $Pa s^{-1}$ .

### Statistical Analysis

The analysis of variance (ANOVA) was carried out to test the possibility of significance of treatment effect. LSD, as described by Ott (1984), was used to perform all possible pair comparisons between means of different treatments.

## RESULTS AND DISCUSSION

### General Composition Of Cactus-Pear Fruits

Table 1 shows that the fruits of the three regions varied significantly in fruit weight and in each of the pulps, peels, and seeds percentages. Fruits of the Al Sharqiyah region were significantly higher in fruit weight and pulp content but lower in peels and seeds percentages. The differences may be due to the nature and, consequently, the fertility of the soil. The orchard of Al Sharqiyah region has a loamy soil while the other regions have a sandy soil. The values obtained agreed with those obtained by others (Abdel-Nabey, 2001; Barbera et al., 1992; Cantwell, 1995; Karababa, 2004; Parish and Felker, 1997; Piga, 2004; Sawaya et al., 1983; Stintzing et al., 2005).

### Chemical Composition Of Cactus-Pear Pulps

In concordance with data obtained by others (Abdel-Nabey, 2001; Askar and EL-Samahy, 1981; Cantwell, 1995; Parish and Felker, 1997; Saenz-Hernandez, 1995; Saenz and Sepulveda, 1999; Sawaya *et al.*, 1983; Sepulveda and Saenz, 1999), Egyptian cactus-pear pulps were characterized by a high pH, a low acidity, and good contents of sugars, proteins, crude fibers, pectin, ash, and vitamin C (Table 2). The chemical composition of cactus-pear pulps appeared to be similar to some other fruit pulps, but could be higher than some other fruit pulps, such as guava pulp, in sugar content. These unique characteristics in addition to its attractive color make the cactus-pear pulps sweeter and very suitable to be a good natural food or natural-food additive with many categories of foodstuffs. However, the high soluble solids, high pH values, and low acidity of all investigated pulps present a great challenge to processing of cactus-pear pulps. More wariness is required during processing because these characteristics make the pulp a very good medium for spoilage due to microbial activity.

### Rheological Properties of Cactus-Pear Pulps

Table 3 shows that the relationship between shear stress ( $\tau$ ) and shear rate for all cactus-pear pulps were nonlinear, which related to non-Newtonian behavior in addition to the presence of thixotropy. The data

obtained showed that cactus-pear pulp is a pseudoplastic liquid with yield stress like many other fruit pulps and purees such as mango pulp (Bhattacharya, 1999), strawberry pulp (Bahlol, 2000), and peach and papaya purees (Guerrero and Alzamora, 1998).

The results showed that the pulp extracted from Al Isma'iliyah fruits had higher  $k$ ,  $\eta$ , and 10-rpm viscosity values than those for pulp extracted from Al Sharqiyah and Al Qalyubiyah fruits at the same temperature (20°C). The flow-behavior index ( $n$ ) values ranged from 0.35 to 0.38 at 20°C for the pulp of the three regions' fruits. The pulp extracted from Al Sharqiyah fruits had the highest value of yield stress 2.26 N m<sup>-2</sup>. These differences may be attributed to the specific chemical composition of the fruit pulps Table 2, especially nonsoluble materials, acidity, and total soluble solids (El-Samahy *et al.*, 2006b).

Because the thixotropy term refers to the time-dependent decrease in viscosity, due to shearing, and the subsequent recovery of viscosity when shearing is removed (Mewis, 1979), and is used to describe a reversible isothermal gel-sol-gel transformation (Kramer and Twigg, 1984; Steffe, 1996), cactus-pear pulp is a thixotropic material. Thixotropy values of the pulp extracted from Al Sharqiyah fruits were higher than those from Al Qalyubiyah and Al Isma'iliyah fruits, whereas 19.30 Pa s<sup>-1</sup> was found for Al Sharqiyah fruit pulp and 12.87 and 4.13 Pa s<sup>-1</sup> were registered for Al Qalyubiyah and Al Isma'iliyah pulps, respectively, at 20°C.

Moreover, values of all studied parameters, except flow-behavior index and plastic viscosity, decreased with increasing temperature for the pulp extracted from different fruits up to 50°C. At higher than 50°C, all values of studied parameters increased, while the flow index and plastic-viscosity values decreased. These results agree with those obtained by Crandall *et al.* (1982), El-Samahy *et al.* (2006b), Ibrah and Pagan (1987), and Juszczak and Fortuna (2003). Van Buren (1991) reported that the differences in pectin fractions must be taken into account because polymer interactions play the major role in flow behavior of the fruit products. Goycoolea and Cardenas (2003) reported that pectins of cactus pear do not form gels and only increase the viscosity of the solutions. In addition to the influence of temperature and dissolved solids on viscosity of juices (Bayindirli, 1992), we suggest that the changes we observed in flow behaviour may also be attributable to changes in the colloid state of the pulp components (especially pectins) that are, in turn, influenced by acidity, sugars, and bivalent cations such as Ca<sup>2+</sup>.

## CONCLUSION

This investigation shows the potential value of cactus-pear fruits as a good natural source of energy, nutritive components, and antioxidants such as vitamin C. Based on its low acidity, high sweetness, and attractive stable colors, cactus-pear pulp could be very suitable as a natural additive or substituted material in the production of many foodstuffs. Cactus-pear pulp is a non-Newtonian liquid that has pseudoplastic behavior with the presence of thixotropy and yield stress. The rheological properties are important factors, especially in the relation between the manufacturing process and product acceptance, and correlate with food composition and organoleptical properties. There is a need to do more research on the rheological properties of cactus-pear fruits, especially in the areas in the world that have rapidly increasing production of *Opuntia ficus-indica* fruits.

## REFERENCES

- A.A.C.E. (2003). American Association of Clinical Endocrinologists Medical Guidelines for the clinical use of dietary supplements and nutraceuticals. *Endocrine Practice*, 9(5): 417-470.
- A.O.A.C. (1990). Official Methods of Analysis, 15<sup>th</sup> Ed. Association of Official Analytical Chemists, Inc. USA.
- Abdel-Nabey, A. A. (2001). Chemical and technological studies on prickly pear (*Opuntia ficus indica*) fruits. *Alex. J. Agric. Res.*, 46(3): 61-70.
- Anaya-Perez, M. A. (2001). History of the use of *Opuntia* as forage in Mexico. In C. Mondragon-Jacobo and S. Perez-Gonzalez (Eds.), *Cactus (Opuntia spp.) as storage* (pp. 5-12). Rome, Italy: FAO.
- Askar, A. and El-Samahy, S. K. (1981). Chemical composition of prickly pear fruit. *Deutsche Lebensmittel-Rundschau*, 77(8): 279-281.
- Bahlol, H. El. M. (2000). Rheological properties of strawberry juice and its products. *Annals of Agricultural Sciences, Moshtohor*. 38(2): 1041-1056.
- Barbagallo, R. N.; Pappalardo, P. and Tornatore, G. (1998). Chemical and sensory evaluation of prickly pears concentrated puree. *Industrie Alimentari*, 37(371): 745-749.
- Barbera, G. (1995). History, Economic and Agro-ecological importance. pp.1-11. In: *Agro-ecology, cultivation and uses of cactus pear*. Ed. by Barbera, G.; Inglese, P. and Pimienta-Barrios, E. FAO Plant Production and Protection Paper N° 132.
- Barbera, G.; Carimi, F.; Inglese, P. and Panno, M. (1992). Physical, morphological and chemical changes during fruit development and ripening in three cultivars of prickly pear, *Opuntia ficus indica* (L.) Miller. *J. Horticulture Sci.*, 67(3): 307-312.
- Bayindirli, L. (1992). Mathematical analysis of variation of density and viscosity of apple juice with temperature and concentration. *J. Food Proc. Pres.* 16: 23-28.
- Benson, L. (1982). *Cacti of the United States and North America*. Stanford University Press, Stanford, CA.
- Bhattacharya, S. (1999). Yield stress and time-dependent rheological properties of mango pulp. *J. Food Sci.*, 64: 1029-1033.
- Cantwell, M. (1995). Postharvest management of fruits and vegetable stems. pp. 120-136. In: *Agro-ecology, cultivation and uses of cactus pear*. Ed. By Barbera, G.; Inglese, P and Pimienta-Barrios, E. FAO Plant Production and Protection Paper N°132.
- Crandall, P. G.; Chen, C. S. and Carter, R. D. (1982). Models for predicting viscosity of orange juice concentrate. *Food Technol.*, 36: 245-252.
- El-Samahy, S. K.; Askar, A. A.; El-Mansy, H. A.; Omran, H. T. and Abd El-Salam, N. A. (2003). Flow behavior of guava puree as a function of different enzyme treatments and concentrations. 3<sup>rd</sup> International Symposium on Food Rheology and Structure, Switzerland. pp. 425-426.

- El-Samahy, S. K.; Abd El-Hady, E. A.; Mostafa, G. A. and Youssef, K. M. (2006a). Rheological properties of date pulp and concentrate. 4<sup>th</sup> International Symposium on Food Rheology and Structure, Switzerland. pp. 583-584.
- El-Samahy, S. K.; Abd El-Hady, E. A.; Habiba, R. A. and Moussa, T. E. (2006b). Effect of ripening stage on rheological properties of prickly pear pulp. 4<sup>th</sup> International Symposium on Food Rheology and Structure, Switzerland. pp. 581-582.
- Fernandez-Lopez, J. A. and Luis-Almela, L. (2001). Application of high-performance liquid chromatography to the characterization of the betalain pigments in prickly pear fruits. *J. Chromatogr A*, 913: 415-420.
- Forni, E.; Polesello, A.; Montefiori, D. and Maestrelli, A. (1992). High-performance liquid chromatographic analysis of the pigments of blood-red prickly pear (*Opuntia ficus-indica*). *J. Chromatogr.* 593: 177-183.
- Goycoolea, F. M. and Cardenas, A. (2003). Pectins from *Opuntia spp.*: A short review. *J. Profess. Assoc. Cactus Develop.*, 5: 17-29.
- Guerrero, S. N. and Alzamora, S. M. (1998). Effect of pH, temperature and glucose addition on flow behavior of fruit purees: II. Peach, papaya and mango purées. *J. Food Eng.*, 37: 77-101.
- Gurrieri, S.; Miceli, L.; Lanza, C. M.; Tomaselli, F.; Bonomo, R. P. and Rizzarelli, E. (2000). Chemical characterization of Sicilian prickly pear (*Opuntia ficus indica*) and perspectives for the storage of its juice. *J. Agric. Food Chem.*, 48: 5424-5431.
- Hegedusic, V.; T. Lovric and A. Parmac (1995). Influence of phase transition (freezing and thawing) on thermophysical and rheological properties of apple puree – like products. *Acta – Aliment*, 22: 337-349.
- Hoffmann, W. (1995). Ethnobotany. pp.12-19. In: *Agro-ecology, cultivation and uses of cactus pear*. Ed. by Barbera, G.; Inglese, P. and Pimienta-Barrios, E. *FAO Plant Production and Protection Paper N° 132*.
- Ibraz, A. and Pagan, J. (1987). Rheology of raspberry juices. *J. Food Eng.*, 15: 269-289.
- Inglese, P.; Basile, F. and Schirra, M. (2002). Cactus pear fruit production. In: Nobel, P. S. (ed.) *CACTI: Biology and uses*. University of California Press, Chapter 10: 163-183.
- Juszczak, L. and Fortuna, T. (2003). Viscosity of concentrated strawberry juice: effect of temperature and soluble solids content. *Electronic Journal of Polish Agricultural Universities*, 6(2): 1-7
- Karababa, E.; Coskuner, Y. and Aksay, S. (2004). Some physical fruit properties of cactus pear (*Opuntia spp.*) that grow wild in the eastern mediterranean region of turkey. *J. Profess. Assoc. Cactus Develop.*, 6: 1-8.
- Kindler, B. S. (1989). Taurine: an overview of its role in preventive medicine. *Prev. Med.*, 18: 79 – 100.
- Kramer, A. and Twigg, B. A. (1984). *Quality control for the food industry*. Third edition, Vol. 1. The AVI Publishing Company, INC. Westport, Connecticut, USA.
- Krifa, F.; Villet, A.; Roussel, A. M. and Alary, J. (1994). New natural colorant extracted from *Opuntia stricta*. *Ann. Fals. Exp. Chim. Toxicol.*, 87: 183-192.

- Kuti, J. O. (1992). Growth and compositional changes during the development of prickly pear fruit. *J. Hort. Sci.*, 67: 861-868.
- Lozano, J. E. and Ibarz, A. (1994). Thixotropic behavior of concentrated fruit pulps. *Lebensm. Wiss. Technol.*, 27: 16-18.
- MALR (1994). Ministry of Agriculture and Land Reclamation, Economic Affairs Sector (EAS), Agriculture Planning Central Administration, General Administration of Agric. Economic Resources, National Agricultural Income, 342-343.
- MALR (2004). Ministry of Agriculture and Land Reclamation, Economic Affairs Sector (EAS), Agriculture Planning Central Administration, General Administration of Agric. Economic Resources, National Agricultural Income, 343-344.
- Mewis, J. (1979). Thixotropy – a general review. *J. Non-Newtonian Fluid Mech.* 6: 1-20.
- Mizrahi, Y.; Nerd, A. and Nobel, P. S. (1997). Cacti as crops. *Hort. Rev.*, 18: 291-346.
- Montefiori, D. (1990). Ricerche sull'estrazione, la stabilità e l'impiego dei pigmenti del fico d'indica sanguigno. Tesi di Laurea. Università degli studi di Milano, Italia. 94pp. In: Saenz, C. (2002). Cactus pear fruits and cladodes: A Source of functional components for foods. *Acta Hort.* (Proc. 4<sup>th</sup> IC on Cactus Pear and Cochineal), 581: 253-263.
- Munos de Chavez, M.; Chavez, A.; Valles, V.; Roldan, J. A. (1995). The Nopal: A Plant of Manifold Qualities. In: *World Rev. Nutr. Diet.*, 77: 109-134.
- Nobel, P. S. (1995). Environmental Biology. pp.36-48. In: *Agro-ecology, cultivation and uses of cactus pear*. Ed. by Barbera, G.; Inglese, P. and Pimienta-Barrios, E. FAO Plant Production and Protection Paper N° 132.
- Odoux, E. and Dominguez, L. A. (1996). Prickly pear: an industrial source of betalains. *Fruits*, 51: 61-78.
- Ott, L. (1984). *An Introduction to Statistical Methods and Data Analysis*. 2<sup>nd</sup> edition, PWS publisher, Boston, M. A., USA.
- Parcell, S. (2002). Sulfur in Human Nutrition and Application in Medicine. *Alt. Med. Rev.*, 7: 22-44.
- Parish, J. and Felker, P. (1997). Fruit quality and production of cactus pear (*Opuntia* spp.) fruit clones selected for increased frost hardiness. *J. Arid Environ.*, 37: 123-143.
- Piga, A. (2004). Cactus pear: A fruits of nutraceutical and functional importance. *J. Profess. Assoc. Cactus Develop.*, 6: 9-22.
- Piga, A.; Del Caro, A.; Pinna, I. and Agabbio, M. (2003). Changes in ascorbic acid, polyphenol content and antioxidant activity in minimally processed cactus pear fruits. *Lebensm. Wiss. Technol.*, 36: 257-262.
- Pimienta-Barrios, E. and Munoz-Urias, A. (1995). Domestication of *Opuntias* and cultivated Varieties. pp.58-63. In: *Agro-ecology, cultivation and uses of cactus pear*. Ed. by Barbera, G.; Inglese, P. and Pimienta-Barrios, E. FAO Plant Production and Protection Paper N° 132.



- Rodriguez-Felix, A. (2002). Postharvest physiology and technology of cactus pear fruits and cactus leaves. *Acta Hort.*( Proc.4<sup>th</sup> IC on Cactus Pear and Cochineal), 581: 191-199.
- Russell, C. E. and Felker, P. (1987). The prickly-pears (*Opuntia* spp., Cactaceae): A source of Human and Animal Food in Semiarid Regions. *Econ. Bot.*, 41: 433-445.
- Saenz, C. (2000). Processing technologies: an alternative for cactus pear (*Opuntia* spp.) fruits and cladodes. *J. Arid Environ.*, 46: 209-225.
- Saenz, C. (2002). Cactus pear fruits and cladodes: A Source of functional components for foods. *Acta Hort.*( Proc.4<sup>th</sup> IC on Cactus Pear and Cochineal), 581: 253-263.
- Saenz, C. and Sepulveda, E. (1999). Physical, chemical and sensory characteristics of juices from pomegranate and purple cactus pear fruit. *Annals of the 22<sup>nd</sup> IFU Symposium, Paris.* pp. 91-100.
- Saenz, C. and Sepulveda, E. (2001). Cactus-Pear Juices. *J. Profess. Assoc. Cactus Develop.*, 4: 3-10.
- Saenz, C.; Vasquez, M.; Trumper, S. and Fluxa, C. (1992). Extraccion y composicion quimica de mucilage de tuna (*Opuntia ficus-indica*). Cited from Piga, A. (2004). Cactus pear: A fruits of nutaceutical and functional importance. *J. Profess. Assoc. Cactus Develop.*, 6: 9-22.
- Saenz, C.; Sepulveda, E.; Calvo, C. and Costell, E. (1997). Influencia del pH y la temperatura sobre los parametros de color de jugo de tuna purpura. Resumenes: X Seminario Latinoamericano y del Caribe de Ciencia y Tecnologia de Alimentos. Buenos Aires, Argentina. P. 10-54.
- Saenz, C.; Estevez, A. M.; Sepulveda, E. and Mecklenburg, P. (1998). Cactus pear fruit: A new source for natural sweetener. *Plant Foods for Human Nutr.*, 52: 141-149.
- Saenz-Hernandez, C. (1995) Food Manufacture and by-products. pp. 137-143. In: *Agro-ecology, cultivation and uses of cactus pear.* Ed. by Barbera, G.; Inglese, P. and Pimienta-Barrios, E. FAO Plant Production and Protection Paper N° 132.
- Sawaya, W. N.; Knatchadourian, H. A.; Safi, W. N. and Al-Muhammad, H. M. (1983). Chemical characterization of prickly pear pulp, *Opuntia ficus-indica*, and the manufacturing of prickly pear jam. *J. Food Tech.*, 18: 183-193.
- Sepulveda, E.; and Saenz, C. (1990). Chemical and physical characteristics of prickly pear (*Opuntia-ficus indica*) pulp. Cited from Saenz, C. and Sepulveda, E. (2001). Cactus-Pear Juices. *J. Profess. Assoc. Cactus Develop.* 4: 3-10.
- Sepulveda, E.; and Saenz, C. (1999). Tuna anaranjada cultivada en Chile: caracterizacion del fruto y de la pulpa. Cited from Saenz, C. and Sepulveda, E. (2001). Cactus-Pear Juices. *J. Profess. Assoc. Cactus Develop.* 4: 3-10.
- Sepulveda, E.; Saenz, C. and Alvarez, M. (2000). Physical, chemical and sensory characteristics of dried fruit sheets of cactus pear (*Opuntia ficus indica* (L.) MILL.) and quince (*Cydonia oblonga* MILL.). *Italian J. Food Sci.*, 12: 47-54.
- Steffe, J. F. (1996). *Rheological methods in food process engineering.* Second edition. Freeman Press, East Lansing, MI 48823, USA.

Stintzing, F. C.; Schieber, A. and Carle, R. (1999a). Amino acids composition and betaxanthin formation in fruits from *Opuntia ficus-indica*. *Planta Med.*, 65: 632-635.

Stintzing, F. C.; Schieber, A. and Carle, R. (1999b). Cactus pear: A source of pigments and nutritionally important components. *Annals of the 22<sup>nd</sup> IFU Symposium, Paris*. pp. 349-365.

Stintzing, F. C.; Schieber, A. and Carle, R. (2000). Cactus pear-a promising component to functional food. *Obst Gem. Kartoffelver./Fruit Vegetale Potato Process*, 86: 40-47.

Stintzing, F. C.; Schieber, A. and Carle, R. (2001). Phytochemical and nutritional significance of cactus pear. *Eur. Food Res. Technol.*, 212: 396-407.

Stintzing, F. C.; Schieber, A. and Carle, R. (2002). Identification of betalins from yellow beet (*Beta vulgaris* L.) and cactus pear (*Opuntia ficus indica* (L.) Miller.) by high performance liquid chromatography electrospray ionization mass spectrometry. *J. Agric. Food Chem.*, 50: 2302-2307.

Stintzing, F. C. and Carle, R. (2005). Cactus stems (*Opuntia* spp.): A review on their chemistry, technology, and uses. *Mol. Nutr. Food Res.*, 49: 175-194.

Stintzing, F. C.; Herbach, K. M.; Mosshammer, M. R.; Carle, R.; Yi, W.; Sellappan, S.; Akoh, C. C.; Bunch, R. and Felker, P. (2005). Color, betalain pattern, and antioxidant properties of cactus pear (*Opuntia* spp.) clones. *J. Agric. Food Chem.*, 53: 442-451.

Van Buren, J. P. (1991). Function of pectin in plant tissue structure and firmness. In: Walter, R. H. (ed.), *The Chemistry and Technology of Pectin*, Academic Press, New York, pp. 1-22.



Figure 1. Cactus-Pear Cladode



Figure 2. Orange-yellow cactus-pear fruits



Figure 3. Internal Longitudinal Section of Fruit



Figure 4. Overview of Cactus-Pear Plant



Figure 5. Overview of Cactus-Pear Field

Table 1. General Composition of Cactus-Pear Fruits

Property	Al Sharqiyah	Al Qalyubiyah	Al Isma'iliyah
Fruit weight (g)	133.50 <sup>a</sup>	120.57 <sup>b</sup>	110.19 <sup>c</sup>
Pulp (%)	49.63 <sup>a</sup>	42.28 <sup>b</sup>	41.53 <sup>b</sup>
Peels (%)	39.23 <sup>b</sup>	45.37 <sup>a</sup>	44.53 <sup>a</sup>
Seeds (%)	11.14 <sup>c</sup>	12.35 <sup>b</sup>	13.80 <sup>a</sup>

- Means of triplicates

- Means having the same letter within each property are not significantly different at  $p \leq 0.05$

Table 2. Some Technological and Chemical Properties of Cactus-Pear Pulps

Property	Plantation Region		
	Al Sharqiyah	Al Qalyubiyah	Al Isma'iliyah
pH value	6.20 <sup>a</sup>	6.00 <sup>b</sup>	6.05 <sup>b</sup>
Acidity (%)	0.049 <sup>b</sup>	0.057 <sup>a</sup>	0.054 <sup>a</sup>
TSS (°Brix)	13.50 <sup>a</sup>	11.25 <sup>b</sup>	11.50 <sup>b</sup>
Vitamin C (mg 100 g <sup>-1</sup> )	21.50 <sup>b</sup>	23.44 <sup>a</sup>	23.51 <sup>a</sup>
Formol number (mg 100 g <sup>-1</sup> )	21.50 <sup>c</sup>	23.53 <sup>a</sup>	22.18 <sup>b</sup>
Color attributes $L^*$	30.60 <sup>a</sup>	30.10 <sup>a</sup>	27.40 <sup>b</sup>
$a^*$	1.60 <sup>c</sup>	2.70 <sup>b</sup>	3.30 <sup>a</sup>
$b^*$	10.90 <sup>a</sup>	9.80 <sup>b</sup>	7.1 <sup>c</sup>
Moisture (%)	86.27 <sup>b</sup>	88.32 <sup>a</sup>	88.18 <sup>a</sup>
TS (%)	13.73 <sup>a</sup>	11.68 <sup>b</sup>	11.82 <sup>b</sup>
Total Sugars (%) *	88.02 <sup>a</sup>	85.49 <sup>b</sup>	86.50 <sup>a,b</sup>
Reducing sugars (%) *	85.24 <sup>a</sup>	73.43 <sup>c</sup>	75.50 <sup>b</sup>
AIS (%)*	7.10 <sup>b</sup>	7.59 <sup>a</sup>	6.86 <sup>b</sup>
Protein (%)*	4.59 <sup>b</sup>	6.01 <sup>a</sup>	4.67 <sup>b</sup>
Pectin (%)*	2.39 <sup>c</sup>	2.81 <sup>a</sup>	2.60 <sup>b</sup>
Fiber (%)*	1.40 <sup>b</sup>	1.44 <sup>b</sup>	1.61 <sup>a</sup>
Ash (%)*	2.39 <sup>b</sup>	2.63 <sup>a</sup>	2.76 <sup>a</sup>
Sugar/acidity ratio	246.6 <sup>a</sup>	175.1 <sup>b</sup>	189.3 <sup>b</sup>

TSS: Total Soluble Solids, TS: Total Solids, AIS: Alcohol Insoluble Solids.

\* Calculated on dry-weight basis

- Means of triplicates

- Means having the same letter within each property are not significantly different at  $p \leq 0.05$

Table 3. Rheological Properties of Cactus-Pear Pulps

Plantation Region	Temp. °C	Parameters for Different Rheological Models					Thixotropy Pa s <sup>-1</sup>	
		Power law		Bingham		IPC Paste		
		k	n	η	τ <sub>0</sub>	10 rpm viscosity	N <sub>1</sub>	
Al Sharqiyah	5	147.7	0.31	45.6	2.27	315.1	0.69	19.55
	10	146.9	0.32	51.6	2.28	325.0	0.68	18.00
	20	137.6	0.35	55.7	2.26	325.1	0.65	19.30
	30	134.8	0.31	44.0	2.08	291.5	0.69	18.00
	40	90.3	0.35	39.1	1.39	210.8	0.65	13.50
	50	96.9	0.40	54.4	1.63	252.9	0.60	27.38
	60	134.4	0.33	52.1	2.13	303.4	0.67	35.00
	70	246.3	0.19	35.3	3.20	403.5	0.81	35.45
	80	352.0	0.10	19.4	4.10	475.8	0.90	36.50
90	482.4	0.01	0.05	4.85	511.2	0.99	39.45	
Al Qalyubiyah	5	92.9	0.33	35.8	1.40	206.8	0.67	16.31
	10	87.6	0.35	35.0	1.39	203.7	0.65	13.05
	20	84.3	0.38	40.0	1.40	210.6	0.62	12.87
	30	52.2	0.44	31.5	0.97	148.1	0.56	12.33
	40	39.7	0.50	36.9	0.76	131.5	0.50	11.4
	50	56.1	0.43	34.9	1.01	157.6	0.57	18.17
	60	65.2	0.41	36.8	1.13	174.6	0.59	17.11
	70	78.8	0.36	34.3	1.26	188.4	0.64	19.23
	80	115.9	0.20	11.8	1.68	195.8	0.80	26.34
90	206.0	0.05	8.32	2.18	246.5	0.95	28.18	
Al Isma'iliyah	5	174.2	0.30	64.6	2.43	368.6	0.70	9.98
	10	175.9	0.33	73.3	2.55	392.1	0.67	6.94
	20	142.4	0.36	69.5	2.21	344.8	0.64	4.13
	30	136.6	0.37	68.4	2.13	334.4	0.63	2.60
	40	76.2	0.44	51.6	1.32	195.8	0.56	8.50
	50	79.3	0.42	51.8	1.34	216.1	0.58	10.25
	60	113.3	0.37	56.0	1.81	219.1	0.63	19.55
	70	90.3	0.39	46.6	1.49	229.9	0.61	20.50
	80	115.9	0.20	11.8	1.68	279.1	0.80	34.58
90	344.5	0.02	3.45	3.38	352.3	0.98	36.68	

K = Consistency index (mPa s<sup>n</sup>), n = Flow index (dimensionless), η = Plastic viscosity (mPa s),  
 τ<sub>0</sub> = Yield stress (N m<sup>-2</sup>), 10 rpm viscosity, (mPa s), N<sub>1</sub> = Shear sensitivity (dimensionless)