Agro-ecology, cultivation and uses of cactus pear

edited by
Giuseppe Barbera
Istituto di Coltivazioni Arboree
Università degli Studi di Palermo, Italy
Paolo Inglese
Istituto di Colture Legnose Agrarie e Forestali
Università degli Studi di Reggio Calabria, Italy
Eulogio Pimienta-Barrios
Facultad de Ciencias Biológicas
Universidad de Guadalajara, Jalisco, Mexico

coordinated by
E. de J. Arias-Jiménez
Horticultural Crops Group
FAO Plant Production and Protection Division

produced within the framework of the
FAO International Technical Cooperation Network
on Cactus Pear

(1995)

FAO PLANT PRODUCTION AND PROTECTION PAPER 132

Food and Agriculture Organization of the United Nations

FIAT PANIS

Rome 1995

POST-HARVEST MANAGEMENT OF FRUITS AND VEGETABLE STEMS

by M. Cantwell

University of California, Davis, California

INTRODUCTION

This chapter provides an overview of the quality and post-harvest physiology and handling of the fruits and vegetable stems of *Opuntia* sp. pl. The Spanish-language names, *tunas* and "nopalitos" are used interchangeably with the English-language terms "cactus fruits" and "cactus or vegetable stems". Since the production and post-harvest management of cactus fruits and vegetable stems is distinct, they are considered separately in this review.

TUNAS OR CACTUS FRUITS

Composition and nutritional characteristics of ripe fruit

The cactus pear is an oval or elongated berry fruit (typically 100-200 g), consisting of a thick fleshy skin or rind (30-40 percent of total fruit weight) surrounding a juicy pulp (60-70 percent of total fruit weight), which contains many hard-coated seeds (5-10 percent of the pulp weight) (Barbera *et al.*, 1992a; Borrego-Escalante and Burgos-Vázquez, 1986; Cantwell, 1991; Griffiths and Hare, 1907; Lakshminarayana *et al.*, 1979; Pimienta *et al.*, 1987; Sáenz-Quintero and Díaz-Cervantes, 1990). Each *Opuntia* species or type produces fruits of different shapes, colours and delicate flavours. The major components of the fruit pulp are water (85 percent) and carbohydrates (10-15 percent), with important amounts of Vitamin C (25-30 mg 100 g^{-1}) (Tables 13 and 14). Pimienta (1990) and Kuti (1992) reported that the Vitamin C content of ripe fruits varied from less than 10 to more than 40 mg 100 g^{-1} pulp among different *Opuntia* species. Table 13 compares the composition of cactus fruits (*O. amyclaea*) with that of oranges and papayas. The seeds of cactus fruits contain significant amounts of protein and lipid, the latter composed of about 75 percent linoleic acid (Table 14). In fruits of different *Opuntia* species, seed protein content varied from 3 to 10 percent dry weight, and seed lipid content varied from 6 to 13 percent dry weight (Pimienta *et al.*, 1987).

Fruit development, maturity indices and quality attributes

Typical changes in the physical characteristics and chemical composition of cactus pears are illustrated by data from "Tuna Blanca" fruits harvested at different stages of development (Table 15). This fruit type has a pale green, almost white pulp within a yellow-coloured peel when ripe. Sugar and Vitamin C contents increase substantially during the ripening process, while firmness and acid content decline.

TABLE 13
A comparison of the composition of the pulp of cactus pears, orange and papaya fruits.

Component	Cactus pear	Orange	Papaya
Water (%)	85.0	87.8	88.7
Total Carbohydrates (%)	11.0	11.0	10.0
Crude Fibre (%)	1.8	0.5	0.8
Lipid (%)	0.1	0.1	0.1
Protein (%)	0.5	0.4	0.6
Ash (%)	1.6	0.4	0.6
Calcium (mg 100 g^{-1})	60	40	20
Vitamin C (mg 100 g^{-1})	30	50	50
Vitamin A (IU)	50	200	1 100

Source: M. Hernández *et al.*, 1980. Valor Nutritivo de los Alimentos Mexicanos, Instituto Nacional de Nutrición, México, D.F.; USDA Agricultural Handbook 8-9. 1982. Composition of Foods. Fruits and Fruit Juices.

TABLE 14
Chemical composition of the pulp and seeds of the fruits of *O. ficus-indica*.

Component	Fruit pulp (fresh wt. basis)	Seed (dry wt. basis)
Water (%)	85.60	5.3
Protein (N x 6.25) (%)	0.21	16.6
Lipid (%)	0.12	17.2
Fibre (%)	0.02	49.6
Pectin (%)	0.19	-
Vitamin C (mg 100 g^{-1})	22	-
B-carotene (IU)	traces	-
Ash (%)	0.44	3.0
Ca (mg 100 g^{-1})	28	16
Mg (mg 100 g^{-1})	28	75
K (mg 100 g^{-1})	161	163
Na (mg 100 g^{-1})	0.8	68
P (mg 100 g^{-1})	15.4	152
Fe (mg 100 g^{-1})	1.5	9

Source: Sawaya *et al.*, 1983 (modified).

Stages of development and ripening for 'Tuna Blanca' fruits can be briefly described as follows:

1) Mature green fruits: almost fully developed, with a light green peel.
2) Ripening fruits: peel begins to show colour change; colour development may vary from incipient up to 75 percent of the fruit surface; fruits at this stage are considered optimal for commercial harvest; glochids begin to abscise.
3) Ripe fruits: have 75 to 100 percent yellow peel colour; are noticeably softer than "Stage 2" fruits, and damage easily during harvest.
4) Over-ripe fruits: may show an increasing intensity of the yellow peel colour, with small, rusty-brown discoloured areas beginning to form.

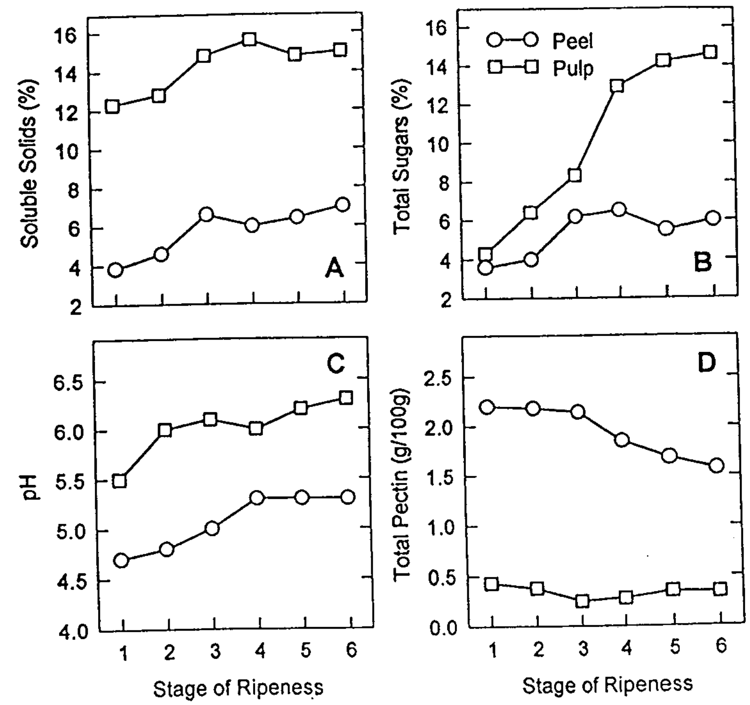

Figure 23. Changes in soluble solids (A), total sugar (B), pH (C) and total pectin content (D) of the pulp (square symbols) and the peel (circle symbols) of tunas (*O. amyclaea*, Copena 1) harvested at different stages of ripeness. Stage 1 fruits are mature-green and stage 6 fruits are overripe.
Source: Martínez-Olea, 1986.

The progression of changes described for "Tuna Blanca" are similar to those observed with fruits of other *Opuntia* sp. pl. selections or species (Barbera *et al.*, 1992a; Kuti, 1992; Martínez-Olea, 1986). In some cultivars, however, changes in the fruit pulp occur with little change in external peel colour (Pimienta, 1990).

For commercial handling, the stage of maturity or ripeness at harvest is very important for fruit quality. Several external maturity indices may be used, including: 1) fruit size and fullness, 2) changes in peel colour, 3) abscission of the glochids, 4) fruit firmness and 5) flattening of the floral cavity or receptacle. These external changes should correlate with internal quality attributes, but their relative importance varies among cultivars. Other important fruit quality characteristics include: the percentage of pulp, the thickness of the peel and its ease of removal, and the resistance of the peel to physical handling (Wessels, 1988).

During the latter stages of development, the fruit pulp rapidly accumulates sugars (Table 16) (Barbera *et al.*, 1992; Kuti, 1992; Lakshminarayana *et al.*, 1979). Harvesting the fruit too early on in the ripening process, therefore, reduces fruit sweetness and should be avoided. Glucose and fructose are the predominant sugars in the pulp of ripe cactus fruits, although in the peel sucrose is also present (Alvarado and Sosa, 1978). The low sucrose content of ripe fruits is consistent with the presence of active invertases (Ouelhazi *et al.*, 1992). Pimienta *et al.* (1987) have identified numerous fruit cultivars, in which reducing sugars comprise only about 50 percent of total sugars, however. The organic acid content is low in comparison to that of other fruits, and acid levels decrease during fruit ripening (Tables 15 and 16). The major organic acids are oxalic and citric acids, with minor amounts of malic and succinic acids (Barbera *et al.*, 1992a).

Both the pulp and peel of cactus fruits exhibit important compositional changes during ripening (Alvarado and Sosa, 1978) (Figure 23). Figures 23A and 23B show that changes in soluble solids, although generally useful as an approximation of sugar content, do not necessarily correlate well with changes in sugar content. In other research, however, soluble solids levels have correlated more closely with sugar content (Alvarado and Sosa, 1978; Lakshminarayana *et al.*, 1979). The titratable acid content of the peel is much higher than that of the pulp; fruit pulp contains very little acid at any stage of development. While there was a decrease in acid content during ripening, the pH values of the peel and pulp tissues increased with ripening (Figure 23C). Changes in fruit firmness are often correlated with changes in cell wall constituents and enzymes, especially pectins and pectinases (Tucker, 1993). There were no changes in the pectin content of the pulp during ripening, whereas total pectin content of the peel was notably higher and decreased with ripening (Figure 23D). The percentage of soluble pectin, however, remained relatively constant during ripening (Martínez-Olea, 1986). Bicalho and Camargo (1982) reported few changes in pectin content during ripening until the cactus fruit became over-ripe, at which time total pectin content decreased and soluble pectin content increased.

The pigments in the fruits of *Opuntia* species are betalains, the red-violet betacyanins and the yellow betaxanthins (Piatelli, 1976). These water-soluble pigments are similar to anthocyanins, since they are aromatic compounds and contain sugar moieties; they are distinguished from the more commonly occurring anthocyanins by their response to pH, their nitrogen content (Piatelli, 1976) and their heat stability (Merin *et al.*, 1987). There are different patterns of pigment accumulation in the pulp and peel of different cultivars (Pimienta, 1990). The peel of "Tuna Blanca" contains significant levels of phenolic compounds (approx. 0.4 percent fresh weight), but their expected role in the development

TABLE 15

Physical and compositional changes in the fruits of *O. amyclaea*, Copena 18 during development and ripening.

Stage of development	Weight (G)	Diameter min-max (mm)	Floral depth (mm)	Pulp (%)	Firmness (kg cm^{-2})	TSS (%)	TTA (%)	pH	Vit. C (mg 100 g^{-1})
Immature	86	42-44	7.2	44	4.6	7.5	0.08	5.2	12
Mature green	102	47-49	3.5	57	3.7	8.8	0.04	6.1	18
Intermediate	105	49-53	1.9	63	2.7	10.1	0.03	6.2	18
Ripe	112	50-54	1.4	65	2.4	11.5	0.02	6.3	26
Over-ripe	108	49-53	1.0	75	2.2	12.5	0.02	6.4	28

Source: Montiel-Rodríguez, 1986.

TABLE 16

Composition of fresh and stored fruits of cactus fruits (*O. amyclaea*) harvested at various stages of development.

Component	Days from fruit set					
	91	98	105	110	115	120
FRESHLY HARVESTED						
Pulp (% fruit weight)	21	40	48	52	59	62
Soluble solids (%)	9.7	13.4	14.6	14.8	15.8	15.5
Total sugars (%)	10.8	15.0	15.2	15.8	17.5	16.0
Titratable acidity (%)	0.15	0.11	0.12	0.08	0.05	0.03
pH	5.79	6.00	6.20	6.25	6.10	6.60
Vitamin C	16.3	13.9	21.4	14.1	11.6	22.0
STORED 15 DAYS AT 20°C, 60-70% RH						
Soluble solids (%)	9.4	12.0	14.0	14.6	13.8	14.8
Total sugars (%)	0.06	0.03	0.05	0.04	0.05	0.04
pH	6.00	6.00	6.50	6.60	6.00	6.20
Vitamin C	17.6	15.6	21.8	21.8	21.9	32.3

Source: Lakshminarayana *et al.*, 1979 (modified).

of surface discolorations remains to be studied (Alvarado and Sosa, 1978; Lakshminarayana *et al.*, 1979).

Cactus fruits have a mild pleasant taste, with subtle differences in the flavour of fruits of different species. For a white-flesh type (*O. ficus-indica*), Flath and Takahashi (1978) reported that most of the 61 identified aroma volatiles were also found in other ripe fruits. A diverse group of alcohols was the major class of compounds represented, with low concentrations of esters, ethers, aldehydes and ketones also present. The melon-like flavour character of this white-flesh type was attributed to several alcohols previously reported in melon and cucumber volatile profiles (Flath and Takahashi, 1978).

Sugars and acids are the principle contributors to flavour in fruits, and their ratio is often used as harvest and quality indices in different fruits (Kader, 1992). The acid content is very low, and the juice of cactus fruits with a higher acid content was favoured in sensory tests (Sepúlveda and Sáenz, 1990). Chávez-Franco and Saucedo-Veloz (1985) found that the stored fruits of *O. amyclaea* had higher sweetness scores than the fruits of *O. ficus-indica*, although soluble solids and sugar contents were similar between fruits. Sensory evaluation has been included in few studies on cactus pears, and Kuti (1992) emphasized the need to conduct such studies to determine consumer preferences for different cultivars and stages of ripeness.

Post-harvest physiology

Cactus pears are non-climacteric fruits (Cantwell, 1991; Lakshminarayana and Estrella, 1978; Lakshminarayana *et al.*, 1979) with low respiration rates in comparison to those of other common fruits (Table 17). Moreno-Rivera *et al.* (1979) reported a pre-harvest climacteric-like pattern of respiration in fruits harvested at different stages of development. For ripeness stages at which the fruits are harvested commercially, however, fruits did not differ in respiration rates, and respiratory activity declined slowly with time in storage (Table 18). Ethylene production by cactus fruits is very low, is similar for fruits harvested at three stages of ripeness, and increases slightly during storage (Table 18).

Physical damage or decay cause increased respiration and ethylene production rates (Cantwell, unpublished).

Non-climacteric fruits are also characterized by a lack of starch as a carbohydrate reserve. There is, therefore, no significant increase in sugar content of non-climacteric fruits after harvest (Tucker, 1993). In ripe fruits from three selections of "Tuna blanca", the soluble solids of the pulp increased by less than 1 percent during storage at 20°C for one month (Cantwell *et al.*, 1985). This small increase in soluble solids was probably due to hydrolysis of complex carbohydrates other than starch. Chávez-Franco and Saucedo-Veloz (1985) also reported a small increase in soluble solids for one selection of cactus fruits stored at 18°C. Alvarado and Sosa (1978), however, reported a slight decline in soluble solids and sugars of cactus fruits after two weeks of storage at 20°C. The sugar content of cactus fruits is essentially determined at the time of harvest, with post-harvest changes being relatively small.

The firmness of cactus fruits (measured on the fleshy peel after removal of the cuticle) decreased slowly during storage at 20°C for one month (Cantwell, 1986). Post-harvest-firmness changes in cactus fruits are small when compared to firmness changes in other fruits (Tucker, 1993). As the cactus fruit develops and ripens, the peel decreases in thickness and becomes easier to remove (Wessels, 1988). Thinning and softening of the peel both contribute to the fruits' increased susceptibility to physical damage during handling (Cantwell *et al.*, 1985).

Harvest and packing

The perishability of cactus fruit results, therefore, not from their physiological behaviour, but principally from the physical damage inflicted on the peel and stem-end during harvest (Cantwell, 1986; Curtis, 1977; Rodríguez-Félix, 1991; Wessels, 1988). Cactus fruits are attached to the mother cladode at an articulation which permits them to be twisted off. The skill of the harvester and the cultivar determines whether this technique is injurious or not to the base or stem-end of the fruit. Oval or barrel-shaped fruits are easier to harvest than elongated fruits, and therefore suffer less harvest damage to the stem-end. Many researchers have noted high levels of physical damage to harvested cactus fruits (Cantwell, 1991; Chávez-Franco and Saucedo-Veloz, 1985; Rodríguez-Félix *et al.*, 1992).

TABLE 17
Maximum respiration and ethylene production rates of selected climacteric and non-climacteric fruits at 20°C.

Fruit	Respiration (μl $CO_2 \cdot g^{-1} \cdot h^{-1}$)	C_2H_4 Production ($nl \cdot g^{-1} \cdot h^{-1}$)
CLIMACTERIC		
Avocado	150	100
Banana	50	5
Mango	60	40
NON-CLIMACTERIC		
Orange	15	0.1
Strawberry	80	0.1
Cactus pear	20	0.2

Source: Various publications.

TABLE 18
Respiration and ethylene production rates of cactus pears (*O. amyclaea*, Copena 18) harvested at 3 stages of ripeness and stored at 20°C, 95% RH.

	CO_2 Production ($\mu l \cdot g^{-1} \cdot h^{-1}$)			C_2H_4 Production ($nl \cdot g^{-1} \cdot h^{-1}$)		
Ripeness Stage	2 days	8 days	16 days	2 days	8 days	16 days
Mature green	21.1±2.9	19.4±1.4	18.4±1.5	0.20±.06	0.20±.05	0.25±.08
Intermediate	20.9±1.6	20.0±2.9	18.6±2.9	0.16±.06	0.21±.07	0.26±.10
Ripe	19.8±3.0	19.0±3.6	18.6±3.1	0.17±.06	0.20±.08	0.30±.10

Source: Cantwell, 1991.

In addition to carefully rotating the fruit off the cladode, fruits are often cut from the cladode. They may be cut carefully at the articulation or be cut with a very small amount of the mother cladode attached. The latter fruit may be "cured" or held for one to two days under ambient conditions with increased air flow so that the cladode tissue dries up and falls off when the fruit is selected and packed. This technique has been used effectively to reduce harvest damage in red fruits in California and it is common practice in Italy. In some *Opuntia* species it is not possible to use this harvest technique, due to the presence of large spines on the cladode near the base of the fruit.

Various hand-held tools have been developed to facilitate the harvesting of cactus fruits. Many of these tools consist of a cutting edge and a device to retain the harvested fruit. More advanced designs of rapid individual fruit harvesters, with cutting or twisting tools attached to extended light-weight arms, have been developed (Lara-López and Manríquez-Yépez, 1985; Lara-López and Torres-Ledesma, 1986). Lara-López (1992) has also described a non-selective, counter-rotating disk harvester for fruits destined for processing. These harvest tools result in a level of damage to the fruits which is similar to that obtained with careful hand harvesting (Lara-López, 1992). The difficulties associated with the harvest of cactus fruits have limited their commercialization, and, above all, their industrialization. Further development of harvest tools is critical for improved post-harvest quality of fresh market fruits.

Another characteristic of the fruits that leads to post-harvest mechanical damage is the presence of tufts of glochids. Glochids are small barbed spines, consisting of almost pure crystalline cellulose (Pritchard and Hall, 1976); the number of glochid tufts varies greatly among fruit cultivars. Fruits with many glochids are more difficult to harvest; the harvester tends to avoid the spiny tufts by using two fingers to grasp the fruit, instead of distributing the force more uniformly across all fingers of the hand. Damage to the peel from finger pressure may be visible at the time of harvest; however, it usually shows up later, during the post-harvest period, as discoloured areas which often dry out, resulting in an unsightly appearance. Compression injury at harvest particularly detracts from the visual quality of cultivars with light-coloured peels.

Glochids begin to abscise during the normal course of fruit ripening. Preliminary work showed that ethylene-generating compounds loosened the fruit at the articulation on the cladode and also loosened the glochids (Cantwell, unpublished). Other preliminary work has shown that pectolytic enzymes produced by bacteria can soften spines and glochids (Fucikovsky, 1992). In cactus fruit production areas, where dew is present in the mornings, moisture prevents the small spines from dispersing in the air during harvest; but in dry desert production areas, no dew may be formed and the air-borne glochids are a menace to the pickers. Techniques to facilitate glochid removal, prior to and after harvest, need to be further investigated.

Loose glochids may also damage the surface of harvested fruits, resulting in small rusty-brown discoloured areas which increase in severity with time in storage. Removal of these small spines immediately after harvest or at the packing house did not produce any differences in the appearance of the glochid-caused discolorations (Berger *et al.*, 1978).

Handling for the national market in Mexico involves cleaning the fruit, sizing and classifying by colour, and packing the fruits into crates of approximately 25 kg.

The glochids are usually eliminated by spreading the fruits on grass or straw-covered areas or on open mesh tables and brushing with brooms.

The packed crates of cactus fruits may be overwrapped with paper and are transported and marketed under ambient conditions. For the Mexican market, white-fleshed fruits are the most popular and are marketed under four grades based on size and defect tolerances (Rodríguez-Félix, 1991).

Due to rough handling, mechanical damage is a common post-harvest defect. In addition to harvest damage, mechanical injury occurs when fruits are transferred from harvest buckets or bags to crates, by overfilling crates, and by inappropriately stacking the filled crates.

Post-harvest operations for export-quality fruit involve much more careful handling and glochid removal (Figure 24).

Fruits are harvested more carefully and placed in crates or shallow bins. These are usually dry dumped, and fruits are passed over a series of brushes with the application of water sprays or an air suction to trap and remove the glochids. After brushing, fruits are waxed, sized (manually or by weight sizes) and packed. Larger-size fruits, free of defects and of uniform colour, are selected for the export market. Fruits may be wrapped in tissue paper and packed into single or double layers in fibreboard cartons weighing about 5 kg.

Cut fruit from stem; place into harvest container
↓
Transfer fruit to field bin or crates
↓
Transport to packing station
↓
[Hold 1-2 days at 15°-20°C with air flow to cure stem]
↓
Dump crates or bins
↓
Brush (wet or dry) to remove spines
↓
Wax fruits
↓
Select for defects (misshapes, scars, physical damage, etc.)
↓
Classify for colour and size (manually or by weight sizes)
↓
Wrap with tissue paper and pack into box (~5.5 kg)
↓
Palletize, cool, store and transport at ~5°C

Figure 24. Post-harvest handling of cactus pears for international markets.

Single or double-layer plastic trays, such as those used for kiwi or peach fruits, have also been used for packing cactus pears for the export market (Wessels, 1988). Cactus fruits of all pulp and peel colours are exported, although fruits with red pulp colours are favoured in some international markets (Caplan, 1990; Castilla and Pimienta, 1990).

Cactus fruits are a speciality-produce item in international markets, and informational leaflets on how to peel and use the fruit are therefore useful (Caplan, 1990).

Storage and marketing conditions

From their study of the marketing system for cactus fruits, Castilla and Pimienta (1990) estimated post-harvest losses to be about 15%. Harvest damage to the stem-end will lead to attack by numerous pathogens and result in fruit decay (Guzmán, 1982). Examination of carefully harvested "Tuna Blanca" fruits showed that 59% of the fruits were damaged at the stem-end; 70% of the fruits had stem-end decay after one month, while peel rots were present in less than 18% of the fruits (Cantwell, unpublished). Common post-harvest pathogens found on cactus fruits include *Fusarium* spp., *Alternaria* spp., *Chlamydomyces* spp., and *Penicillium* spp. (Chessa, 1993; Guzmán, 1982). Hot water treatments (53°-54°C for 5 minutes) and fungicide-containing waxes have been reported effective in reducing post-harvest decay of the fruits (Guzmán, 1982). Other researchers, however, have shown these treatments to be ineffective where stem-end injury was the major cause of post-harvest decay (Rodríguez-Félix *et al.*, 1992).

Curing or healing of the stem-end after harvest may reduce post-harvest decay. Curing was the explanation offered by Chávez-Franco and Saucedo-Veloz (1985), who found that fruits of two species showed no decay after storage for 15 days at 18°C, but there was significant decay at lower storage temperatures. A traditional technique for storing fruits under ambient conditions for long periods is to harvest with pieces of cladode attached or to harvest the entire cladode with fruits attached and store under fresh conditions (Alvarez-Armenta and Cruz-Hernández, 1985; Esquivel-Gómez, 1992; Rodríguez-Félix, 1991). Harvesting cactus fruit with small amounts of cladode attached is a commercial practice that protects the stem-end and therefore reduces decay incidence.

Water loss is important because it affects the visual appearance and texture of the fruits and causes a reduction in saleable weight. Generally, products must lose about 5% of their fresh weight before visual appearance is affected (Kader, 1992). For cactus fruits, a weight loss of about 8% was necessary to affect their visual appearance (Rodríguez-Félix *et al.*, 1992). Weight loss of ripening cactus fruits was approximately 0.5% per day at 20°C and 60 to 70% RH; whereas weight loss in less mature fruits was 1% per day (Lakshminarayana *et al.*, 1979). Removal of glochids from "Tuna Blanca" fruits increased weight loss by 50% over that of uncleaned fruits, and waxing reduced weight loss of the cleaned fruits by about 75% (Rodríguez-Félix *et al.*, 1992). High-gloss fruit waxes are commonly used in California, but numerous other types of waxes have been used on cactus fruits to improve visual appearance and reduce weight loss (Estrella-Bolio, 1977; Guzmán, 1982; Rodríguez-Félix *et al.*, 1992).

Storage at low temperatures is a very effective method for reducing water loss, since it reduces the vapour pressure deficit between the fruit and the storage environment (Cantwell, 1991; Chessa and Barbera, 1984). Storage of "Gialla" fruits at 6°C and 90 to 95% RH resulted in a weight loss of less than 0.2% per day (Chessa and Schirra, 1992). Other techniques to reduce weight loss include the use of polyethylene liners in the boxes (a common way to reduce water loss in many fruits and vegetables). The use of paper and other absorbent materials is generally required with the plastic liners, however, otherwise condensed moisture will increase decay (Cantwell, unpublished; Rodríguez-Félix *et al.*, 1992).

Cactus pears are chilling sensitive, and injury is manifested as small dark surface discolorations, and a "bronzing" of the fruit peel. Storage at 5° to 8°C is generally recommended for a storage life of about three to four weeks (Cantwell, 1991; Chessa, 1993; Chessa and Barbera, 1984). Chávez-Franco and Saucedo-Veloz (1985) reported chilling injury on fruits of *O. amyclaea* and *O. ficus-indica* stored at 8° or 10°C for 15 days. Chessa and Schirra (1992) reported the appearance of chilling symptoms after two weeks at 6°C in *O. ficus-indica* "Gialla" fruits. Other researchers, however, consider that the fruit is more chilling tolerant. Berger *et al.* (1978) stored fruits of *O. ficus-indica* for up to two months at 0°C and concluded that they are relatively tolerant to low temperature storage. Variation in susceptibility to chilling injury among cultivars and according to the season of harvest may be expected and should be further investigated.

Techniques to reduce the onset of chilling injury symptoms during storage at low temperatures include the use of high relative humidity, waxing, and intermittent warming (Saltveit and Morris, 1990; Wang, 1990a). Waxing, however, did not reduce chilling injury symptoms in *O. amyclaea* (Rodríguez-Félix *et al.*, 1992). An intermittent warming procedure of ten days at 2°C, followed by four days at 8°C, reduced the development of chilling injury in "Gialla" cactus fruits over a six-week period, in comparison to continuous storage at 6°C (Chessa and Schirra, 1992). So far, however, the logistic of providing intermittent warming periods has prevented its commercial application.

Modified or controlled atmospheres are used to retard ripening and other symptoms of senescence in stored fruits (Kader, 1992). Atmospheres high in carbon dioxide (> 10 percent) may significantly inhibit decay of fruits and the loss of organic acids and sugars (Wang, 1990b). No work has yet been published on controlled atmosphere storage.

Potential benefits from controlled atmospheres would probably include decay control and reduced compositional change.

Research on the sensory evaluation of stored fruits is very limited. Berger *et al.* (1978) reported that fruits of *O. ficus-indica* could be stored for up to two months at 0°C and retain their palatability, although there was slight softening and some loss of flavour. Chávez-Franco and Saucedo-Veloz (1985) reported no difference in the flavour of fruits stored at 8°, 10° or 18°C for 15 days.

Future research and extension needs

Common post-harvest quality problems observed during the marketing of cactus fruits in the United States include: undesirable variation in form and size; extensive physical damage to the fruit surface and stem-end; decay, particularly on the stem-end, but also on the fruit surface; discoloured and dehydrated fruit surfaces; and the presence of glochids.

Future research and extension needs include: 1) determination of maturity and quality indices for different cultivars; 2) amplifying criteria for selection of cultivars, to include sensory evaluation at harvest and after storage; 3) development of harvest tools and techniques to reduce physical damage; 4) studies on the development and elimination of glochids; 5) evaluation of curing and other techniques to protect the stem-end; 6) evaluation of storage conditions for different cultivars; and 7) promotion of the health value and various uses of the fruit.

"*NOPALITOS*" OR CACTUS STEMS

Quality and nutritional characteristics

"Nopalitos" are a traditional vegetable in Mexico and a speciality vegetable in the United States and elsewhere. The tender developing flattened stems or cladodes of the genus *Opuntia* are also often called "cactus leaves". In the early stages of growth, vestigial true leaves, usually subtended by spines, are present, but the leaves usually begin to abscise by the time the "nopalitos" reach commercial size. Good quality cactus stems or "nopalitos" are thin, fresh-looking, turgid and have a brilliant green colour. After trimming and chopping, the cactus stems may be eaten as a fresh or cooked vegetable, and resemble green beans somewhat in flavour (Rodríguez-Félix and Cantwell, 1988). There are consumer preferences for "nopalitos" from certain cultivars (Pimienta, 1993a).

"Nopalitos" are mostly water (92%) and carbohydrates, including fibre (4-6%), with a little protein (1-2%) and minerals, principally calcium (1%). They also contain moderate amounts of vitamin C (10-15 mg 100 g^{-1}) and the vitamin A precursor, B-carotene (30 μg 100 g^{-1} carotenoid) (Feitosa-Teles *et al.*, 1984; Rodríguez-Félix and Cantwell, 1988). Table 19 compares the composition of "nopalitos" with two other green vegetables, head lettuce and spinach. While the carotenoid and vitamin C levels are intermediate between those of spinach and lettuce, the contribution of "nopalitos" to the diet can be significant, especially in arid areas. The amino acid profile of "nopalitos" protein is similar to that of other green vegetables (Feitosa-Teles *et al.*, 1984). Tender "nopalitos" can be readily and abundantly produced from plants subjected to high temperatures with little water - conditions unfavourable for the production of most green leafy vegetables (Luo and Nobel, 1993; Robles-Contreras, 1986).

TABLE 19
The composition of fresh "nopalitos", head lettuce and spinach.

Component	"Nopalitos"	Head Lettuce	Spinach
Water (%)	91.8	95.5	90.7
Protein (%)	1.5	1.0	3.2
Lipid (%)	0.2	0.1	0.3
Crude Fibre (%)	1.1	0.5	0.9
Total Carbohydrate (%)	4.5	2.1	4.3
Ash (%)	1.3	0.5	1.8
Calcium (mg 100 g^{-1})	90	19	99
Vitamin C (mg 100 g^{-1})	11	4	28
Carotenoids (μg 100 g^{-1})	30	19	55

Source: Data for cactus stems from Rodríguez-Félix and Cantwell, 1988; data for lettuce and spinach from USDA Agric. Hdbk 8-11, 1984.

Because the cactus pear plant is a CAM plant, the acid content of the "nopalitos" may fluctuate greatly during the day and affect their flavour (Feitosa-Teles *et al.*, 1984; Rodríguez-Félix and Cantwell, 1988). Figure 25 shows the diurnal variation in the tritable acid content of "nopalitos" of *O. ficus-indica* of commercial size (20 cm); "nopalitos" 10 cm in length were not CAM-active. The chemical composition of "nopalitos" varies according to the species, the cultural conditions and the stage of development (Bicalho and Camargo, 1982; Camarillo and Grajeda, 1981; Retamal *et al.*, 1987; Rodríguez-Félix and Cantwell, 1988).

Figure 26 illustrates some of the physical and chemical changes in "nopalitos" at different stages of development at which they may be harvested as a vegetable.

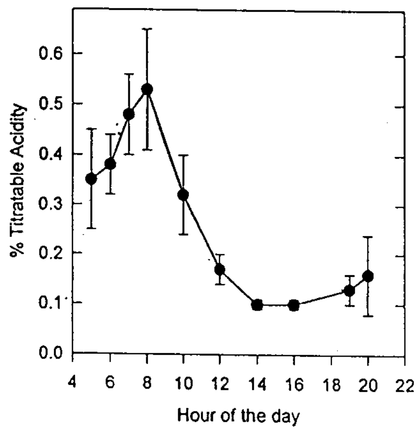

Figure 25. Diurnal fluctuation in tritable acid content of 20-cm "nopalitos" harvested in the summer from 05.00 to 22.00 hours from irrigated *O. ficus-indica*.
Source: Rodríguez-Félix and Cantwell, 1988.

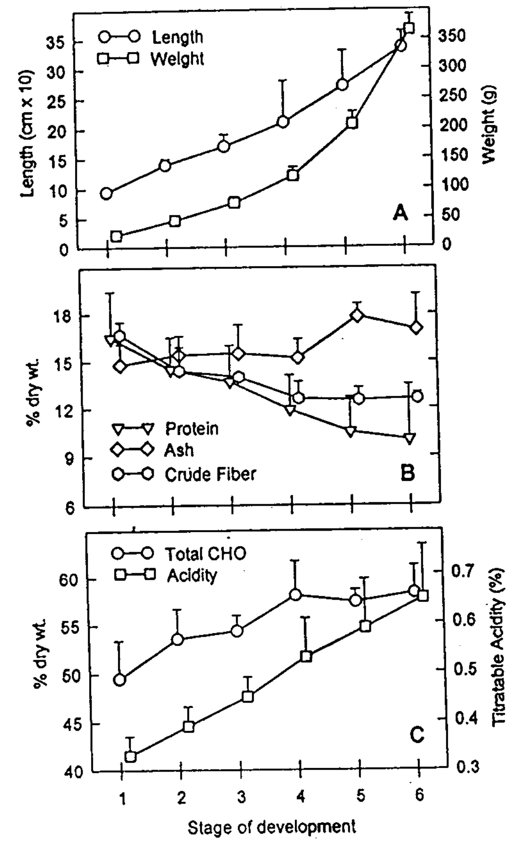

Figure 26. Changes in length and weight (A); protein, ash content and crude fibre (B); and total carbohydrates and acidity (C) during the growth of cactus stem. Data are the means for testing the "nopalitos" of three species, *O. inermis*, *O. ficus-indica* and *O. amyclaea*. Stems are typically harvested commercially from stages 2 to 4.
Source: Rodríguez-Félix and Cantwell, 1988.

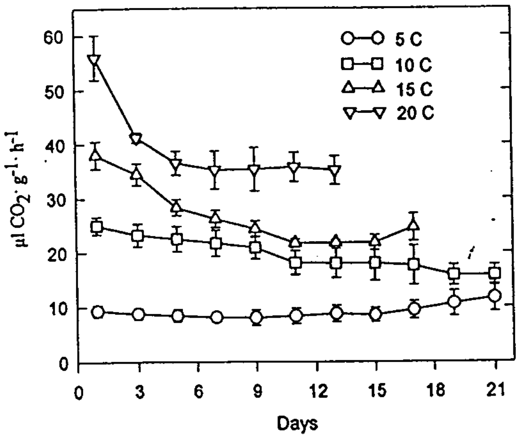

Figure 27. Carbon dioxide production of 10-cm "nopalitos" (*O. inermis*) stored at 5°, 10°, 15° and 20°C.
Source: Cantwell *et al.*, 1992.

Post-harvest physiology

Respiration rates of small cactus stems at different storage temperatures are shown in Figure 27. Respiration rates decreased over the first days of storage and then remained relatively constant until the end of shelf-life. Cactus stems have moderate respiration rates which are comparable to those of topped carrots, head lettuce and celery (Cantwell *et al.*, 1992). The respiration rates of young 10-cm stems are 25 to 50 percent higher than carbon dioxide production rates of the more developed 20-cm CAM-active stems. Ethylene-production rates of "nopalitos" are very low, and are similar to rates of production of other green vegetables (Cantwell *et al.*, 1992).

The acid content of "nopalitos" may also be modified by post-harvest storage temperatures. Figure 28 shows changes in titratable acidity of young (10 cm) and commercial size (20 cm) "nopalitos", which have been harvested in the morning or afternoon and stored at 20° or 5°C. Storage at low temperatures maintains or increases acid content, whereas storage at 20°C results in a decrease in acid content.

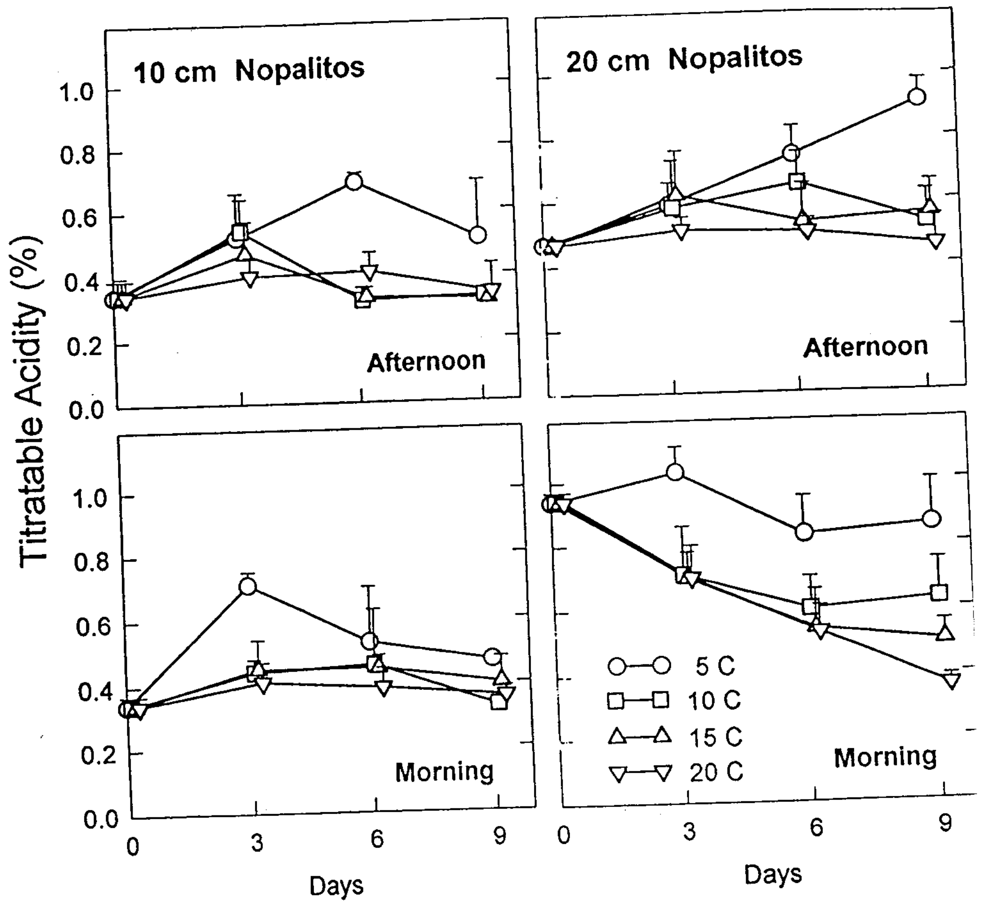

Figure 28. Changes in tritable acid content of 10-cm (left graphs) and 20-cm (right graphs) "nopalitos" (*O. inermis*) harvested at 08.00 (lower graphs) and 18.00 hours (upper graphs), and stored for nine days at 5°, 10°, 15° or 20°C.
Source: Cantwell *et al.*, 1992.

Harvest and packing
"Nopalitos" are harvested commercially when they are from 15 to 20 cm long, by cutting at the articulation with the "mother cladode". In Mexico, they are collected in baskets or stacked in cylindrical packs about 1.5 to 1.75 m high for transportation to the market under ambient conditions. They are often cleaned (trimmed of spines and small leaves and sometimes diced) prior to sale (Bautista-Castañón, 1982; Fernández-Montes, 1992; Flores-Valdez, 1992; Sánchez-Grados and Alvarez-Ramírez, 1990). Considerable heat from the respiration of the "nopalitos" is generated in the centre of the traditional cylindrical packs. This is associated with rapid decreases in visual quality and the abscission and darkening of the small vestigial leaves. These conditions also favour decay organisms but since the "nopalitos" are generally marketed within two to three days of harvest, this is not usually a problem. "Nopalitos" produced in California or exported from Mexico are usually packed loosely in 5 to 10-kg wooden or fibreboard cartons. As the "nopalitos" move inside the cartons during handling, they often have significant numbers of spine-caused wounds which discolour.

Storage and marketing conditions
Cactus stems lose their brilliant shiny appearance and become dull green in colour with time following harvest (Cantwell *et al.*, 1992). "Nopalitos" stored under ambient conditions may also begin to yellow and curve inward due to water loss (Neri *et al.*, 1992). Storing "nopalitos" at 5° to 10°C (41°-50°F) significantly reduces their respiration rate, increasing post-harvest shelf-life from less than one week at 20°C to three weeks at 5°C (Cantwell *et al.*, 1992). Visual quality was maintained for about two weeks at 10°C and for three weeks at 5°C. After one week at 20°C and two weeks at 15°C, the vestigial leaves began to senesce, blacken and abscise. Most of the vestigial leaves were intact and green after four weeks at 5°C (Cantwell *et al.*, 1992). The season and production conditions can affect the shelf-life of "nopalitos" (Aguilar-Becerril, 1990).

After three weeks of storage at 5°C, "nopalitos" may begin to show signs of chilling injury, in particular a bronzing or unattractive diffuse surface discoloration. Chilling injury is also significant as, if severe enough, the "nopalitos" will deteriorate rapidly when removed from storage and marketed at ambient temperatures (Ramayo-Ramírez *et al.*, 1978a). Before the visual symptoms of chilling injury appear, low temperature damage is manifested by increased respiration and ethylene production rates (Cantwell *et al.*, 1992). There appears to be some variation in the development of chilling injury among stems of different *Opuntia* species and different stages of development (Ramayo-Ramírez *et al.*, 1978a and 1978b; Cantwell *et al.*, 1992).

Decay at the cut stem-end may be a problem if "nopalitos" are stored for more than two weeks. Decay is usually avoided by ensuring that the "nopalitos" have not been damaged when cut from the mother cladode. Fungicide dips have been shown to reduce post-harvest decay of "nopalitos", but fungicides are not used commercially (Ramayo-Ramírez *et al.*, 1978b).

Handling of fresh-cut "nopalitos"
Recent research has focused on improving the shelf-life of cleaned and diced "nopalitos", a common form in which they are marketed. Cleaned and prepared - or "fresh-cut" - fruit and vegetable products are popular for their convenience, but are also more perishable than the corresponding intact product. The shelf-life of diced "nopalitos" was one day at room temperature and six days at 5°C (Rodríguez-Félix and Soto-Valdez, 1992). Reducing brown

discoloration at the cut surfaces and preventing fluid (mucilage) loss are the main problems in the handling of diced cactus stems (Rodríguez-Félix and Soto-Valdez, 1992). Washing trimmed and diced "nopalitos" is not effective because the water will extract the mucilage at the cut surfaces (Trachtenberg and Mayer, 1982). Keeping cut surfaces clean and dry, and storing at low temperatures are necessary for optimizing the shelf-life of fresh-cut "nopalitos". Notwithstanding the chilling-sensitive nature of the intact "nopalitos", the fresh-cut product should be stored between 0° and 5°C (Cantwell, unpublished). High levels of carbon dioxide in the atmosphere, used to reduce discoloration in other cut products (such as lettuce), may also be beneficial to retard browning of the cut "nopalitos" (Cantwell, unpublished). Various chemical treatments, including dips of sodium bisulphite, citric acid and ascorbic acid, have been reported effective in reducing discoloration of fresh-trimmed "nopalitos" (Camara-Cabrales *et el.*, 1990).

Future research and extension activities
Common quality problems observed during the marketing of "nopalitos" include: the unattractive appearance of the spiny stems; excessive breakage and mechanical damage to tender stems; surface discoloration of damaged areas; decay on the apex and stem-ends; yellowing at the apex; dehydration; overmature "nopalitos"; and the variation in appearance and cuticle thickness of "nopalitos" cultivars.

Research and extension needs include:

1) the development of handling techniques to reduce physical damage;
2) "nopalitos" cultivars with fewer, less-developed spines;
3) improved packaging for better protection and more attractive presentation;
4) equipment for trimming and spine removal;
5) sensory evaluation of different cultivars of "nopalitos" at harvest and after storage;
6) evaluation of storage conditions including temperatures and modified atmospheres;
7) protection of the stem-end to prevent decay;
8) treatments to reduce brown discolorations on intact and diced "nopalitos";
9) physiology and handling of diced "nopalitos";
10) promotion of the health benefits and nutritional value of "nopalitos".

Literature Cited

Aguilar-Becerril, G. 1990. Influencia de la época y hora de cosecha de nopal verdura (*Opuntia* spp.) en la vida de postcosecha. IV Reunión Nacional y II Congreso Internacional sobre el Conocimiento y Aprovechamiento del Nopal, Zacatecas, Mexico. p. 34.

Alvarado y Sosa, L. 1978 Fisiología y Bioquímica del desarrollo del fruto del Nopal Tunero (*Opuntia amyclaea* Tenore). Tésis de Maestria, Colegio de Postgraduados, Chapingo, Mexico. 73 pp.

Alvarez-Armenta, R. y J. Pablo Cruz-Hernández. 1985. La influencia del cladodio aislado en la conservación de la tuna (*Opuntia amyclaea* Tenore). Abstract #131. I Congreso Nacional de Horticultura, Hermosillo, Sonora.

Barbera, G., F. Carimi, P. Inglese and M. Panno. 1992. Physical, morphological and chemical changes during fruit development and ripening in three cultivars of prickly pear, *Opuntia ficus-indica* (L.) Miller. J. Hort. Sci. 67(3): 307-312.

Bautista-Castañon, R. 1982. Los agrosistemas nopaleros del Valle de Mexico. Professional thesis, Univ. Autónoma Chapingo, Chapingo, Mexico. 98 pp.

Berger-S., H., Z. Ortuzar-R., C. Auda-M., L.A. Lizana-M., and A. Reszczynski-P. 1978. Conservación de tunas (*Opuntia ficus-indica*) en almacenaje refrigerado. Invest. Agricola 4(1): 21-24.

Bicalho, U. de O., M. de V. Camargo Penteado. 1982. Estudo do fruto e do artículo da *Opuntia ficus-indica* (L.) Miller cultivada em Valinhos, S.P. II. Características bioquímicas. Rev. Farm. Bioquim. Univ. S. Paulo 18: 68-74.

Borrego-Escalante, F. and N. Burgos-Vázquez. 1986. El Nopal. Univ. Autónoma Agraria 'Antonio Narro', Saltillo, Mexico. 202 pp.

Camara-Cabrales, L., A. Higareda Ruiz, M. Coronado-Herrera, M. Rosales-Domínguez, M.G. Mariño y M. Darbouze-Trejo. 1990. Conservación postcosecha del nopal (*Opuntia ficus-indica*) como verdura. Memorias III Reunión Nacional y la I Reunión Internacional, El Nopal: su conocimiento y aprovechamiento, Univ. Autónoma Agraria 'Antonio Narro', Saltillo, Mexico. pp. 309-318.

Camarillo, B. and J.E. Grajeda. 1979. Comparative study on 5 selections of prickly pear for human consumption. Proc. Trop. Region Amer. Soc. Hort. Sci. 23: 236-238.

Cantwell, M.I. 1986. Postharvest aspects of prickly pear fruits and vegetable cladodes. Perishables Handling (Univ. Calif., Davis) No. 59: 6-9.

Cantwell, M. 1991. Quality and postharvest physiology of "nopalitos" and "tunas" Proc. Second Annual Texas Prickly Pear Conference, Texas Prickly Pear Council, McAllen, Texas. pp. 50-66.

Cantwell, M.I., A. Rodríguez-Felix and F. Robles-Contreras. 1992. Postharvest physiology of prickly pear cactus stems. Scientia Horticulturae 50: 1-9.

Cantwell de Trejo, M., S. Montiel-Rodríguez, A. Vega-Flores y S. Ayala-Lizárraga. 1985. Cambios fisico-químicos durante la maduración y almacenamiento de tunas de selecciones de *Opuntia amyclaea*. Abstract #133. I Congreso Nacional de Horticultura, Hermosillo, Sonora

Caplan, K. 1990 Marketing strategies for cactus pears and cactus leaves for the 1990's. Proc. First Annual Texas Prickly Pear Council, Texas A & I Univ., Kingsville, Texas. pp. 85-89.

Castillo-Castillo, M. and E. Pimienta-Barrios. 1990. Comercialización del nopal (*Opuntia* spp.) tunero en la zona centro de México. Memorias de la III Reunión Nacional y I Reunión Internacional, El Nopal: su conocimiento y aprovechamiento. Univ. Autónoma Agraria 'Antonio Narro', Saltillo, Mexico. pp.336-343.

Chávez-Franco, S. and C. Saucedo-Veloz. 1985. Conservación en refrigeración de dos variedades de tunas. Horticultura Mexicana 1(1): 6-13.

Chessa, I. 1993. Conservazione, Capitolo 12. In: La Coltura del Ficodindia. B. Barbera and P. Inglese, eds. Edagricole, Bologna, Italy. pp. 147-154.

Chessa, I. and G. Barbera. 1984. Indagine sulla frigoconservazione dei frutti della cv. Gialla di Ficodindia. Rivista di Frutticoltura e di Ortofloricoltura 46(8): 57-61.

Chessa, I. and M. Shirra 1992. Prickly pear cv "Gialla": intermittent and constant refrigeration trials. Acta Hort. 296: 129-137.

Curtis, J. 1977. Prickly pear farming in the Santa Clara Valley, California. Econ. Bot. 31: 175-179.

Esquivel-Gómez, D. 1992. Una alternativa para mejorar la comercialización de tuna. V Congreso Nacional y III Congreso Internacional, Conocimiento y Aprovechamiento del Nopal, Chapingo, Mexico. Abstract, p. 99.

Estrella-Bolio, J.I. 1977. Efectos de recubrimientos de cera en Tuna Blanca Tésis Profesional, Esc. Nacional Ciencias Biológicas, Mexico, D.F. 42 pp.

Feitosa-Teles, F.F., J.W. Stull, W.H. Brown and F.M. Whiting. 1984. Amino and organic acids of the prickly pear cactus (*Opuntia ficus-indica* L.). J. Sci. Fd. Agric. 35: 421-425.

Fernández-Montes, M.R. 1992. Características del mercadeo del nopalito en el Distrito Federal durante 1985-1990. Abstracts, V Congreso Nacional y III Congreso Internacional, Conocimiento y Aprovechamiento del Nopal, Chapingo, Mexico. p. 101-102.

Flath, R.A. and J.M. Takahashi. 1978. Volatile constituents of prickly pear (*Opuntia ficus indica* Mill., *de Castilla* variety). J. Agric. Food Chem. 26(4): 835-837.

Flores-V., C.A. 1992. Growing, commercializing, and marketing cactus leaves in Mexico. Proc. 3rd Annual Texas Prickly Pear Conference, Texas Prickly Pear Council, McAllen, Texas. pp. 56-65.

Fucikovsky, L. 1992. Reblandecimiento de espinas y aguates de nopal con suspension bacteriana. V Congreso Nacional y III Congreso Internacional, Conocimiento y Aprovechamiento del Nopal, Chapingo, Mexico. Abstract. p. 91.

Griffiths, D. and R.F. Hare. 1907. The tuna as food for man. USDA Bureau Plant Industry Bulletin No. 116, Washington, D.C. 73 pp.

Guzman-Romero, G. 1982. Causas y control de los daños que exhibe la Tuna Blanca (*Opuntia* sp.) en el almacenamiento. Tésis de Maestria, Escuela Nacional de Fruticultura, Comisión Nacional de Fruticultura, Mexico, D.F. 143 pp.

Kader, A.A. (ed.). 1992. Postharvest Technology of Horticultural Crops. Univ. California Special Publication 3311, Oakland CA. 296 pp.

Kuti, J.O. 1992. Growth and compositional changes during the development of prickly pear fruit. J. Hort. Sci. 67: 861-868.

Lakshminarayana, S. and I. Estrella-Bolio. 1978. Postharvest respiratory behavior of tuna (prickly pear) fruit (*Opuntia robusta*). J. Hort. Sci. 53: 327-330.

Lakshminarayana, S., L. Alvarado y Sosa and F. Barrientos-Pérez. 1979. The development and postharvest physiology of the fruit of prickly pear (*Opuntia amyclaea* Tenore). Tropical Foods. Vol 1. Chemistry and Nutrition (ed. G.E. Inglett and G. Charalambous), Academic Press, New York. pp. 69-93.

Lara-López, A. 1992. Mechanical principles for harvesting prickly pears. Proc. 3rd Annual Texas Prickly Pear Conference, Texas Prickly Pear Council, McAllen, Texas. pp. 26-28.

Lara-López, A. and J. Manríquez-Yepez. 1985. A hand tool for selective harvesting of the prickly pear fruit. Proc. Amer. Soc. Agric. Eng. Paper No. 85-1067. 12 pp.

Lara-López, A. and Z. Torres-Ledesma. 1986. A principle for nonselective prickly pear harvesting. Proc. Amer. Soc. Agric. Eng. Paper No. 86-1553. 7 pp.

Luo, Y. and P.S. Nobel. 1993. Growth characteristics of newly initiated cladodes of *Opuntia ficus-indica* as affected by shading, drought and elevated CO_2. Physiol. Plant. 87: 467-474.

Martínez-Olea, O.R. 1986. Características de calidad de tunas de diferentes selecciones de *Opuntia* cultivadas en el estado de Sonora. Professional thesis, Univ. de Sonora, Hermosillo, Mexico. 54 pp.

Merin, U., S. Gagel, G. Popel, S. Bernstein, and I. Rosenthal. 1987. Thermal degradation kinetics of prickly-pear-fruit red pigment. J. Food Sci. 52(2): 485-486.

Montiel-Rodríguez, S.M. 1986. Producción y calidad de frutas maduras de 9 selecciones de Tuna Blanca (*Opuntia amyclaea*) en la Costa de Hermosillo. Professional thesis, Univ. de Sonora, Hermosillo, Mexico. 48 pp.

Moreno-Rivera, M.A., L. Alvarado y Sosa and S. Lakshminarayana. 1979. Preharvest respiratory trend of the fruit of prickly pear (*Opuntia amyclaea* Tenore). Proc. Fla. State Hort. Soc. 92: 235-237.

Neri-L., C., E. Pimienta-B., y C. Robles-M. 1992. Cambios fisiológicos durante el proceso de senescencia en cladodios jóvenes de nopal (*Opuntia ficus-indica* (L.) Miller). Abstracts, V Congreso Nacional y III Congreso Internacional, Conocimiento y Aprovechamiento del Nopal, Chapingo, Mexico. p. 107.

Ouelhazi, N.K., R. Ghrir, K.H. Diep Le and F. Lederer. 1992. Invertase from *Opuntia ficus-indica* fruits. Phytochem. 31(1): 59-61.

Piatteli, M. 1976. Betalains. In: T.W. Goodwin, Chemistry and Biochemistry of Plant Pigments. Academic Press, London. pp. 560-596.

Pimienta-Barrios, E. 1990. El Nopal Tunero. Universidad de Guadalajara, Guadalajara, Mexico. pp. 217-235.

Pimienta-Barrios, E. 1993. Vegetable cactus (*Opuntia*). In: J.T. Williams (ed.) Pulses and Vegetables. Chapman and Hall, London. p.178-191.

Pimienta-Barrios, E., A. Delgado-Alverado, y R. Mauricio-Leguizano. 1987. Evaluación de la variación en formas de Nopal (*Opuntia* spp.) Tunero en la Zona Centro de Mexico. Strategies for Classification and Management of Native Vegetation for Food Production in Arid Zones. USDA/RM/SARH/INIFAP General Technical Report RM-150. pp. 82-86.

Pritchard, H.N. and J.A. Hall. 1976. The chemical composition of glochids from *Opuntia*. Can. J. Bot. 54: 173-176.

Ramayo-Ramírez, L., C. Saucedo-Veloz and S. Lakshminarayana. 1978a. Prolongación de la vida de almacenamiento del nopal hortaliza (*Opuntia inermis* Coulter) por refrigeración. Chapingo, Nuevo Epoca 10: 30-32.

Ramayo-Ramírez, L., C. Saucedo-Veloz and S. Lakshminarayana. 1978b. Causas de altas pérdidas en nopal hortaliza (*Opuntia inermis* Coulter) almacenado por refrigeración y su control. Chapingo, Nuevo Epoca 10: 33-36.

Retamal, N., J.M. Durán and J. Fernández. 1987. Seasonal variations of chemical composition in prickly pear (*Opuntia ficus-indica* (L.) Miller). J. Sci. Food Agric. 38: 303-311.

Robles-Contreras, F. 1986. Efecto de la frecuencia de riego sobre las relaciones hídricas, producción y calidad de nopal para verdura (*Opuntia ficus-indica*). Professional thesis, Univ. de Sonora, Hermosillo, Mexico. 66 pp.

Rodríguez, Felix, A. 1991. Postharvest handling of minor fruits in Mexico. Proc. National Symposium on Postharvest Physiology and Technology of Horticultural Crops in Mexico. E.M. Yahia and I. Higuera (eds.). Editorial Limusa, Mexico. pp. 305-310.

Rodríguez-Felix, A. and M. Cantwell. 1988. Developmental changes in composition and quality of prickly pear cactus cladodes (nopalitos). Plant Foods for Human Nutrition 38: 83-93.

Rodríguez-Felix, A. and H. Soto-Valdez. 1992. Quality changes of diced nopal during storage in polyethylene bags. Proc. 3rd Annual Texas Prickly Pear Conference, Texas Prickly Pear Council, McAllen, Texas. pp. 22-25.

Rodríguez-Felix, A., M.I. Gonzáles-Salas, H. Soto-Valdez, and M. I. Silveira-Gramont. 1992. Effects of postharvest treatments on the quality of tuna during storage. Proc. 3rd Annual Texas Prickly Pear Conference, Texas Prickly Pear Council, McAllen, Texas. pp. 9-21.

Sáenz-Quintero, L.A. y M.I. Díaz-Cervantes. 1990. Caracterización fisicoquímica de tuna de 14 formas de nopal de la colección del CEZAC. IV Reunión Nacional y II Congreso Internacional sobre el Conocimiento y Aprovechamiento del Nopal, Zacatecas, Mexico. p. 13

Saltveit Jr., M.E. and L.L. Morris. 1990. Overview on chilling injury of horticultural crops. In: C.Y. Wang (ed.), Chilling Injury of Horticultural Crops. CRC Press, Boca Raton, Fl. pp. 3-15.

Sánchez-Martínez, C.A. y F. Alvárez-Ramírez. 1990. Comercialización de nopal de verdura en la Central de Abastos de la Ciudad de México. Memorias III Reunión Nacional y la I Reunión Internacional, El Nopal: su conocimiento y aprovechamiento, Univ. Auto. Agr. Antonio Narro, Saltillo, Mexico. pp. 303-309.

Sawaya, W.N., H.A. Khatchadourian, W.M. Safi and H.M. Al-Muhammad. 1983. Chemical characterization of prickly pear pulp, *Opuntia ficus-indica*, and the manufacturing of prickly pear jam. J. Fd. Technol. 18: 183-193.

Sawaya, W.N., J.K. Khalil and M.M. Al-Mohammad. 1983. Nutritive value of prickly pear seeds, *Opuntia ficus-indica*. Qual. Plant Foods Hum. Nutr. 33: 91-97.

Sepúlveda, E. and C. Sáenz. 1990. Características químicas y físicas de pulpa de tuna (*Opuntia ficus indica*). Rev. Agroquim. Tecnol. Aliment. 30:551-555.

Trachtenberg, S. and A.M. Mayer. 1982. Biophysical properties of Opuntia ficus-indica mucilage. Phytochem. 21: 2835-2843.

Tucker, G.A. 1993. Introduction. In: G.B. Seymour, J.E. Taylor, and G.A. Tucker (eds.). Biochemistry of Fruit Ripening. Chapman & Hall, London. pp. 1-51.

Wang, C.Y. 1990a. Alleviation of chilling injury of horticultural crops. In: C.Y. Wang (ed.), Chilling Injury of Horticultural Crops. CRC Press, Boca Raton, Fl. pp. 281-302.

Wang, C.Y. 1990b. Physiological and biochemical effects of controlled atmospheres on fruits and vegetables. In: M. Calderon and R. Barkai-Golan (eds.). Food Preservation by Modified Atmospheres. CRC Press, Boca Raton, Fl. pp. 197-223.

Wessels, A.B. 1988. Spineless Prickly Pears. Perskor Publishers, Johannesburg, South Africa. 61 pp.