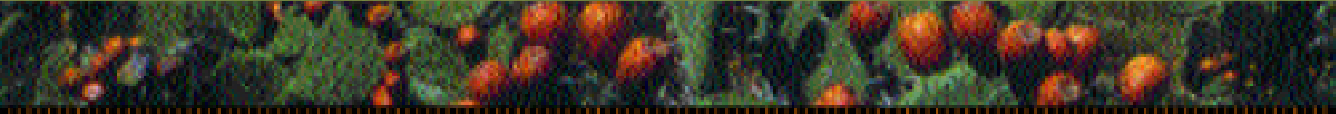
CACTI

BIOLOGY AND USES

EDITED BY PARK S. NOBEL



CACTI

BIOLOGY AND USES

Edited by Park S. Nobel

UNIVERSITY OF CALIFORNIA PRESS
Berkeley Los Angeles London

University of California Press
Berkeley and Los Angeles, California

University of California Press, Ltd.
London, England

Library of Congress Cataloging-in-Publication Data

Cacti: biology and uses / Park S. Nobel, editor.
p. cm.
Includes bibliographical references (p.).
ISBN 0-520-23157-0 (cloth : alk. paper)
1. Cactus. 2. Cactus—Utilization. I. Nobel, Park S.

QK495.C11 C185 2002
583'.56—dc21 2001005014

Manufactured in the United States of America
10 09 08 07 06 05 04 03 02 01
10 9 8 7 6 5 4 3 2 1

The paper used in this publication meets the minimum requirements of ANSI/NISO Z39.48–1992 (R 1997) (*Permanence of Paper*).

CHAPTER

› 13 ‹

NOPALITOS, MUCILAGE, FIBER, AND COCHINEAL

Carmen Sáenz-Hernández, Joel Corrales-García, and Gildardo Aquino-Pérez

Introduction

A common use of cactus stems is nopalitos—tender young cladodes—a traditional vegetable eaten fresh or cooked in various dishes. Mexicans are the principal consumers. Nopalitos are generally obtained from *Opuntia ficus-indica, O. robusta,* or *Nopalea* spp. The number of spines and the color are quality factors evaluated by consumers. Several new consumable products are being developed from the stems (e.g., marmalades, blends for breakfasts, and pickles), and the cladodes have medical and cosmetic uses.

Another important use of *Opuntia* stems is the production of carminic acid, a natural colorant developed by the precolonial indigenous people of Mexico. Carminic acid is produced by an insect known as cochineal, or *cochinilla del nopal,* a parasite that infests several species of cacti belonging to two closely related genera, *Opuntia* and *Nopalea.* Identified by the scientific name, *Dactylopius,* the genus has been recognized worldwide since the 16th century as the source of a valuable red pigment, whose main component is carminic acid. Native to the Americas, cochineal was known in colonial times as *nocheztli* or *grana* in New Spain, and as *macno* or *magno* in the Andean region of South America.

The chemical composition of cladodes determines their use as a raw material in the food industry. Cactus stems, as other vegetables, have low protein and fat contents (Table 13.1). The crude fiber is higher than in most other vegetables and is an important consideration for human health. The nitrogen-free extract content is high and includes soluble dietary fiber, insoluble dietary fiber, and some sugars. The ash depends on the soil composition, but the main components are calcium and potassium; sodium and phosphorus are present in lesser amounts. Calcium oxalate crystals, which are insoluble in water, increase with age and can constitute 85% of the ash of old cladodes (Pimienta Barrios 1990; Granados and Castañeda 1991; Sáenz et al. 1997). The crude fiber also increases with cladode age (Table 13.1). This is significant, because young nopalitos can be used as a fresh vegetable in salads, whereas old nopalitos, whose high fiber content makes them difficult to chew, are useful for other purposes. Cladodes have high concentrations of phenylalanine, leucine, and vitamins (retinol and ascorbic acid; Zambrano et al. 1998

Processing of Nopalitos

Nopalitos have formed part of the diet of Mexican people since pre-Hispanic times; nowadays, they are also a specialty vegetable in the United States. Production in Mexico is about 600,000 tons fresh weight per year; under intensive management involving close planting in irrigated and fertilized beds that are often covered with plastic, productivity can be 250 tons ha^{-1} $year^{-1}$ (Flores 1997; Nobel 1998). In Mexico, people prefer to buy thin and turgid cladodes with a fresh appearance and a brilliant green color. They are cooked at home as an ingredient in various recipes for stews, dishes and desserts. Outside Mexico, people of Mexican origin can purchase processed nopalitos. Young cladodes are in a rapid growth phase and have high metabolic activity and high transpiration rates (Cantwell 1991). However, once they are harvested as nopalitos, they have moderate respiration rates (25 microliter CO_2 g^{-1} $hour^{-1}$ at 20°C) and a low ethylene production (0.2 nanoliter g^{-1} $hour^{-1}$ at 20°C; Cantwell et al. 1992). Nopalitos are highly perishable after harvest; the deterioration processes lead to wilting, browning, and microbial contamination by *Alternaria* sp., *Penicillium* sp., and other fungi (Ramayo-Ramirez et al. 1978a), especially when they have been despined and diced.

Harvest

Cladodes for nopalitos are harvested by hand, gripping the bottom of a pad and twisting more than 90° until it snaps off the mother plant. The lower tissues can be torn if this action is not carried out with care, so detached cactus stems and the mother plants can easily be infected by microorganisms. For this reason, cutting a pad at its base with a knife is better than simply twisting it off. In any case, harvested nopalitos must be protected from the sun to lessen metabolism, transpiration, and infection (Corrales 1992a). After harvest, intact nopalitos (with spines) are directly taken to local markets; for distant markets, nopalitos are packed in a shady area.

The form in which nopalitos are transported depends on where the sale takes place and on the distance to the market. The following modalities occur: (1) transportation of intact or despined nopalitos over short distances in vans for sale by bulk in local markets; (2) intact or despined nopalitos, packed in baskets called *colotes* containing approximately 200 pads; (3) 500 to 550 intact nopalitos packed in sacks for the large markets of Mexico City; (4) intact or despined nopalitos packed in cardboard boxes or wooden crates of 10 to 15 kg capacity, when the market is in California or in Mexico near the U.S. border; and (5) intact nopalitos packed in a cylindrical packing unit (*paca*), which is the main mode used for the large markets of Mexico City and other cities in central Mexico (Nobel 1998). The latter packing unit is 1.6 to 1.7 m in height and 0.7 to 0.8 m in diameter, containing 2,500 to 3,000 pads (Corrales 1992a). For a paca, nopalitos are placed horizontally on cloth as a layer inside a metal mold; following its

TABLE 13.1
Chemical composition of cladodes (% of dry matter)

Age (years)	Protein (%)	Fat (%)	Crude fiber (%)	Nitrogen-free extract (%)	Ash (%)
1	5.4	1.29	12.0	63	18.2
2	4.2	1.40	14.5	67	13.2
3	3.7	1.33	17.0	64	14.2
4	2.5	1.67	17.5	64	14.4

Reference: López et al. (1977), cited by Pimienta (1990).

circular form, another nopalito layer is placed upon the first one, and so forth (Corrales-García 1997). Pacas have proved practical, especially when periods of commercialization are short (1–3 days). If the period is longer, considerable heat is generated in the center of the packing units by respiration of the nopalitos (Cantwell 1991), reducing the quality of product.

Storage

Refrigeration atmospheres with reduced O_2 and/or elevated CO_2 concentrations extend the storage life of many fruits and vegetables by reducing respiration rates. However, postharvest deterioration can result from many factors besides high respiration rates, including the biochemical changes associated with respiratory metabolism, ethylene production and action, compositional changes, physiological disorders, and pathological breakdown (Kader 1986). Furthermore, under certain conditions, atmospheric changes shift cladodes from aerobic to anaerobic respiration, leading to fermentation and the accumulation of ethanol and acetaldehyde (Chang et al. 1982) and causing unpleasant flavors and odors.

Storing at low temperatures extends the shelf life of nopalitos and maintains their vitamin content. This is especially true under modified atmospheres, which also implies low O_2 availability for oxidation and browning, low degradation of vitamins, and, in general, low enzymatic activity. Other factors, such as harvest technique, storage duration and relative humidity, and packing technique also affect the shelf life of nopalitos (Cantwell 1995). Ramayo et al. (1978b) found that 21% of pads packed in wooden crates and stored at 10°C (at 80–85% relative humidity) showed decay at the cut surface at 10 days; however, if carefully harvested, the shelf life can be extended to 21 days without decay development under the same storage conditions.

Nopalitos are susceptible to chilling injury when exposed to nonfreezing temperatures below 10°C. This physiological disturbance is typical of some tropical and subtropical fruits and vegetables (Saltveit and Morris 1990; Wang 1990) as well as nopalitos (Ramayo-Ramírez et al. 1978a; Cantwell 1991) and leads to surface discoloration and softening, which, in turn, usually promotes microbial infections. The susceptibility to chilling injury and its consequences vary with species and stem age, the harvest method, and the method of packing as well as with the atmosphere, temperature, relative humidity, and duration of cold storage. Nopalitos of *Opuntia* spp. packed in vented polyethylene bags (leading to a modified atmosphere inside the bag) may show signs of chilling injury at 21 days of storage at 5°C, whereas cactus stems packed in wooden crates and also stored at 5°C show chilling injury at 15 days (Rodríguez-Félix and Villegas-Ochoa 1998). Stems of *Nopalea cochenillifera* are more susceptible to chilling injury during storage at 4°C than are those of *Opuntia* spp. Outside of bags, they develop symptoms of chilling injury at 7 days, but if stored in plastic bags, an additional 4 days of storage is gained before symptoms appear (Nerd et al. 1997).

Minimally Processed Nopalitos

In general, "minimally processed" horticultural products are prepared and handled to maintain their freshness while providing convenience to the consumer. Producing minimally processed products involves cleaning, washing, trimming, coring, slicing, and shredding (Brecht 1995; Schlimme 1995). Other terms used to refer to minimally processed products are "lightly processed," "partially processed," "fresh-processed," and "preprepared" (Cantwell 1992). According to Avena (1996), minimum processing includes the operations generally used for canned, frozen, or dehydrated food products, but without scalding for inactivation of enzymes. Most of these products are sold as ready-to-eat foods, which is a major advantage. "Pre-cut," "minimally processed," or "fresh-cut" can describe a special modality for postharvest handling of fresh nopalitos.

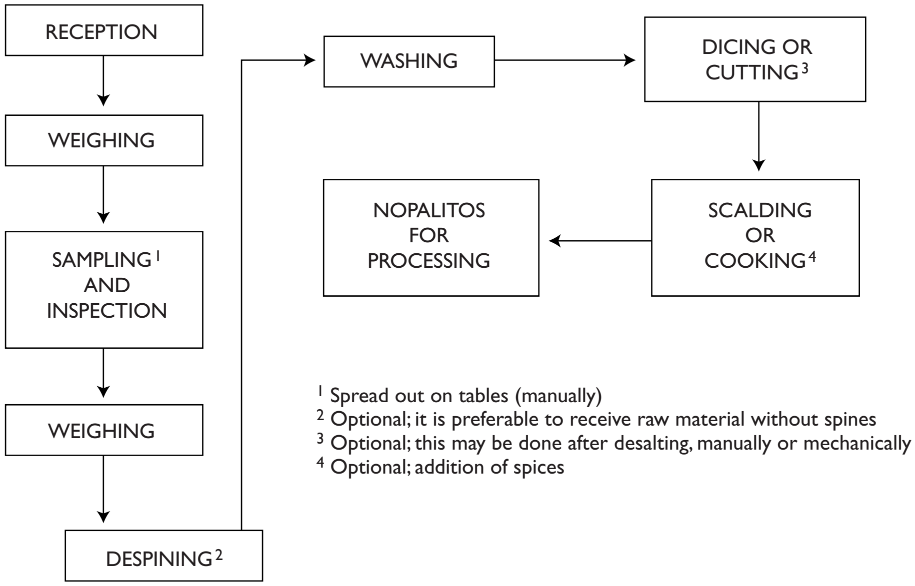


Figure 13.1. Flow diagram for conditioning raw nopalitos for later processes. Adapted from Corrales-García (1998).

Cleaning and despining of nopalitos—the latter an obligatory postharvest practice for nopalitos—is usually done at the destination market just before the retail sale. This practice is generally carried out using a knife by people with highly developed skill. Nowadays, diced pads, whose spines have been removed, are packed in plastic bags and sold in Mexico and the southwestern United States.

Nopalitos whose spines have been cut off have higher metabolic activity and transpiration rates than do intact nopalitos. Also, mucilage leaking, wilting, and oxidation occur quickly, and their shelf life is short. For these reasons, despined and diced nopalitos are more perishable than is the intact product. In general, the main problems that limit shelf life of minimally processed nopalitos are brown discoloration at the cut surfaces (caused by polyphenol oxidases), mucilage leakage (undesirable mucilage accumulation inside the bag, which increases with dicing), unpleasant flavor caused by accumulation of anaerobic metabolites, and a surface yellowing, which leads to a color change from brilliant green to brownish green and gives them a cooked appearance. Vacuum packing of diced pads does not increase the shelf life at refrigerated storage temperatures (Rodríguez-Félix and Soto-Váldez 1992). Also, the type of packaging, the storage temperature, and the local atmosphere affect storage of minimally processed nopalitos. For instance, 4°C is better than 10°C for storage up to 15 days, and polypropylene (25 µm thick) is better than polyethylene (35 µm thick).

Industrial Techniques

Many alternatives for processing cladodes, nopalitos, and tuna fruits have been described (Colin 1976; Corrales 1992b; Sáenz 1995). Industrially processed nopalitos can last longer than fresh ones, allowing sales in distant markets. Also, the supply can be extended to other months, and prices and quality can be controlled. The variety of products obtained by industrialization adds value to the product and makes diversification of markets possible. Industrialization also generates rural employment, which contributes income that benefits the producer communities (Corrales 1992b). Today in Mexico some companies process nopalitos mainly for export, because domestic consumers prefer to buy fresh nopalitos and then cook them at home.

The first steps in industrial processing of nopalitos are reception and conditioning of the raw material, which should be of the highest quality and be despined by the grower (Fig. 13.1). Conditioning consists of scalding and washing. Scalding deactivates enzymes, destroys microorganisms, softens the tissues, and partially eliminates the mucilage. The main variables are temperature and duration of scalding, as well as additives that improve the product. Nopalitos of the wild nopal 'Tapón' (*Opuntia robusta*) lend themselves to higher temperature and longer cooking time than do cultivated nopalitos, such as the variety 'Milpa Alta' (*Opuntia ficus-indica*). The final product is washed with cold clean water, which fixes the characteristic green

Figure 13.2. Various brands and preparations of processed nopalitos available in Mexico as collected by the Programa Nopal (Cactus Pear Program) of Centro de Investigaciones Económicas, Sociales y Tecnológicas de la Agroindustria y la Agricultura Mundial (CIESTAAM), Universidad Autónoma Chapingo, México.

color of nopalitos and eliminates adhering pectins and mucilage (Corrales-García 1998). The resulting nopalitos can be used for various products, e.g., nopalitos in brine, pickled nopalitos, and marmalades.

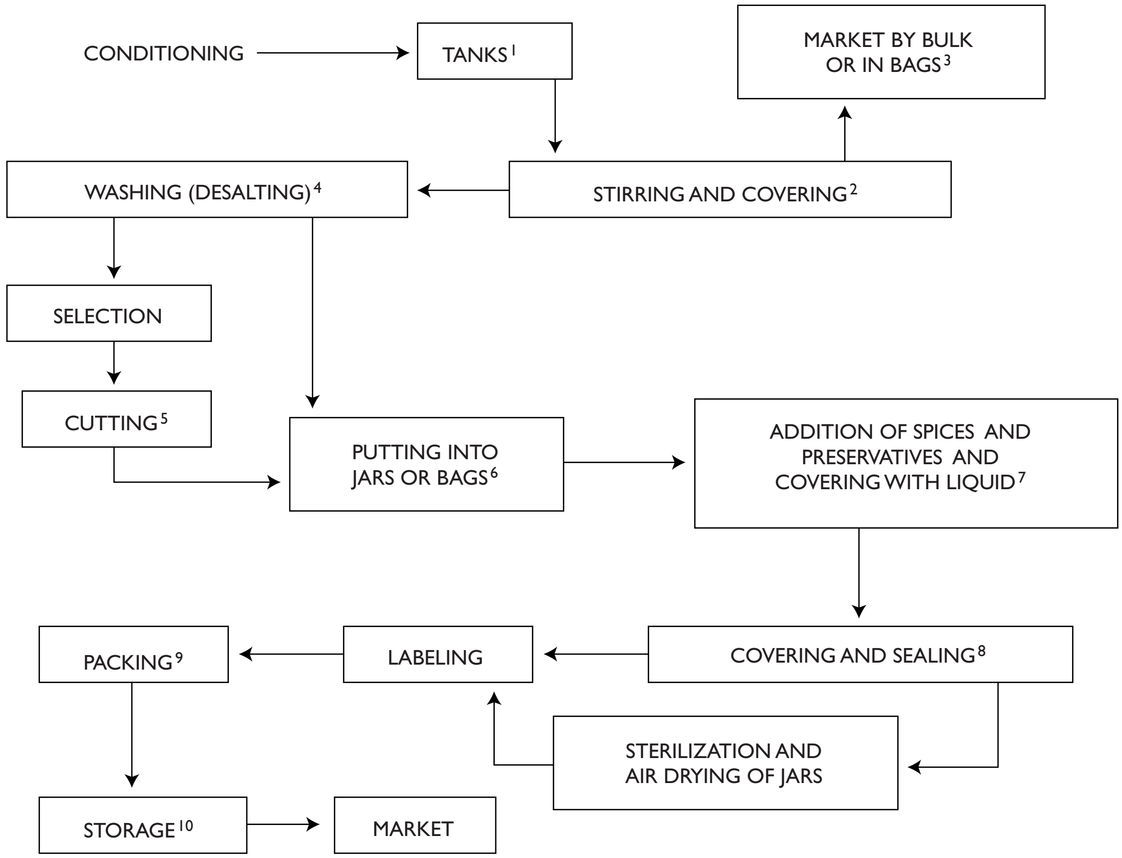
Nopalitos as Products

In Brine

Nopalitos can be preserved in a saline solution (maximum 2% NaCl) and then canned, placed in plastic bags, or packed in glass or plastic jars to be used later to prepare various Mexican foods. More than 20 brands are currently available in Mexico (Fig. 13.2), many with their own preparation process. The conditioned nopalitos (Fig. 13.1) are commonly salted in large tanks containing 12% NaCl brine, using approximately 1.7 liters of brine for each kilogram of nopalitos (Fig 13.3). Nopalitos must remain in these tanks for at least 10 days and can be kept there for months. The high concentration of salt extracts water from the nopalitos, so salt must be added to maintain the brine. The tanks should be stirred daily with a wooden paddle. Also, the tanks should be covered to avoid contamination and discoloration of the product by light.

When salting is finished, the product is taken to the process room, where it is desalted by washings (Fig. 13.3). Later, it is sorted, diced, and canned, or put into plastic bags or jars with a few spices and covered with 2% brine. The bags are sealed; the cans or jars are evacuated, covered, and sterilized in an autoclave or water-bath, then left to air dry before labeling. Bags, cans, or jars are packed in cardboard boxes and stored for the quarantine period; eventually they are shipped to the market. The product can also be sold in bulk without desalting (Fig. 13.3).

Compared with intact nopalitos (with spines), the final yield of nopalitos in brine ready for sale is about 57%, depending on the process and its control. The following procedures can improve success: (1) implement a well-defined program and rigorous quality control beginning with the reception of the raw material—e.g., remove pads that are bruised or flawed; (2) implement a quarantine program that maintains the product's quality for as long as possible; (3) avoid direct contact of the brine with a reactive metal (such



[1] 12% brine
[2] Daily stirring with wooden paddle
[3] In wooden or plastic containers
[4] During approximately 6 hours, until reaching 1-2% salt
[5] Optional: manual or mechanical
[6] In plastic bags or glass or plastic jars
[7] 2% brine
[8] Brine must cover nopalitos completely (to avoid air reaching the pads)
[9] In cardboard boxes
[10] Quarantine

Figure 13.3. Flow diagram for processing nopalitos in brine. Adapted from Corrales-García (1998).

as unpainted iron); (4) maintain the brine at a minimum NaCl concentration of 10% that is verified constantly with a special salt meter, and stir daily to help ensure uniform salinity; (5) completely cover the nopalitos with brine (weigh them down with a plastic or wooden screen); and (6) because light and extraneous material (e.g., dust, dirt, litter, water, insects) are detrimental, cover the tanks.

Pickled

Pickled nopalitos consist of scalded nopalitos preserved in vinegar (maximum 2% of acetic acid) with spices and vegetable seasonings (García 1993). More than 25 companies in Mexico currently pickle nopalitos, and many have their own preparation processes (Fig. 13.2). The conditioned nopalitos (Fig. 13.1) are cut or diced (manually or mechanically; Fig. 13.4). Pickling is done with vinegar (1.9–2.0% acetic acid), spices, aromatic herbs, and olive oil. The vinegar is heated to boiling, and then the spices are added, either directly or in a cloth bag. The mixture is boiled for 5 minutes to allow the vinegar to absorb the aromas. Separately, onion slices, garlic cloves, laurel leaves, and carrot discs are lightly fried in vegetable oil. Then the nopalitos, vinegar, and sautéed vegetables are mixed. This mixture is canned, or put into plastic bags or jars. The bags are sealed, and the cans and jars are evacuated and covered; they are then sterilized in an autoclave or in a water-bath.

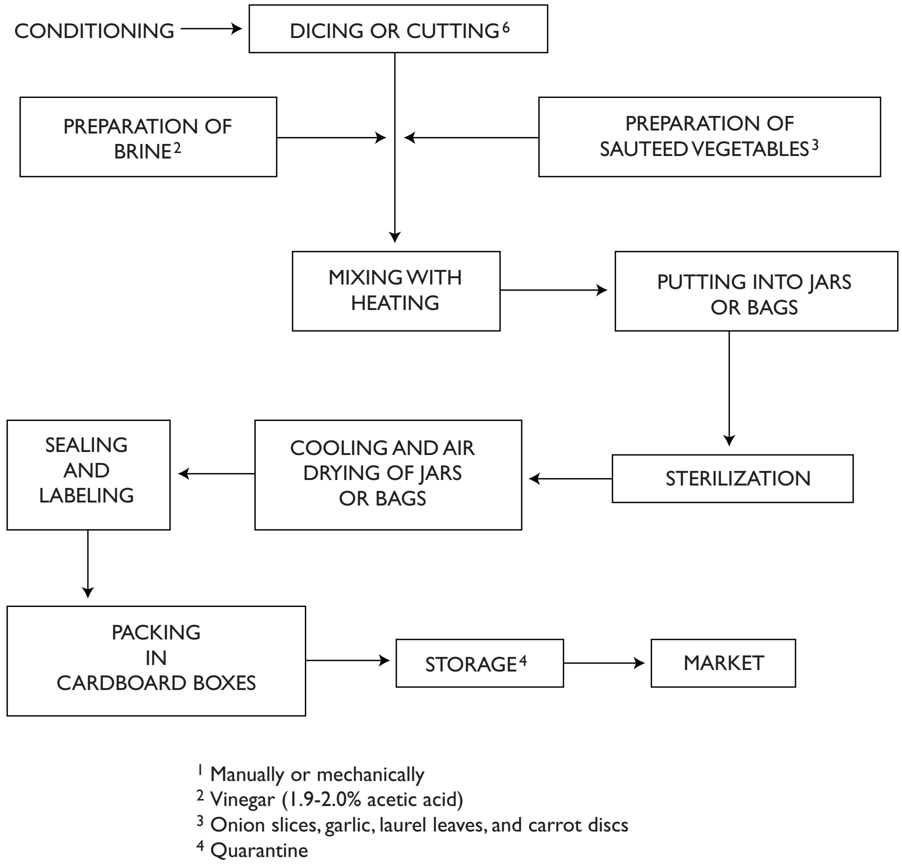


Figure 13.4. Flow diagram of production process for pickled nopalitos. Adapted from Corrales-García (1998).

Finally, they are left to air dry before labeling. Bags, cans, or jars are packed in cardboard boxes, stored for the quarantine period, and then shipped to the market.

Sauces, Marmalades, Jams, Candies, and Juices

Nopalito sauces are prepared using milled nopalitos, with addition of various chilis, tomato, onions, vinegar, and spices (in different proportions), and, often, a preservative. More than 15 brands of nopalito sauce occur, some with white wine or lemon concentrate. The sauces can have whole pieces of nopalito or be totally milled, depending on the market preference. In Mexico, nopalito sauces are generally prepared daily using fresh ingredients, rather than as canned sauces for the market. In addition to sauces, recently in Mexico nopalitos are incorporated into sausages using soybean flour, and nopalitos are prepared with tuna fish, beans, jalapeño chilis, and mushrooms. These products are prepared by large, established companies, following principles of modern food technology.

Another product from nopalitos is marmalade. This product is prepared using milled nopalitos cooked with various concentrations of sugar, pectin, and preservatives. The conditioned (scalded) nopalitos (Fig. 13.1) are chopped (manually or mechanically) and cooked for a second time. Tirado (1986) made a jam with cladodes, adding orange juice, peel, and sugar in the ratio of 1:1.5:0.8:0.8. The jam had no microbial growth after 40 days of storage. This product is similar to other jams in the Mexican market (e.g., fig and orange) with respect to aroma, color, taste, texture, and appearance.

Badillo (1987) made a jam using cladodes, sugar, and citric acid, obtaining a product with good sensory quality and microbiological stability. Sáenz et al. (1995a) made a marmalade from cladodes after treating with 2% $Ca(OH)_2$ to lower the mucilage content (which causes texture and acceptability problems). Lemon juice and lemon peel were included; the first lowered the pH and the second, together with pectin, aided the gelling of the product (67°Brix, 0.97% acidity, and good acceptability). About six companies in Mexico and the United States presently manufacture marmalades. Mucilage obtained by milling and filtrating nopalitos can lead to better consistency in marmalades of other fruits (e.g., blueberry, raspberry, blackberry, strawberry, peach, apple, pear, pineapple, and plum), and therefore has potential to expand the world market for nopalito products.

Candies made with nopalitos are processed with sugar and often various other ingredients. The main confectionary products include crystallized nopalitos, nopalitos in syrup, nopalito candies covered with chocolate, marshmallows with nopalito mucilage (*gomitas*), candies of nuts cooked with honey and platyopuntia mucilage. Villareal (1996) studied the manufacture of crystallized cladodes, which are similar to crystallized melon peel. Sucrose or sugar-cane syrup can be used, and the candies are especially enjoyed by children. The cladodes are cut into pieces that are 1.8 × 4.0 cm, treated with $Ca(OH)_2$ (to remove the mucilage), washed, osmotically dehydrated with a high concentration sucrose solution, and further dehydrated in a forced-draft oven at 60°C. The final product has an intermediate moisture content and can be covered with sweet or bitter chocolate to be more attractive to consumers.

Rodríguez (1999) developed a nopal juice using young pads by scalding, milling, and filtering, then adding citric acid and aspartate. The juice was put in bottles, pasteurized, and vacuum sealed. The product has a pleasant sweet taste, brilliant green color, only 10 calories per bottle, and 10% nopal pulp. A mixed juice of nopal and guava is being marketed nationally and internationally by a Mexican company. Despined and diced nopalitos are milled in a blender with water, the thick juice is filtered to separate solids, the filtered juice is mixed with guava juice, and finally the mixture is pasteurized and bottled. The world market for fruit and vegetable juices has expanded, so nopal juices, mainly in mixtures with other fruits, offer great possibilities for development.

Mucilage

The complex polysaccharide mucilage is an important component of platyopuntias. Mucilage has great potential as part of dietary fiber and also imbibes large amounts of water, forming viscous or gelatinous colloids (Amin et al. 1970; McGarvie and Parolis 1979a,b, 1981; Paulsen and Lund 1979; Trachtenberg and Mayer 1981; Sáenz et al. 1992). Mucilage is composed of varying proportions of L-arabinose, D-galactose, L-rhamnose, D-xylose, and galacturonic acid, the latter representing 18 to 25% of the residues, depending on whether the mucilage comes from fruit or cladodes (Sáenz 1995). The primary molecular structure is a linear chain containing galacturonic acid, rhamnose and galactose, to which xylose and arabinose residues are attached in peripheral positions.

Mucilage can be used as a thickening agent in foods and pharmaceutical products. Sáenz et al. (1992) showed that increasing the pH from 2.6 to 6.6 increased the viscosity of water dispersions of mucilage from 37 to 58 centipoise (37–58 mPa s). Cárdenas and Goicoolea (1997) and Cárdenas et al. (1997) studied the rheological properties of mucilage of different concentrations (0.4 to 6%) with NaCl (0.1 M) and report that the non-Newtonian shearing behavior is similar to that of okra mucilage solutions. In particular, with increasing mucilage concentration a strong tendency occurs for aggregation. Nobel et al. (1992) report that the mucilage content of cacti varies with species and is influenced by irrigation and temperature. For instance, for four sympatric cacti from the Sonoran Desert, mucilage is absent from *Ferocactus acanthodes,* is 19% of the dry weight for *Opuntia basilaris,* 26% for *O. acanthocarpa,* and 35% for *Echinocereus engelmannii;* L-arabinose varied from 17 to 51% of the sugar monomers. For *Opuntia ficus-indica* mucilage in the cladodes increases 24% as the day/night air temperatures during growth are reduced from 30/20°C to 10/0°C (Goldstein and Nobel 1991). For the widely occurring, cold-hardy *Opuntia humifusa,* mucilage in the stems approximately doubles when plants growing at day/night air temperatures of 25/15°C are transferred to 5/–5°C for 7 weeks (Loik and Nobel 1991).

With regard to special applications, farmers in Chile and some other countries use cactus mucilage to clarify drinking water. As for other water-soluble polymers, mucilage flocculates sediment particles and precipitates them out of solution (B. Crabb, personal communication). Another traditional use by the farmers in Chile is to take advantage of the adhesive properties of mucilage to improve external paint; chopped cladodes are blended with lime (mostly $Ca[OH]_2$) and applied to the external walls of houses. Cladode mucilage has also been used for a long time as a glue in combination with lime plaster in Mexico. Mucilage helps the lime to set more quickly and improves the water repellency. This plaster is traditionally used over both earthen (adobe) and brick walls and also as a breathing water-barrier in stucco. Gardiner et al. (1999) found that a cladode extract improves water infiltration in soils, similar to the effects of polyacrylamides. Cactus mucilage also has culinary uses, such as a fat replacer and a flavor binder (J. McCarthy, cited in Cárdenas et al. 1997).

Dietary Fiber from Cladodes

The market in developed countries is increasing for healthful foods with low calories, low cholesterol, low fat, and a high fiber content. Studies showing the relation among fiber consumption and control of cholesterol as well as the prevention or treatment of some illnesses, such as diabetes, obesity, gastrointestinal disorders associated with a lack of dietary fiber intake, and even colon cancer (Sloan 1994; Grijspaardt-Vink 1996; Hollingsworth 1996), have helped to promote this market. Dietary fiber is composed of several chemical components that are resistant to digestive enzymes, e.g., cellulose, hemicellulose, pectin, lignin, and gums (Spiller 1992; Periago et al. 1993). The fiber content of a food varies with the plant species and the stage of maturity, but seeds, berries, fruit skins, and the bran layers of cereal grains generally contain a large amount of fiber. Based on water solubility, soluble dietary fiber is contributed by mucilage, gums, pectin, and some hemicelluloses, and insoluble dietary fiber by cellulose, lignin, and most hemicelluloses (Periago et al. 1993). Nopal cladodes (i.e., nopalitos) are a good source of dietary fiber.

Sepulveda et al. (1995) obtained a natural concentrate of nopal fiber ("nopal flour") using 2- to 3-year-old cladodes obtained from pruning. Sáenz et al. (1997) and Sáenz (1998) studied the dietary fiber content and some physical and chemical characteristics of this concentrate, as well as the effect of concentration (2.5, 5.0, and 7.0%), temperature, and pH on the viscosity. Viscosity of nopal flour suspensions is an important parameter when the nopal flour is mixed with other food ingredients; the pH also affects such suitability (Lecaros 1997). Nopal flour consists of 43% total dietary fiber, of which 28% is insoluble and 15% is soluble. Rosado and Díaz (1995) reported a dietary fiber content in dehydrated nopal of 50%, indicating that the type of *Opuntia,* the climatic conditions, irrigation, and/or the age of the cladodes can influence the dietary fiber. The water-holding capacity in the former case is 5.6 g per g dry mass, and in the latter case is 11.1 g g^{-1} dry mass for cladodes and 7.1 g g^{-1} for a nopal isolate. The water content indicates the physiological status of the fiber, as water absorption increases the bolus and produces a satiation effect. The water absorption ability depends mainly on particle size and can be modified by controlling the milling process: the smaller the size of the particles, the greater the water retention, as for wheat bran flour.

Nopal flour is being tested for various foods, such as vegetable soup and a gelled dessert (Albornoz 1998; Vallejos 1999). The percentage of added flour is limited: greater than 20% affects the texture of the product. Sáenz et al. (1995b) and Fontanot (1999) tested different replacement proportions of wheat flour by nopal flour in biscuits; more than 15% replacement affects the texture and sensory characteristics of the biscuits but increases the dietary fiber content. Recently, a dehydrated pelletlike product made from dehydrated cladodes has appeared in the Mexican market. This product, which is a blend of wheat fiber, nopal fiber, salt, and the sweetener aspartame, is similar to a common breakfast cereal and is recommended to help control obesity.

Use of Cladodes in Medicine

According to popular medicine, mainly in Mexico, many diseases can be fought and cured with the cladodes, fruit, or other parts of cacti, such as the flowers (Hegwood 1990; Pimienta Barrios 1990; Barbera 1991; Mulas 1993). Nevertheless, only a few applications have a strong scientific basis, such as their effect on diabetes mellitus, blood glucose levels, hyperlipidemy (excess of lipids in the blood), and obesity (Gulías and Robles 1989).

Frati-Munari et al. (1990) studied the hypoglycemic effect of cladodes of *Opuntia ficus-indica,* concluding that glycemia decreased in all patients tested following ingestion and reached statistically significant lower levels after 3 hours; Ibañez-Camacho et al. (1983) confirmed this hypoglycemic action. Ramírez and Aguilar (1995) in a meta-analysis conclude that *Opuntia* has a strong glucose reduction effect. Trejo et al. (1995) evaluated the hypoglycemic activity of a purified extract from platyopuntias on STZ-induced diabetic rats; although the mechanism of action is unknown, the magnitude of the glucose control by the small amount of *Opuntia* extract required (1 mg per kg body weight per day) precludes a predominant role for dietary fiber. Hernández et al. (1997, 1998) used Wistar rats to compare the effect on weight loss of the consumption of nopal fiber and other vegetable fibers, such as cellulose and corn peel fiber. The nopal fiber produces more feces than the other fibers, although all rats lost weight during the study.

Frati-Munari et al. (1992) evaluated the role of commercial capsules (Fig. 13.5) containing dried and ground cladodes in the management of diabetes mellitus. Thirty capsules, each containing 335 mg of dried cladodes, were given to diabetic subjects, and serum glucose was measured throughout 3 hours; the control was performed with 30 placebo capsules. The dried cladodes did not show a hypoglycemic effect and did not influence the glucose tolerance test. In diabetic patients, serum glucose, cholesterol, and triglycerides levels did not change with ingestion of *Opuntia* cladodes. In healthy individuals, glycemia did not change with cladode ingestion, whereas cholesterol and triacylglycerides decreased. Fernández et al. (1990) found effects of platyopuntia cladodes on low-density lipoproteins, suggesting that an extract may decrease cholesterol levels.

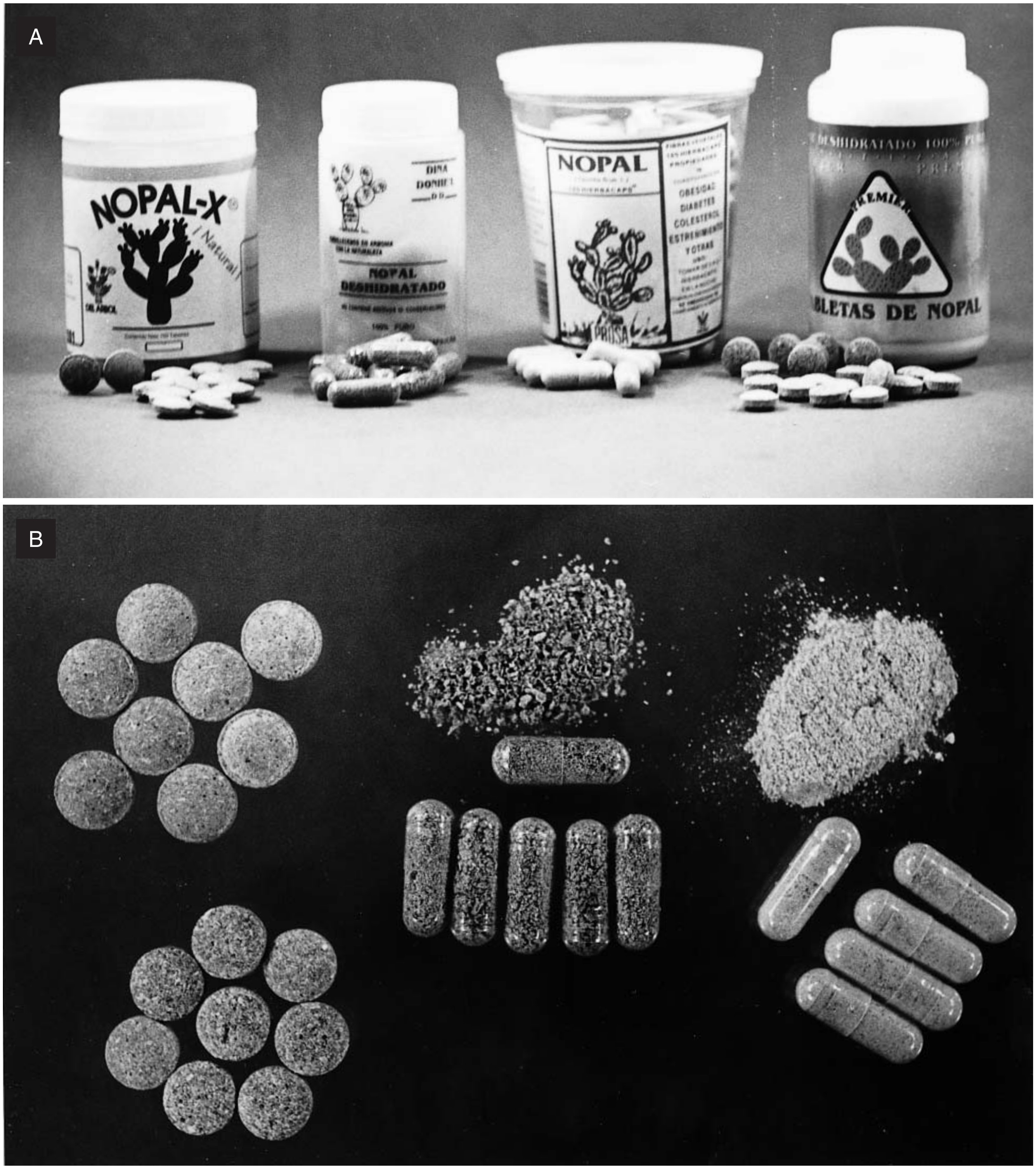


Figure 13.5. Capsules and tablets prepared from dried *Opuntia* cladodes in Mexico: (A) packaging and (B) contents.

Figure 13.6. Various brands and preparations of *Opuntia* cladode extracts used cosmetically in Mexico, as collected by CIESTAAM (see Fig. 13.2.).

More than 30 brands of powders, capsules, and tablets made of dried platyopuntia cladodes are produced in Mexico as nutritious complements (Fig. 13.5). Powder is prepared from cladodes (1.5–2.5 years old) that are washed (chlorinated water), despined, cut, and then dehydrated (at 35–40°C), preferably with forced air. They are then milled and screened, until a fine powder is obtained. This powder is sold in bulk or encapsulated, or it is added with an agglutinant and then compressed to obtain tablets (Frati-Munari et al. 1992; Sepúlveda et al. 1995). Such products are marketed by promoting their alleged medicinal effects, and consumers consume them as medications. Indeed, cladode-derived products are sold for the control of diabetes, cholesterol, gastric and intestinal afflictions, and obesity. This utilization is due to three main factors: (1) the existence of customs, traditions, and pre-Hispanic knowledge of medicine and the traditional herbalists of Mesoamerica (cladodes can cure renal illnesses and erysipelas, induce childbirth, alleviate pain, and heal wounds); (2) various medical studies indicating that the consumption (ingestion) of raw, boiled, roasted, or stewed cladodes decreases glucose and cholesterol in blood in healthy and certain diabetic people, but not in insulin-dependent animals or humans (Ibañez-Camacho and Roman 1979; Ibañez et al. 1983; Fernández et al. 1990; Meckes and Roman-Ramos 1986; Frati-Munari et al. 1989; Trejo et al. 1991); and (3) a modern trend toward "natural" product consumption.

The production of cladode products as over-the-counter medicinal products is growing fast. Frequently, these products have scientifically unfounded claims as to their healing properties. Currently, 21 companies in Mexico produce capsules, 15 produce tablets, and five produce powders (Fig. 13.5). Some of these companies export their products to the United States as nutritious complements. The hypoglycemic effects that many of these products purport to have is unproved (Frati-Munari et al. 1992). At least 30 capsules may need to be consumed per day, which is not comfortable for the patients.

Cosmetics (Fig. 13.6) incorporating cladodes are used for hygienic purposes to beautify the skin and the hair, in accordance with the herbalists of Mesoamerica and popular as well as traditional knowledge. In Mexico more than 20 companies manufacture more than 40 different cosmetic products with platyopuntias, adding portions of juice of the cladodes in their formulations. These products, being of "natural" origin, are increasingly accepted in

Mexico and the United States. However, the cosmetics industry does not require large quantities of cladodes, because they are only a small ingredient in the formulations of these products. The principal cosmetic products (Fig. 13.6) are: (1) shampoos, conditioners, and gels for the hair; (2) soaps; (3) creams as well as facial masks to reconstitute, moisten, clean, or strengthen the skin; and (4) astringent or absorbent lotions (to reduce epidermal fat).

Cochineal

Two types of cochineal, the dye-producing cactus parasite, are recognized. They are classified according to the quality and concentration of their pigments, as well as their biological and morphological characteristics: (1) fine cochineal (*Dactylopius coccus* Costa), and (2) wild cottony cochineal, comprising a group of eight species. Though a noxious pest in nopal fruit orchards, wild cochineal is beneficial as a biological control of weedy nopal infestations throughout the world. Both *D. coccus* and cottony cochineal are easily propagated in various microclimates of North and South America. Although Mexico's central, southern, and southeastern highlands harbor a great diversity of both *Opuntia* and *Dactylopius* and the Mesoamerican region has the oldest records of systematic exploitation of cochineal, Mexico is presently not a major commercial producer of cochineal. The Andean region of South America, noteworthy for having the oldest evidence of cochineal use, currently accounts for 95% of world production. Use of the dye has spread to all nations except several Middle Eastern and Asian countries. Cochineal depends on platyopuntias for its propagation and survival, making its role as host one of the most important uses of *Opuntia.* Therefore, until technological development obviates the need of a host in the cultivation of cochineal, platyopuntias will be a determining factor in the production of the dye insect.

Pre-Colonial and Colonial History

Archaeological evidence for the use of cochineal exists in prehistoric textiles recovered from the Nazca (Classic) and Chimu (Postclassic) cultures of Peru. Saltzman (1992) reports incipient use of *Dactylopius* around the time of Christ and increased utilization in woolen textiles from the late Classic period (7th century). By the 10th century, cochineal was in common use. The first historical reports of cochineal from Peru date from 1533 (Donkin 1977). Evidence of pre-Hispanic cochineal use in Mexico is surprisingly scarce; only a few fragments of pre-Conquest cochineal-dyed fabrics have been found (Donkin 1977). Nevertheless, cochineal was a tribute item in Aztec and Inca empires, in the form of richly colored woolen and cotton mantles (Donkin 1977) and in dye taxed by the Aztec governors. Two basic forms were used: (1) dried cochineal, and (2) cakes or tablets (*panes, pastillas*), known as *nochezt-laxcalli* in Nahuatl, produced by the Indians from the dried, milled insect, leaves of the *tezhoatl* tree, and alum (Dahlgren 1963; Donkin 1977). In contrast to wool, cotton is difficult to dye with cochineal alone. To make the color bind and become permanent, a mordant is required, and alum was used for this in both Mexico and South America. De Sahagún (1829) reported that alum (*tlaxocotl*) was well known in Mexico; other additives were also used as reinforcing agents with cochineal or to vary the shades of red (Donkin 1977).

Cochineal was also used as a paint for articles ranging from houses (Zoque Indians in Chiapas) to the famous Mixtec codices. It was employed by Indian women as a cosmetic, and possibly had pharmaceutical and culinary uses (Dahlgren 1963; Brana 1964; Donkin 1977). Cochineal and silk production flourished in New Spain during the 16th century, although competition occurred between the two insect cultures, particularly in the Mixteca Alta region of Oaxaca. Main producing areas continued to be Oaxaca and Puebla, and at the urging of governor Gómez de Cervantes, Tlaxcala became an important producer. Before 1600, proposals for a royal monopoly of cochineal production in New Spain were circulating. Production in Tlaxcala and Puebla, however, dropped in the mid-17th century. After 1650, Oaxaca was described as the main supplier, and, by the end of the 18th century, Oaxaca was the only significant producer of fine cochineal (Donkin 1977).

Decline and Resurgence

In the 1860s, the introduction of aniline dyes, stronger and faster binding than cochineal, apparently sounded the death knell for the insect dye. France, in 1860, and soon thereafter, the United States, authorized the use of synthetic colorants in foods. In the early 1880s, mineral colorants, including lead-based pigments, began to be used in foods and cosmetics. However, toward the end of the 19th century, medical problems arising from dye use began to be detected. For this reason, in the late 1890s and early 1900s, several European countries, including Italy, Germany, France, and Belgium, as well as Australia and the United States, promulgated regulations for the control and use of certain colorants in food. During 1950 to 1980, various synthetic colorants were decertified. As a result of these prohibitions, interest in natural colorants was renewed. The natural red dyes belonging to three pigment groups (carminic acid, anthocyanin, and betalains) were allowed to bypass the certification process by the United States Federal Drug Administration Agency (von Elbe 1977).

In 1974 possible toxicological effects of cochineal carmine were reported. In response, the Joint FAO/WHO Expert Committee on Food Additives demanded testing of the colorant for toxicity, and urged lower levels in food products. In 1976, the use of carmine was only permitted in alcoholic beverages and only for a limited time, thus precipitating a price drop for cochineal and carmine. At the request of Peru, the principal producer country, and of the FAO/WHO, the British Industrial Biological Research Association (BIBRA) undertook a series of investigations to determine effects of carmine in food and cosmetics. Several studies were undertaken in 1980 through 1982, including tests of teratogenicity and embryotoxicity as well as effects on multigenerational reproduction in rats (Ford et al. 1987; Grant and Gaunt 1987; Grant et al. 1987). On the basis of these results, in 1982 the FAO/WHO renewed authorization of carmine and its derivatives. Certain imprecision in the BIBRA studies, as well as cases of reactions to carmine in persons with allergies, have led to more recent studies with contradictory results: adverse effects were reported by Quirce et al. (1994), whereas innocuousness was indicated by Kawasaki et al. (1994) and many others. The pros and cons of carmine use have had a significant impact on the prices of this pigment in the world market.

Importance and Uses

The main coloring element of cochineal is carminic acid (Fig. 13.7); secondary elements include kermesic and flavokermesic acid (Wouters 1990) and minor pigments (Sugimoto et al. 1998). Carminic acid is used today in the industrial production of cosmetics, food, and medicines, as well as in textile and other dyeing, although azo synthetic dyes have, to a great extent, replaced the natural dyes in the latter two categories. Tütem et al. (1996) have also reported possible therapeutic uses. Moreover, cochineal, in powdered form, is utilized in food products and especially in the dyeing of textiles in countries such as Iran and Iraq and, in Mexico, among the Zapotec Indians (Ross 1986). Color and hue in textiles depend upon the mineral salts or reagents with which the powder is mixed (Avila and Remond 1986).

As an aqueous or alcohol extract, cochineal is an important colorant in food and beverages; as carmine, it is of importance in cosmetology, medicine, and food products. Carmine is marketed in a number of commercial presentations, including carminic acid at 90% (used as a colorant in processed food products and soft drinks) and lakes (purplish red pigments) composed of carminic acid at concentrations of 40 to 65% combined with a variety of inorganic carriers, of which aluminum and calcium are the most common. Carmine 50 is the most sought-after commercially, e.g., as an additive to acidic beverages.

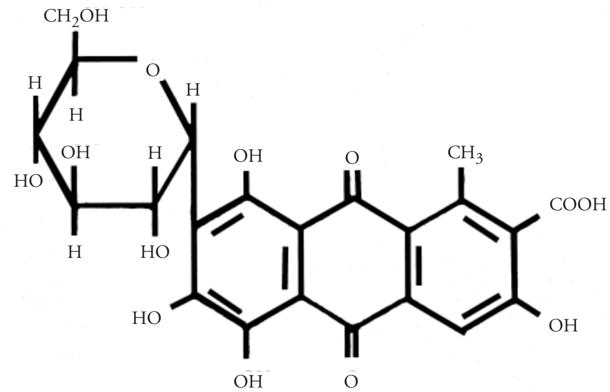


Figure 13.7. Structure of carminic acid.

Carminic Acid

The physical and chemical properties of carminic acid were studied by Lieberman and his associates in 1909 and by Dimroth and colleagues from 1909 to 1920. The molecular structure of carmine was first proposed by Miyagawa and Justin-Mueller in 1920s, with further evidence provided by Fieser and Fieser in 1944 and by Hay and Haynes in 1956 and 1958 (Ali and Haynes 1959). Carminic acid is a hydroxyanthraquinone linked to a glycosyl group (Fig. 13.7). Lac dye and kermesic acid (Old-World insect-derived red dyes) have the same basic chemical structure but without the glycosyl linkage. Glycosyls apparently enhance the intensity of the anthraquinone group in the visible part of the spectrum. The chemical formula of carminic acid is 7β-D-glucopyranosyl-9,10-dihydro-3,5,6,8-tetrahydroxy-1-methyl-9,10- dioxo-2 anthracene carboxylic acid (Fiecchi et al. 1981). The colorant is listed in the *Chemical Index* as Natural red 75470. Carmine is an aluminum chelate of this molecule at a rate of 1:2 aluminum:carminic acid. The great resistance of carminic acid to hydrolysis is due to the glucosyl group. According to Hay and Haynes (1956, 1958; cited in Ali and Haynes 1959), the glucosyl can be D-arabinose, which lends it a pink color, or glucose, which provides a yellow color. There are many commercial products on the market, so chemical and physical properties are asssigned by the firms. Carminic acid precipitates from alkaline solutions as prism-shaped crystals, obliquely truncated and red; they turn reddish-orange in the presence of light. The *Merck Index* describes their characteristics as:

(1) no distinct melting point; (2) darken at 120°C; and (3) deep red color in water and yellow to violet in acid solutions.

For the fabrication of carmine and its derivatives, Avila and Remond (1986) review 12 of the many extraction and purification techniques commonly employed. All techniques follow the principles established by De la Rue, Lieberman, Dimroth, and others. In particular, the processing steps are: (1) separation of fats; (2) extraction of the coloring agent by steeping in a solvent; (3) salt precipitation, which also varies according to the technique employed; and (4) separation, washing, concentration, and drying of the final product. ITINTEC (1990) published a detailed methodology to obtain a carmine extract with a carminic acid content of 62 to 64%: (1) cleaning of insect using a screen; (2) separation of fats with hexane; (3) milling; (4) water extraction (100°C for 10 minutes) adding sodium carbonate until the pH is 9.0; (5) screening and filtering; (6) precipitation (aluminum and calcium salts, 100°C for 15 minutes); (7) pH modification (4.8–5.4); (8) decanting for 2 hours; (9) centrifuging or press filtering; (10) washing with deionized water; (11) drying (40°C) to achieve a water content of 7 to 10%; and (12) packaging in polyethylene bags. Acetone can be used for the separation of fats, an ethanol-water solution for their extraction, and a concentration operation done before filtration (Pérez 1992). To obtain essentially pure carminic acid (99.5%), the main operation is crystalization, beginning with a supersaturated solution.

The extraction of dye from the insect is generally made without any other aid but pure water (J. A. Bustamante, personal communication). The water should be near boiling, and the dye is extracted from dried insects using two or three extractions (70:1 H_2O:cochineal). The resulting fluid is filtered, usually through a press filter, to obtain a solid-free extract (the pH is often reduced to 4.5 with hydrochloric acid). The carminic dye solution can either be spray-dried or laked with aluminum-calcium salts in the presence of citric acid at a high temperature, and then allowed to cool and precipitate in the form of insoluble, bright-red carmine lake particles. The lake is then dried in a low-temperature oven and later milled to the customer's particular requirement.

Biology of Cochineal

Despite some controversy, cochineal apparently belongs to order Homoptera, suborder Stenorryncha, and superfamily Coccoidae, which includes all mealy bugs and scale insects (Gullan and Kosztarab 1997). The family Dactylopiidae belongs to the Neococcoidea group of the Coccoidae (Miller and Kosztarab 1979). Named by Ferris (1955), it comprises the genera *Apezcoccus, Cryptococcus, Dactylopius, Eriococcus, Gymnococcus, Kermes, Oncerotyga, Trachiococcus,* and *Xerococcus.* De Lotto (1974) has identified nine species in the genus *Dactylopius: Dactylopius autrinus* (De Lotto), *D. ceylonicus* (Green), *D. coccus* (Costa), *D. confertus* (De Lotto), *D. confusus* (Cockerell), *D. opuntieae* (Cockerell), *D. salmianus* (De Lotto), *D. tomentosus* (Lamarck), and *D. zimmermani* (De Lotto). *Dactylopius ceylonicus, D. coccus, D. confusus, D. opuntieae,* and *D. tomentosus* are abundant in the southwestern United States, Mexico, and northern South America (Miller 1976; Macgregor L. and Sampedro R. 1984).

Origin and Diversity

The center of origin and dispersal of the various species of cochineal have not been unambiguously determined. However, the place or places of origin undoubtedly are intimately related to the development and diffusion of the genera *Opuntia* and *Nopalea.* The cacti apparently originated in the neotropical regions of the Americas (southern Mexico and northern South America), and then spread both northward and southward (Gibson and Nobel 1986; Nobel 1998). Maximum diversity is found from southern Mexico to the southwestern United States. Although many platyopuntias are important for fruit and forage, *Opuntia ficus-indica* (L.) Miller is the species of greatest economic importance and is the most useful host for cochineal (Borrego and Burgos 1986). Although the range of nopal species and varieties that serve as host to the cochineal insect is ample—75, according to Portillo (1995)—those that function as natural hosts to *D. coccus* are few: notably, *O. ficus-indica* var. Castilla, *O. pilifera* Weber, *O. sarca* Griff, *O. tomentosa* Salm-Dyck, and *Nopalea cochenillifera* (L.) Salm-Dyck (Piña 1977, 1981). A number of species and varieties can, however, be artificially adapted as hosts, including several varieties of *O. amyclaea* Webber, *O. atropes* Rose, *O. jaliscana* Bravo, *O. megacantha* Salm-Dyck, and *O. streptacantha* Lemaire. In South America, *D. coccus* is reared on both spiny and spineless varieties of *O. ficus-indica* (Flores 1995; Tekelemburg 1995).

The greatest diversity of natural enemies of the nopal cactus is found in Mexico, among which are the different species of *Dactylopius.* Unfortunately, however, detailed studies of the full potential and diversity of the cochineal insect in Mexico do not exist, compared with the meticulous investigations of the parasite by Ferris (1955) and Gilreath and Smith (1988) for North America and South America and by De Lotto (1974) for South Africa. Furthermore, the wide diversity of predators and parasitoids that

TABLE 13.2
Life stage durations for *Dactylopius coccus*

Male		Female	
Stage	*Duration (days)*	*Stage*	*Duration (days)*
Emigrant nymph I	15–168	Emigrant nymph I	15–168
Cocoon construction	2–64	Nymph I	12–64
Prepupa	8–22	Nymph II	8–25
Nymph II	2–12	Mating period	2–15
Pupa	4–8	Sexual maturity	3–22
Adult	18–29	Pre-laying period	24–68
Number of females mated	0–3	Laying period	10–58
Life duration	50–89	Life duration with mating	64–150
		Life duration without mating	34–52

References: de Piña (1977); Marín and Cisneros (1977); Quispe (1983); Bustamante (1986); Vargas (1988); Velasco (1988); Cruz (1990); Méndez (1992); Montiel (1995).

prey on both wild cochineal and *D. coccus* remain to be examined.

Morphology and Life Cycle

Like other coccids, cochineal is characterized by sexual reproduction and sexual dimorphism. From the nymph I stage to the first molt, it is difficult to distinguish between the male and the female (Gunn 1978). Cytogenetically, however, males and females are quite different from the embryonic stage onward (Nur 1989; Aquino P. et al. 1994), as females have a diploid chromosome number and males are physiologically haploid. Paternal chromosomes, which look like a heterochromatic mass, are known as H chromosomes (Nur 1989). These chromosomes are inactive, but their presence is necessary for embryo viability, fertility, and sexual differentiation (Chandra 1962).

The morphology and life cycle of *D. coccus* have been extensively studied (Table 13.2). The male has a six-stage life cycle (egg, nymph I, nymph II, prepupa, pupa, adult), while the female has only four stages (egg, nymph I, nymph II, adult). Life cycle duration, morphology, and size of *D. coccus* are variable, depending on many factors, such as population density, host species, nutritional level of the host, soil quality where the host grows, light, and temperature. Despite this variability, certain characteristics are common. The egg is oval and shiny bright-red. Hatching may occur inside the adult female, or the crawlers may hatch 10 to 32 minutes after the eggs are laid. Nymph I is red and oval when recently hatched, but after a time becomes covered by a white powdery wax called coccicerin, characteristic of the species.

From 2 to 12 days after the first molt, the male as nymph II, now clearly distinct from the female, constructs a cocoon of filamentous wax. (Wild cochineal males build their cocoons on the same day as the molt.) In the prepupa stage, the antennae are relatively thick and curved backward, genitalia are distinguishable, and most meiotic activity and the greatest development of the testicles occur. In the pupa, the antennae have grown; the legs are now long and slender and lack nails. Dorsally, the segmentation of the abdomen can be seen, and ventrally the genitalia can be observed. The adult male is approximately 2.2 mm in length with a wingspan of 4.8 mm (wild cochineal males are considerably smaller). The body sections are clearly distinguishable. The antennae are moniliform (tapering), composed of 10 beadlike segments. Other features of the adult include: three pairs of simple eyes; no buccal apparatus; a pair of simple-veined, mid-thoracic wings; slender legs with a single nail; and a pair of white, waxy appendages, measuring up to 3.6 mm in length. Cruz (1990) reports that a male mates with only one to three females; reproductive efficiency is considerably reduced after more than two matings.

The nymph II female does not change form; the duration between nymph II and adult varies from 8 to 25 days (Table 13.2). The adult female is oval, 4 to 6 mm long, and 3 to 5 mm wide. Segmentation of the prosoma is barely evident (De Lotto 1974). Legs and antennae are well developed but small. The rostrum is made up of three segments (De Lotto 1974; Montiel 1995). The body has numerous (15) cuticular pores, both on the dorsum and on the abdomen, this being the characteristic commonly used by taxonomists to classify the species (Ferris 1955; De Lotto 1974). The anal ring is recognized as a modification of segment 10; it is dorsal, has a half-moon shape, and is membranous on the anterior margin and sclerotic on the posterior margin (De Lotto 1974; Montiel 1995). Receptivity or sexual maturity occurs within 3 to 22 days. Pre-oviposition lasts from 24 to 68 days and oviposition is from 10 (when separated from the host) to 58 days. The total biological cycle of the female lasts from 64 to 150 days; during that time, a female may lay over 400 eggs.

Although it is not clear whether parthenogenetic reproduction is possible for *Dactylopius* spp., sexual reproduction is necessary for *D. coccus* and *D. confusus.* Hence, the ratio between the sexes should be 1:1 (Cruz 1990; Gilreath and Smith 1987). However, the ratio is modified by temperature (Mendez 1992) and photoperiod (Montiel 1995), generally favoring the female (Marín and Cisneros 1977). At least for *D. ceylonicus* and *D. coccus,* weather changes, especially low temperature and drought, as well as population density, affect the male population.

Host

The age of the cladodes selected and their utility for cochineal production depend on the species and variety of nopal, environmental conditions, and especially the hydration of the cladode, the quality of the soil, and the relative humidity. One-year-old, peripheral cladodes provide the most favorable conditions for cochineal establishment (Flores 1995). Five or six different kinds of nopal were utilized in Mexico for cochineal production in the 16th century. In time, most of these varieties were introduced into the West Indies and Europe. The most important nopal species for the raising of cochineal has always been *O. ficus-indica,* with its different varieties; *Nopalea cochinellifera* has also been used, but not in Mexico (Donkin 1977). Nutritional levels of nopal also affect the establishment and productivity of cochineal and its carmine content (Arteaga 1990; Vigueras and Portillo 1995). Indeed, oxalate crystals in host tissue can influence the population of cochineal (Castillo 1993).

Spines apparently have no influence on the establishment of *D. coccus.* Nevertheless, Piña (1981) indicates that, both in Mexico and in South America, cochineal occurs naturally on spiny nopal species, and under cultivation, the spiny species are more productive. Portillo (1995) reaffirms the greater adaptability of *D. coccus* to spiny varieties. Nevertheless, the nopal cacti most commonly utilized for the rearing of cochineal are spineless, for the obvious advantage of plant management. Only a weak relationship exists between the establishment of cochineal insects and stomatal frequency or the thickness of the cuticle, epidermis, and hypodermis (Castillo 1993).

Environmental Factors and Natural Enemies

Data from Mexico and other parts of the world indicate that environmental factors influence the growth and development of the cochineal insect (Piña 1977, 1981; Cruz 1990; Méndez 1992; Flores 1995; Tekelenburg 1995; Table 13.3). Important climate hazards include frosts, high temperatures (above 30°C), rainfall with its washing effects, and wind, all of which restrict the establishment of nymph colonies on the host plants. Biological hazards of the cochineal insect include predators and parasitoids, both for natural populations of wild cochineal (Gilreath and Smith 1988; Eisner et al. 1994) and for cultivated cochineal (Piña 1977). Such information can improve biological control of wild cochineal by means of its predators, as well as control of the predators by means of their parasitoids for cultivated cochineal.

Similar predators attack *D. coccus* and *D. confusus,* considerably reducing dye yields (Alzate 1831; Dahlgren 1963). The most common and dangerous predators are *Hyperaspis* sp. (Coccinelidae, Coleoptera), *Chilocorus* spp. (Coccinelidae), "drum worm" (*Bacca* sp., Syrphidae: Diptera), *Laetilia* sp. (Pyralidae: Lepidoptera), *Sympherobius* sp. (Neuroptera), and *Sapingogaster texana* (Syrphidae; Piña 1977; Gilreath and Smith 1988). *Homalotylus cockerella* is a parasitoid of *Hyperaspis trifurcata* (Gilreath and Smith 1988). In Mexico, several parasitoids of the family Pteromalidae have been identified for *Sapingogaster texana* (Syrphidae)—*Brachimeria conica, Spilochalcis flavopicta* (Chalcididae), and *Temelucha* sp. (Ichneumonidae; Gilreath and Smith 1988)—and mites belonging to the family Piemotidae have been identified as parasitoids for *Laetilia* sp. In greenhouse rearings, some parasitoids (Pteromalidae) attack both cochineal and its predators (*Hyperaspis* sp.).

D. coccus *versus Wild Cochineal*

Two characteristics distinguish *D. coccus* from wild cottony cochineal. First, the wild insects produce a waxy, cottonlike coating, which is abundant, loose, soft, and thermally stable on the dorsal side, but compact and resistant on the ventral side, permitting firm adherence of the insect to the host platyopuntia; this coating makes the parasite resistant to wind and rain. Second, wild cochineal yields a much lower concentration of carmine colorant, from 2 to 7% by dry weight, whereas yields from *D. coccus* are 15 to 25%. Among other characteristics of the wild species is the ability to transmit disease to the host (Miller 1976), which in

TABLE 13.3
Environmental parameters influencing *D. coccus*

Factor	Range	Optimal	Observations
Mean temperature (°C)	20–32	26–28	Cochineal can tolerate temperature extremes below 0°C or above 36 to 40°C; the effects depend on the duration of exposure.
Light (% of maximal)	40–60	50	Can be controlled by shading; the amount of light required interacts with the temperature.
Relative humidity (%)	30–60	40	Estimated, as parameters are not fully studied.
Annual rainfall (mm)	0–600	0–100	Depending on the temperature, cochineal can be raised in areas of greater or lesser rainfall, but with protection and, if necessary, irrigation.
Altitude (m)	0–2,300	200–1,800	Not a limiting factor, if temperature and radiation are in the appropriate ranges.
Soil type	Alluvium	Volcanic	Limestone soils, or soils with high calcium or magnesium contents, are apparently not favorable.

addition to its short biological cycle, high reproductive potential, and high resistance to climatic factors, makes wild cochineal very useful in the control of weedy nopal (Zimmermann and Moran 1991; Chapter 14). However, it is also a dangerous competitor of *D. coccus. Dactylopius coccus,* on the other hand, is distinguished by its fine, waxy coating, which takes the form of a powder. Apart from its buccal apparatus, *D. coccus* has no other structure that aids its adherence to the surface of a cladode, making it more susceptible to environmental hazards.

Cytogenetically, all analyzed wild cochineal species have a chromosome number of $n = 5$ and similar chromosomal karyotypes: a long chromosome three times the average length and four short chromosomes (Aquino P. et al. 1994). *Dactylopius coccus* has a chromosome number of $n = 8$ and a different karyotype—all the chromosomes are short. The four longest chromosomes of *D. coccus* do not differ from those of their possible homologue in wild cochineal, and the length of the long wild cochineal chromosome equals the length of the sum of the four shortest chromosomes of *D. coccus* (Aquino P. et al. 1994). Thus, cochineal insects apparently eliminate meiosis II by a simple chromosomal segregation. *Dactylopius coccus* has a very low frequency of "normal" meiosis II, whereas wild species, such as *D. confusus,* have a high frequency of "normal" meiosis II (Aquino P. et al. 1994).

Coccidae generally have evolved toward an increase in chromosome number by means of chromosome fragmentation (Nur et al. 1987; Nur 1989). This has apparently occurred for both *D. coccus* and wild cottony cochineal. Nevertheless, a chromosome breakup usually produces more disadvantages than advantages, and three fragmentations (which is what presumably occurred for *D. coccus*) could make the survival of the progeny more difficult. However, two additional modifications in the chromosomes of this insect group would increase the possibilities of survival of mutant individuals: (1) the presence of a diffuse centromere and (2) the inversion of the meiotic sequence (Chandra 1962). This permits balanced meiosis and equal separation of the chromosome groups, thereby reducing the loss of chromosome fragments—an irreconcilable loss in species with a defined centromere.

Marketing of Cochineal

Production and Prices

Since pre-Hispanic times in America, the cochineal market has been heavily affected by political and natural events, which have had much influence on production and prices. The highest prices for cochineal have always coincided with periods of prosperity in the principal consumer countries—historically England, France, Germany, and Holland, and at present, Italy, Japan, and the United States (Alzate 1831; Houghton 1877; Dahlgren 1963; Brana 1964; Donkin 1977; EPTASA 1983; Avila and Remond 1986; Contreras S. 1996; P. Quintanilla, personal communication; J. A. Bustamante, personal communication). The most favorable prices for cochineal possibly occurred from 1765 to 1775, when 520 metric tons (1 ton = 1,000 kg) were produced annually; the period from 1799 to 1833 was also a time of bonanza, although annual worldwide production had dropped to 190 tons, again almost all from Mexico. After this period, production and prices began to drop in Mexico in response to fierce competition from 1825 to 1880 from Guatemala and the Canary Islands. The Guatemalan market flourished from 1830 to 1865, but was overtaken by the booming Canary Islands' production from 1849 to 1882, despite the fact that world prices for cochineal had been in gradual decline since 1831. The main advantage for the Canary Islands was probably geographic—proximity to the main European consumer countries. Soaring production and lower shipping prices of Canary Islands' cochineal were probably the reasons for the drop in demand for the Guatemalan and Mexican dye; South American cochineal, meanwhile, had been in a slump since the turn of the 17th century. The Canary Islands' production continued from 1880 to 1927, albeit at lower levels and lower prices, due to the introduction of synthetic dyes; annual production averaged approximately 80 tons for 1927 to 1929 and currently is 40 tons $year^{-1}$.

Although little information is available for South American cochineal production for 1750 to 1935, production was apparently over 1,000 tons for 1829 to 1859 (Brana 1964; Donkin 1977). Records of the Peruvian market appear in 1937 and show a linear increase since that date, becoming 100 tons by 1975 (Fig. 13.8A). From 1975 to 1990, Peru cornered the world market, with a share of up to 95%. Since 1990, Argentina, Bolivia, and Chile have entered the world market, causing a reduction in Peru's domination. Indeed, Peru's bulk exportation of the raw material since 1997 has diminished, and a greater volume is being consigned to processed dye (Fig. 13.8).

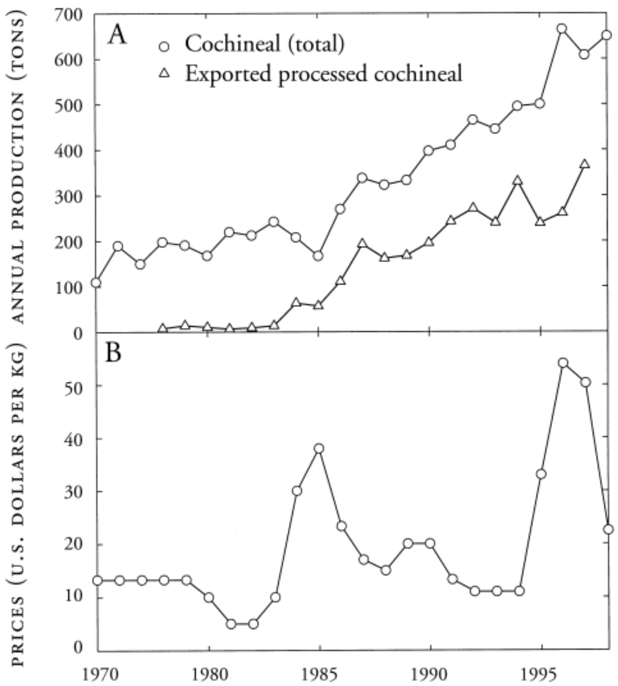


Figure 13.8. Peruvian cochineal production and prices for 1975 to 1998: (A) total production (O) and exportation of processed cochineal (Δ), and (B) prices for processed cochineal. References: Avial and Redmond (1986); EPTASA (1983); Contreras S. (1996); P. Quintanilla (personal communication); J. A. Bustamante (personal communication).

Supply and Demand

Presently Peru is the world's most important producer of cochineal. In response to increasing demand, Peru's production increased sixfold from 1975 to 1998, reaching 650 tons (Fig. 13.8A). Since 1983, Peru has steadily increased its industrial processing capacity for cochineal; since 1986 most of the exported cochineal has been processed (Fig. 13.8A). The price of cochineal has fluctuated widely, generally being below U.S. $20 per kilogram but reaching $40 in 1985 and $75 in 1996 (Fig. 13.8B). Prices of refined carminic acid, which accounts for about 10% of the dye export, tripled from 1994 to 1996, when it reached $400 per kg then decreased twofold by 1998, indicating the volatility of the market. If competition from synthetic dye manufacturers can be surmounted and if cochineal dye is internationally certified, the demand should increase.

Chile entered the world market in 1997 with a production of approximately 150 tons. Traditionally, Spain had 5 to 10% of world production, or approximately 65 tons. Peru, Chile, and Spain recently have annually supplied the world marketplace with 755 tons of cochineal. Moreover, Chile and Peru have predicted increases in production, meaning that the annual supply of the dye from these three countries should approach 1,000 tons.

Conclusions and Future Prospects

A common way to consume cladodes in Mexico is as nopalitos. After despining, minimal processing facilitates consumption of the tender young pads. Nopalitos can be further processed in brine or pickled. The consumption of the young pads not only should increase the cultivation of *Opuntia ficus-indica* and consequently the use of arid lands in many regions of the world, but also should serve as a healthful food due mainly to the dietary fiber content. Dietary fiber increases with stem age, opening up other ways to process and use this part of platyopuntias in addition to the currently more popular use of young pads. Such use could be introduced into those countries where *O. ficus-indica* is presently only a fruit crop. The different alternatives for processing and consuming nopal and nopalitos require educating the consumers, including full information on the nutritional value of the cladodes and technology transfer. The processes used today are quite simple and do not require expensive equipment. The food industry can utilize similar processes already installed for other raw vegetables. The properties of cladodes to alleviate illnesses, such as diabetes and obesity, should be studied more to confirm their effectiveness. Mucilage has great potential as a thickener in foods and an adhesive in paints, but again these properties must be studied in greater detail.

The dye insect *Dactylopius coccus* has enjoyed great importance worldwide since its discovery in Mexico in the 16th century. Cochineal is valued not only as the source of a red colorant, useful in a number of products for human consumption, but also as a biological control of weedy nopal infestations in some parts of the world. Its importance as a colorant has made it the subject of scientific, economic, and historical inquiry since the late 18th century. The most advanced investigations undertaken so far have been historical, chemical, and toxicological, whereas the biology of the parasitic insect has been largely ignored until recently. Genetic and biosynthetic aspects, as well as the host (*Opuntia* spp.)–parasite (*Dactylopius* spp.) interaction, have not received enough attention (Joshi and Lambdin 1996). For these reasons, it is presently difficult to determine the phylogenetic and evolutionary relationships, as well as the agronomic techniques, that would maximize the potential of both susceptible host cacti and *D. coccus.*

Acknowledgments

The authors thank anthropologist Jodie Randall for her comments regarding cochineal history and Mayra Perez Sandi y Cuen (Mac Arthur Foundation) for providing information on the cochineal trade.

Literature Cited

Albornoz, N. 1998. *Elaboración y Evaluación de una Crema de Verduras con Adición de Fibra Dietética de Nopal.* Facultad de Ciencias Agrarias y Forestales. Universidad de Chile, Santiago.

Ali, M. A., and L. J. Haynes. 1959. C-Glycosyl compounds. Part III. Carminic acid. *Journal of the Chemical Society:* 1033–1035.

Alzate, J. A. 1831. *Memoria acerca del insecto grana o cochinilla, su naturaleza y serie de su vida, método de propagarlo y reducirlo al estado en que forma uno de los ramos más útiles del comercio* (Written in 1777). Imprenta del Aguila, Mexico City.

Amin, El-S., O. M. Awad, and M. M. El-Sayed. 1970. The mucilage of *Opuntia ficus-indica. Carbohydrate Research* 15: 159–161.

Aquino, P., G., A. García V., T. Corona T., and N. M. Bárcenas O. 1994. Estudio cromosómico de cuatro especies de cochinilla del nopal (*Dactylopius* spp.) (Homoptera: Dactylopiidae). *Agrociencia, serie Fitociencia* 5: 7–23.

Arteaga, J. L. 1990. Influencia de la fertilización N-P-K en la producción de cochinilla (*Dactylopius coccus* Costa). Bachelor's Thesis, Universidad Nacional de San Cristóbal de Huamanga, Ayacucho, Peru.

Avena, B. R. S. 1996. Proceso de hortalizas pre-cortadas. *Boletín del Centro de Investigación en Alimentos y Desarrollo, A.C.* 5: 7–8.

Avila, R., and Z. Remond. 1986. *Estudio Técnico de la Cochinilla.* Dirección de Servicios Técnicos, División de Extracción Industrial (ITINTEC), Lima, Peru.

Badillo, J. R. 1987. Elaboración de una jalea de nopal. Bachelor's Thesis, Escuela de Ciencias Químicas, Universidad Autónoma de Puebla, Puebla, Mexico.

Barbera, G. 1991. Utilizzazione economica delle Opunzie in Messico. *Frutticoltura* 2: 41–48.

Borrego, F., and N. Burgos. 1986. *El Nopal.* Universidad Autónoma Agraria Antonio Narro, Saltillo, Mexico.

Brana, D. D. 1964. Cochineal: Aboriginal dyestuff from Nueva España. In *Actas y Memorias del XXXVI Congreso Internacional de Americanistas.* University of Texas, Austin. Pp. 77–91.

Brecht, J. K. 1995. Physiology of lightly processed fruits and vegetables. *HortScience* 30: 18–24.

Bustamante, O. 1986. Estudio del ciclo biológico de la cochinilla (*Dactylopius coccus* Costa) en su ambiente natural en Ayacucho. In *Resúmenes del 1er. Congreso Nacional de Tuna y Cochinilla.* Ayacucho, Peru. Pp. 44–45.

Cantwell, M. 1991. Quality and postharvest physiology of "nopalitos" and "tunas." *Proceedings of the 2nd Annual Texas Prickly Pear Conference.* McAllen, Texas. Pp. 50–66.

Cantwell, M. 1992. Postharvest handling systems: Minimally processed fruits and vegetables. In *Postharvest Technology of Horticultural Crops* (A. A. Kader, ed.). Division of Agriculture and Natural Resources, Publication 3311. University of California, Davis. Pp. 227–281.

Cantwell, M. 1995. Post-harvest management of fruits and vegetable stems. In *Agro-ecology, Cultivation and Uses of Cactus Pear* (G. Barbera, P. Inglese, and E. Pimienta-Barrios, eds.). FAO Plant Production and Protection Paper 132. FAO, Rome. Pp. 120–136.

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

Cárdenas, A., and F. Goicoolea 1997. Reología en solución del mucílago del nopal (*Opuntia ficus-indica*). In *Memorias VII Congreso Nacional y V Internacional Conocimiento y Aprovechamiento del Nopal.* Monterrey, Mexico. Pp. 171–172.

Cárdenas, A., I. Higuera-Ciapara, and F. M. Goicoolea. 1997. Rheology and aggregation of Cactus (*Opuntia ficus-indica*) mucilage in solution. *Journal of the Professional Association for Cactus Development* 2: 152–159.

Castillo V., J. 1993. Relación entre algunas características anatómicas y químicas del nopal (*Opuntia* sp.) y el establecimiento de la cochinilla (*Dactylopius coccus* Costa). Bachelor's Thesis, Departamento de Fitotécnia, Universidad Autónoma Chapingo, Chapingo, Mexico.

Chandra, H. S. 1962. Inverse meiosis in triploid female of the mealy bugs, *Planococcus citri. Genetics* 47: 1441–1454.

Chang, L. A., L. K. Hammet, and D. M. Pharr. 1982. Ethanol, alcohol dehydrogenase and pyruvate decarboxylase in storage roots of four sweet potato cultivars during simulated flood damage and storage. *Journal of the American Society for Horticultural Science* 107: 674–677.

Colin, B.C. 1976. Industrialización del nopal y sus productos. *Tecnología Laboratorios Nacionales de Fomento Industrial* II: 11–13.

Contreras S., A. C. 1996. *Capital Comercial y Colorantes en la Nueva España: Segunda mitad del siglo XVIII.* El Colegio de Michoacán y Universidad Autónoma de Yucatán, Mérida, Mexico.

Corrales, G. J. 1992a. Descripción y análisis de la cosecha y del manejo en fresco de nopalito y tuna. In *Memoria de Resúmenes del 5to. Congreso Nacional y 3er. Congreso Internacional Conocimiento y Aprovechamiento del Nopal.* Universidad Autónoma de Chapingo, Mexico. P. 109.

Corrales, G. J. 1992b. Perspectivas de industrialización de nopalito y tuna. In *Memoria de Resúmenes del 5to. Congreso Nacional y 3er. Congreso Internacional Conocimiento y Aprovechamiento del Nopal.* Universidad Autónoma de Chapingo, Chapingo, Mexico. Pp. 97–98.

Corrales-García, J. 1997. Postcosecha de la tuna y del nopal verdura. In *Memorias del VII Congreso Nacional y V Internacional Conocimiento y Aprovechamiento del Nopal.* Facultad de Agronomía, Universidad Autónoma de Nuevo León, Monterrey, México. Pp. 88–98.

Corrales-García, J. 1998. Industrialization of prickly pear pads (nopalitos). In *Proceedings of the International Symposium Cactus Pear and Nopalitos Processing and Uses.* Universidad de Chile, Santiago. Pp. 25–32.

Cruz, M. 1990. Determinación de algunos aspectos biológicos de la grana-cochinilla del nopal (*Dactylopius coccus* Costa) (Coccoidea: Dactylopiidae) en Chapingo, México. Bachelor's Thesis, Universidad Autónoma de Chapingo, Chapingo, Mexico.

Dahlgren, B. 1963. *La Grana o Cochinilla.* Nueva Biblioteca Mexicana de Obras Históricas Vol. I, Editorial José Porrúa Hermanos, Mexico City.

De Lotto, G. 1974. On the status of an identity of the cochineal insect (Homoptera: Coccoidea: Dactylopiidae). *Journal of the Entomological Society of South Africa* 37: 167–193.

De Sahagún, B. 1829. Historia general de las cosas de Nueva España. In *Sepan Cuantos* (A. M. Garibay E., ed.). Editorial Porrua, Mexico City.

Donkin, R. A. 1977. Spanish red: An ethnogeographical study of cochineal and the *Opuntia* cactus. *Transactions of the American Philosophical Society* 67: 63–77.

Eisner, T., R. Ziegler, J. L. McCormick, M. Eisner, E. R. Hoebeket, and J. Meinwald. 1994. Defensive use of an acquired substance (carminic acid) by predaceous insect larvae. *Experientia* 50: 610–615.

EPTASA (Estudios de Planificación y Técnica Aplicada, S. A.). 1983. *Estudio sobre la producción y comercialización de cochinilla y carmín de cochinilla.* Ministerio de Agricultura Pesca y Alimentación, Madrid, Spain.

Fernández, M. L., A. Trejo, and D. McNamara. 1990. Pectin isolated from prickly pear (*Opuntia* sp.) modifies low density lipoprotein metabolism in cholesterol-fed guinea pigs. *Journal of Nutrition* 120: 1283–1290.

Ferris, G. F. 1955. Family Dactylopiidae Fernald. In *Atlas of the Scale Insects of North America.* Stanford University Press, Stanford, California. Pp. 69–217.

Fiecchi, A., M. Anastasia, G. Galli, and P. Gariboldi. 1981. Assignment of the β configuration to the C-glycosyl bond in carminic acid. *Journal of Organic Chemistry* 46: 1511.

Flores, V. 1995. Crianza de la cochinilla en Sudamérica. In *Memorias del 6to. Congreso Nacional y 4to. Congreso Internacional sobre el Conocimiento y Aprovechamiento del Nopal.* Universidad de Guadalajara, Zapopan, Mexico. Pp. 35–47.

Flores, V. C. 1997. La producción de nopalito en México. In *Memorias del VII Congreso Nacional y V Inter-*

nacional Conocimiento y Aprovechamiento del Nopal. Monterrey, Mexico. Pp. 28–38.

Fontanot, M. 1999. Elaboración de galletas de avena con adición de harina de nopal rica en fibra dietética. Master's Thesis, Universidad de Chile, Santiago.

Ford, G. P., T. Gopal, D. Grant, I. F. Gaunt, J. G. Evans, and W. H. Butler. 1987. Chronic toxicity/carcinogenicity study of carmine of cochineal in the rat. *Food and Chemical Toxicity* 25: 897–902.

Frati-Munari, A. C., L. M. Del Valle-Martínez, C. R. Araiza-Andraca, S. Islas-Andrade, and A. Chávez-Negrete. 1989. Hypoglycemic effect of different doses of nopal (O*puntia streptacantha*) in patients with type II diabetes mellitus. *Archivos de Investigación Medica* 20: 197–201.

Frati-Munari, A., E. Jiménez, and C. R. Ariza. 1990. Hypoglycemic effect of *Opuntia ficus-indica* in non insulin-dependent diabetes mellitus patients. *Phytotherapy Research* 40: 195–197.

Frati-Munari, A., O. Vera Lastras, and C. R. Ariza Andraca. 1992. Evaluación de cápsulas de nopal en diabetes mellitus. *Gaceta Médica de México* 128: 431–436.

Gallardo, Y., M. L. Zambrano, and A. D. Hernandez. 1997. Determinación de las propiedades fisicoquímicas del nopal verdura. In *Memorias VII Congreso Nacional y V Internacional Conocimiento y Aprovechamiento del Nopal.* Monterrey, Mexico. Pp. 277–278.

García, J. R. 1993. Análisis de Factibilidad Técnico, económico y financiero de una planta procesadora de nopal en escabeche. Bachelor's Thesis, Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional, Mexico City.

Gardiner, D., P. Felker, and T. Carr. 1999. Cactus extract increases water infiltration rates in two soils. *Communications in Soil Science and Plant Analysis* 30: 1707–1712.

Gibson, A. C., and P. S. Nobel 1986. *The Cactus Primer.* Harvard University Press, Cambridge, Massachusetts.

Gilreath, E. M., and J. W. Smith Jr. 1987. Bionomics of *Dactylopius confusus* (Homoptera: Dactylopiidae). *Annals of Entomological Society of America* 80: 768–774.

Gilreath, E. M., and J. W. Smith. 1988. Natural enemies of *Dactylopius confusus* (Homoptera: Dactylopiidae) exclusion and subsequent impact on Opuntia (Cactaceae). *Environmental Entomology* 17: 730–738.

Goldstein, G., and P. S. Nobel. 1991. Changes in osmotic pressure and mucilage during low-temperature acclimation of *Opuntia ficus-indica. Plant Physiology* 97: 954–961.

Granados, D., and A. D. Castañeda. 1991. *El Nopal. Historia, Fisiología, Genética e Importancia Frutícola.* Editorial Trillas, Mexico City.

Grant, D., I. F. Gaunt, and F. M. B. Carpanini. 1987. Teratogenicity and embriotoxicity study of carmine of cochineal in the rat. *Food and Chemical Toxicity* 25: 913–917.

Grant, D., and I. F. Gaunt. 1987. Three generation reproduction study on carmine of cochineal in rat. *Food and Chemical Toxicity* 25: 903–912.

Grijspaardt-Vink, C. 1996. Ingredients for healthy foods featured at European expo. *Food Technology* 2: 30.

Gulías, A., and G. Robles. 1989. El nopal en su justa medida. *Cuadernos de Nutrición* 12: 42–43.

Gullan, P. J., and M. Koszarab. 1997. Adaptations in scale insects. *Annual Review of Entomology* 42: 23–50.

Gunn, B. H. 1978. Sexual dimorphism in the first instar of the cochineal insect *Dactylopius austrinus* De Lotto (Homoptera: Dactylopiidae). *Journal of the Entomological Society of South Africa* 41: 333–338.

Hegwood, D. 1990. Human health discoveries with *Opuntia* sp. (Prickly pear). *HortScience* 25: 1515–1516.

Hernández, A. D., G. Chamorro, and Y. Gallardo. 1997. Efecto fisiológico de la ingesta de nopal sobre la producción de heces fecales. In *Memorias VII Congreso Nacional y V Internacional Conocimiento y Aprovechamiento del Nopal.* Monterrey, Mexico. Pp. 289–290.

Hernández, A. D., Y. Gallardo, and G. Chamorro. 1998. Caracterización de la fibra de nopal por medio de su respuesta fisiológica. In *Fibra Dietética* (F. Lajolo and E. Wenzel, eds.). Temas en Tecnología de Alimentos, Vol. 2. Instituto Politécnico Nacional, Mexico City. Pp. 215–230.

Hollingsworth, P. 1996. Food trends: Diversity and choice dominate. *Food Technology* 5: 40.

Houghton, H. 1877. *La Cochinilla: Memoria Demostrativa de las Causas que han Producido la Decadencia de este Renglón de Comercio en los Ultimos Años.* Sociedad Económica de Amigos del País, Gran Canaria, Spain.

Ibañez-Camacho, R., and R. Roman Ramos. 1979. Efecto hipoglucemiante del nopal. *Archivos de Investigación Médica* 10: 223–230.

Ibañez-Camacho, R., M. Meckes-Lozoya, and V. Mellado-Campos. 1983. The hypoglycemic effect of *Opuntia* *streptacantha* studied in different animal experimental models. *Journal of Ethnopharmacology* 7: 175–181.

ITINTEC (Instituto Nacional de Investigación Tecnológica Industrial y de Normas Técnicas, Perú). 1990. Perfil Industrial: Producción de carmin a partir de la cochinilla. *Información Tecnológica* 16: 33–36.

Joshi, P. A., and P. L. Lambdin. 1996. The ultrastructure of hemocytes in *Dactylopius confusus* (Cockerell), and the role of granulocytes in the synthesis of cochineal dye. *Protoplasma* 192: 199–216.

Kader, A. A. 1986. Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables. *Food Technology* 40: 99–104.

Kawasaki, Y., T. Umemura, K. Sai, R. Hasegawa, J. Momma, M. Saitoh, Y. Matsushima, Y. Nakaji, M. Tsuda, and Y. Kurokawa. 1994. A 13-week toxicity study of simultaneous administration of cochineal and aluminum potassium sulfate in rats. *Bulletin of the National Institute of Health Sciences* 112: 48–56.

Lecaros, M. 1997. *Caracterización de Harina de Cladodio de Nopal* (*Opuntia ficus-indica*). Universidad de Chile, Santiago.

Loik, M. E., and P. S. Nobel. 1991. Water relations and mucopolysaccharide increases for a winter hardy cactus during acclimation to subzero temperatures. *Oecologia* 86: 340–346.

Macgregor L., R., and G. Sampedro R. 1984. Catálogo de cóccidos mexicanos familia Dactylopiidae (Homoptera-Coccidae). *Anales del Instituto de Biología (Serie Zoología), Universidad Nacional Autónoma de México* 54: 217–223.

Marín L., R., and V. Cisneros F. 1977. Biología y morfología de la cochinilla del carmín (*Dactylopius coccus* Costa) Homoptera: Dactylopiidae. *Revista Peruana de Entomología* 29: 115–120.

McGarvie, D., and P. H. Parolis. 1979a. The mucilage of *Opuntia ficus-indica. Carbohydrate Research* 69: 171–179.

McGarvie, D., and P. H. Parolis. 1979b. The mucilage of *Opuntia ficus-indica.* Part 2. The degraded polysaccharide. *Journal of the Chemical Society, Perkin Transactions* 1: 1464–1466.

McGarvie, D., and P. H. Parolis. 1981. Methylation analysis of the mucilage of *Opuntia ficus-indica. Carbohydrate Research* 88: 305–314.

Meckes, L. M., and R. Roman-Ramos. 1986. *Opuntia streptacantha:* A coadjutor in the treatment of diabetes mellitus. *American Journal of Chinese Medicine* 14: 116–118.

Méndez, G., S. J. 1992. Tasas de supervivencia y reproducción de la grana-cochinilla *Dactylopius coccus* Costa (Homoptera:Dactylopiidae) a diferentes temperaturas. Master's Thesis, Colegio de Postgraduados, Chapingo, Mexico.

Miller, D. H. 1976. Dactylopiidae. In *Syllabus for workshop on scale insect identification. Proceedings of National Meeting of the Entomological Society of America* (J. W. Beradsley and U. Nur, eds.), Honolulu. Pp. 1–10.

Miller, D. R., and M. Kosztarab 1979. Recent advances in the study of scale insect. *Annual Review of Entomology* 24: 1–27.

Montiel R., M. L. 1995. Morfología de *Dactylopius coccus* Costa (Homoptera: Dactylopiidae) y su biología y producción en dos fotoperiodos. Master's Thesis, Colegio de Postgraduados, Montecillo, Mexico.

Mulas, M. 1993. Medicinal properties and yield possibilities of the prickly pear (*Opuntia* spp.) in the mediterranean environment. *Acta Horticulturae* 331: 79–84.

Nerd, A., M. Dumotier, and Y. Mizrahi. 1997. Properties and postharvest behaviour of the vegetable cactus *Nopalea cochenillifera. Postharvest Biology and Technology* 10: 135–143.

Nobel, P. S. 1998. *Los Incomparables Agaves y Cactos.* Editorial Trillas, Mexico City.

Nobel, P. S, J. Cavelier, and J. L. Andrade. 1992. Mucilage in cacti: Its apoplastic capacitance, associated solutes, and influence on tissue water relations. *Journal of Experimental Botany* 43: 641–648.

Nur, U. 1989. Chromosomes, sex-ratios and sex determination: Reproductive biology and genetics. In *Armored Scale Insects, Their Biology, Natural Enemies and Control. Vol. A.* (D. Rosen, ed.). Elsevier Science Publishers, Amsterdam. Pp.179–190.

Nur, U., S. W. Brown, and J. W. Beardsley. 1987. Evolution of chromosome number in mealy bugs (Pseudoccidae: Homoptera). *Genetica* 71: 53–60.

Paulsen, B. S., and P. S. Lund. 1979. Water-soluble polysaccharides of *Opuntia ficus-indica* cv. "Burbank's spineless." *Phytochemestry* 18: 569–571.

Perez, J. A. 1992. Anteproyecto de una planta procesadora de grana cochinilla para la obtención de sus principales derivados: extracto de cochinilla, carmin de cochinilla y acido carmínico. Bachelor's Thesis, Universidad La Salle, Mexico City.

Periago, M. J., G. Ros, G. López, M. C. Martinez, and F. Rincón. 1993. The dietary fiber components and their physiological effects. *Revista Española de Ciencia y Tecnología de Alimentos* 33: 229–246.

Pimienta Barrios, E. 1990. *El Nopal Tunero.* Universidad de Guadalajara, Zapopan, Mexico.

Piña L., I. 1977. *La Grana o Cochinilla del Nopal.* Laboratorios Nacionales de Fomento Industrial de México, Mexico City.

Piña, L., I. 1981. Observaciones sobre la grana y sus nopales hospederos en el Perú. *Cactáceas y Suculentas de México* 26: 10–15.

Portillo, M. L. 1995. Los hospederos de las cochinillas del carmín (*Dactylopius* spp.) y algunas consideraciones sobre su aprovechamiento. In *Memorias del 6to Congreso Nacional y 4to Congreso Internacional Conocimiento y Aprovechamiento del Nopal.* Universidad de Guadalajara, Zapopan, Mexico. Pp. 35–47.

Quirce, S., M. Cuevas, J. M. Olaguibel, and A. I. Tabar. 1994. Occupational asthma and inmmulogical responses induced by inhaled carmine among employees at a factory making natural dyes. *Journal of Allergy and Clinical Immunology* 93: 44–52.

Quispe, I. 1983. Ciclo biológico de la cochinilla del cactus *Dactylopius coccus* Costa. En diferentes épocas del año y en tres pisos altitudinales en Ayacucho. In *Memorias del primer seminario Departamental de Producción y Fomento de Tuna y Cochinilla.* Ayacucho, Peru. Pp. 44–45.

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

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

Ramírez, G., and C. Aguilar. 1995. The effect of Opuntia in lowering serum glucose among NIDDM patients. A systematic review—preliminary findings. In *Proceedings: I Conference of the Professional Association for Cactus Development.* Kingsville, Texas. Pp. 71–78.

Rodríguez, D. 1999. Desarrollo de una bebida pasteurizada a base de nopal. In *Memorias. VIII Congreso Nacional y VI Internacional Conocimiento y Aprovechamiento del Nopal.* San Luis Potosí, Mexico. Pp. 75–76.

Rodríguez-Félix, A., and H. Soto-Valdez. 1992. Quality changes of diced nopal during storage in polyethylene bags. In *Proceedings of the 3rd Annual Texas Prickly Pear Conference, Texas Prickly Pear Council.* McAllen, Texas. Pp. 22–25.

Rodríguez-Felix, A., and M. A. Villegas-Ochoa. 1998. Postharvest handling of cactus leaves (nopalitos). In *Proceedings of the International Symposium "Cactus Pear and Nopalitos Processing and Uses."* Universidad de Chile, Santiago. Pp. 7–16.

Rosado, J., and M. Díaz. 1995. Propiedades fisicoquímicas relacionadas con función gastrointestinal de seis fuentes de fibra dietética. *Revista de Investigación Clinica* 47: 283–289.

Ross, G. N. 1986. The bug in the rug. *Natural History* 86: 67–71.

Sáenz, C. 1995. Food manufacture and by-products. In *Agro-ecology, Cultivation and Uses of Cactus Pear* (G. Barbera, P. Inglese, and E. Pimienta Barrios, eds.). FAO Plant Production and Protection Paper 132. FAO, Rome. Pp. 137–143.

Sáenz, C. 1998. Cladodes: A source of dietary fiber. *Journal of the Professional Association for Cactus Development* 2: 117–123.

Sáenz, C., M. Vásquez., S. Trumper, and C. Fluxá. 1992. Extracción y composición química de mucílago de tuna (*Opuntia ficus indica*). In *Actas: II Congreso Internacional de la Tuna y Cochinilla.* Santiago, Chile. Pp. 93–96.

Sáenz, C., E. Sepúlveda, and M. Moreno. 1995a. Estudio de formulaciones para la obtención de mermelada de nopal (*Opuntia ficus-indica*). In *Resúmenes: XI Congreso Nacional de Ciencia y Tecnología de Alimentos.* Viña del Mar, Chile. P. 163.

Sáenz, C., E. Sepúlveda, M. Moreno, D. Granger, and N. Pak. 1995b. Características funcionales de harina de nopal (*Opuntia ficus-indica*) y su utilización en la formulación de galletas. In *Actas: VI Congreso Nacional y IV Congreso Internacional Conocimiento y Aprovechamiento del Nopal,* Guadalajara, Mexico. Pp. 24–27.

Sáenz, C., N. Pak, E. Sepúlveda, and M. Lecaros. 1997. Caracterización de harina de cladodio de nopal. In *Memorias: VII Congreso Nacional y V Internacional sobre Conocimiento y Aprovechamiento del Nopal.* Monterrey, Mexico. Pp. 302–303.

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

Saltzman, M. 1992. Identifying dyes in textiles. *American Scientist* 80: 474–481.

Schlimme, D.V. Marketing lightly processed fruits and vegetables. *HortScience* 30: 15–17.

Sepúlveda, E., C. Sáenz, and M. Moreno. 1995. Obtención y caracterización de harina de nopal (*Opuntia ficus-indica*). In *Actas: VI Congreso Nacional y IV Congreso Internacional sobre Conocimiento y Aprovechamiento del Nopal.* Guadalajara, Mexico. Pp. 28–31.

Sloan, E. 1994. Top ten trends to watch and work on. *Food Technology* 7: 89–100.

Spiller, G. 1992. Definition of dietary fiber. In *Dietary Fiber in Human Nutrition,* 2nd ed. (G. A. Spiller, ed.). CRC Press, Boca Raton, Florida. Pp. 15–18.

Sugimoto, N., Y. Goda, J. Suzuki, M. Kuroyanagi, T. Yamada, K. Yoshihira, and T. Maitani. 1998. Structure of minor pigments in cochineal dye. *Natural Medicines* 52: 135–139.

Tekelemburg, A. 1995. La producción de cochinilla (*Dactylopius coccus* Costa) en ambientes semicontrolados. In *Memorias VI Congreso Nacional y IV Congreso Internacional Conocimiento y Aprovechamiento del Nopal.* Universidad de Guadalajara, Zapopan, Mexico. Pp. 48–55.

Tirado, L. E. 1986. Elaboración de una mermelada a base de nopal. Bachelor's Thesis, Universidad Autónoma de Puebla, Puebla, Mexico.

Trachtenberg, S., and A. M. Mayer. 1981. Composition and properties of *Opuntia ficus-indica* mucilage. *Phytochemistry* 20: 2665–2668.

Trejo, A., G. G. Ortiz., A. M. Puebla, M. D. Huizar, M. R. Munguía, S. Mejía, and E. Calva. 1995. A purified extract from prickly pear cactus (*Opuntia* sp.) controls experimentally induced diabetes in rats. In *Actas: VI Congreso Nacional y IV Congreso Internacional sobre Conocimiento y Aprovechamiento del Nopal.* Guadalajara, Mexico. Pp. 300–305.

Trejo-Gonzalez, A., E. Calva, P. J. Monterrubio, R. Hernández, L. Sánchez, J. Terrazas, M. A. Ruida, and B. Cobos. 1991. Antidiabetic properties of prickly pear cactus. In *Proceedings of the 2nd Annual Texas Prickly Pear Council.* Kingsville, Texas. Pp. 75–78.

Trejo, A., G. G. Ortiz., A. M. Puebla, M. D. Huizar, M. R. Munguía, S. Mejía, and E. Calva. 1995. A purified extract from prickly pear cactus (*Opuntia* sp.) controls experimentally induced diabetes in rats. In *Actas: VI Congreso Nacional y IV Congreso Internacional sobre Conocimiento y Aprovechamiento del Nopal.* Guadalajara, Mexico. Pp. 300–305.

Tütem, E., R. Apak, and K. Sözguen. 1996. The interaction of antitumor-active anthraquinones with biologically important redox couples: I. Spectrophotometric investigation of the interaction of the carminic acid and mitoxantrone with the Iron (II, III) and copper (I, II) redox couples. *Journal of Inorganic Biochemistry* 61: 79–96.

Vallejos, X. 1999. Elaboración y evaluación de la calidad de un flan con adición de fibra dietética de nopal. Bachelor's Thesis, Universidad de Chile, Santiago.

Vargas, F. N. 1988. Biología de la cochinilla del carmín *Dactylopius coccus* Costa bajo condiciones de laboratorio en Pampa del Arco (2,750 msnm) Ayacucho. Bachelor's Thesis, Universidad Nacional de San Cristóbal de Huamanga, Ayacucho, Peru.

Velasco, P. H. 1988. Estudio del ciclo biológico de la cochinilla o Grana-cochinilla (*Dacylopius coccus* Costa). Bachelor's Thesis, Universidad Autónoma Chapingo, Chapingo, Mexico.

Vigueras, A. L., and L. Portillo. 1995. Determinación del ácido carmínico en dos generaciones de *Dactylopius coccus* Costa mediante cultivo hidropónico en nopal. *Nakari* 4: 41–48.

Villarreal, P. 1996. Obtención de confitados a base de cladodios de nopal. Bachelor's Thesis, Universidad de Chile. Santiago.

von Elbe, J. H. 1977. Status of colors in dairy products. *Dairy and Ice Cream Field* 160: 60–62.

Wang, C. Y. 1990. Alleviation of chilling injury of horticultural crops. In *Chilling Injury of Horticultural Crops* (C. Y. Wang, ed.). CRC Press, Boca Raton, Florida. Pp. 281–302.

Wouters, J. 1990. Dyestuff analysis of scale insects by high performance liquid chromatography (Homoptera: Coccoidea). In *Proceedings of the Sixth International Symposium of Scale Insect Studies Part II.* Institute of Applied Zoology Agricultural University, Cracow, Poland. Pp. 61–70.

Zambrano, M. L., A. D. Hernández, and Y. Gallardo. 1998. Caracterización fisicoquímica del nopal. In *Fibra Dietética* (F. Lajolo, and E. Wenzel, eds.). Temas en Tecnología de Alimentos, Vol. 2. Instituto Politécnico Nacional, Mexico City. Pp. 29–42.

Zimmerman, H. G., and V. C. Moran. 1991. Biological control of prickly pear, *Opuntia ficus-indica* (Cactaceae), in South Africa. *Agriculture, Ecosystems and Environment* 37: 29–36.