RURAL INFRASTRUCTURE AND
AGRO-INDUSTRIES DIVISION

Agro-industrial utilization of cactus pear

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Foreword

An important part of the work of FAO Rural Infrastructure and Agro-Industries Division (AGS) is to support and improve the livelihoods of rural populations by promoting and supporting agro-industries. This includes adding value to primary products, which helps job creation and income diversification, the drivers of rural development. Growth in agro-industrial systems to meet fast-evolving market demand through efficient commercial operations and appropriate natural resource use leads to economic improvements for farmers. At the same time, farmers receive higher prices for value-added goods, helping to improve household food security. In turn, growth in agro-industries promotes the development of related sectors and the supply chain while improving postproduction management, including the transportation, storage, processing and marketing of fresh, minimally processed and other products. Modern global markets offer opportunities for farmers, processers and traders with innovative ideas on how to use hitherto untapped resources.

A number of FAO field projects and activities in developing countries in which AGS has played an active part, alongside the Plant Production and Protection Division (AGP), have demonstrated the importance of the cactus pear (*Opuntia* spp.) as a natural resource and as a potential source of income, employment and nutrients. Previous FAO publications have discussed various aspects of the cactus pear but never its use in agro-industry. As there are many countries where this natural resource is underutilized, AGS considered it important to consolidate into a single publication the entire body of current technical information for industrial use of the cactus pear, including its chemical composition, physical properties, postproduction management and processing required to produce food for people or other industrial products of importance to national and international markets, together with relevant economic information to share experiences in different countries. This book[1] represents an important tool for sharing experience and knowledge on the use of cactus pear and for disseminating technology, chiefly between developing countries.

AGS intends this book on the agro-industrial use of cactus pear to serve as specialized input for high-level strategic and technical personnel involved in planning, managing, advising on or supporting actions to resolve problems with the agro-industrial use of *Opuntia* spp. in rural communities, particularly in Latin America, the Caribbean and Africa.

Chapter 1 of the book contains an introduction on the cactus pear as a natural resource. Chapter 2 discusses the chemical composition and characteristics of *Opuntia* spp. and Chapter 3 summarizes field operations for producing the high-quality raw materials required for agro-industrial production. Chapter 4 presents general technical principles for the use of *Opuntia* spp., Chapter 5 discusses the use of cladodes and Chapter 6 details the technology and economic factors influencing small-scale food production. Chapter 7 discusses the industrial production of non-food products and Chapter 8 reviews bioenergy production from cactus pear. Chapter 9 provides a synthesis of worldwide experience based on national case studies on the agro-industrial use of *Opuntia* spp. and, finally, Chapter 10 provides basic guidelines for the development of value chains and networks based on cactus pear cultivation.

The target audience of this book includes advisors and analysts responsible for planning and designing sector strategies, government officials and agro-industry experts. It will also be useful to technical and management advisors in decision-making and to technicians from specialized agencies in implementing or helping to plan the development and implementation of agro-industry projects. This book focuses mainly on developing countries where cactus pear is already widespread or where its expansion could offer favourable agricultural, ecological and economic prospects. For this reason, it contains solid scientific and concrete technical information to make it useful for practical implementation. Cost–benefit and

[1] This English language version is a direct translation of FAO Agricultural Services Bulletin 162, first published in 2006, *Utilización agroindustrial del nopal.*

economic feasibility aspects are taken into account as it stresses the importance of value added through cost-effective processing of the cactus pear. This book is meant to serve as an information tool on the use of technology to add value to the cactus pear plant in order to produce agro-industrial products that meet market and consumer demand.

Shivaji Pandey
Director (2005–2006)
Rural Infrastructure and Agro-Industries Division

Preface

Writing in support of the meeting of the Network on International Technical Cooperation on Cactus Pear (CACTUSNET) held in Palermo, Italy, in 1994, a Sicilian journalist captured the virtues of *Opuntia* spp. in a single phrase:
"A treasure that lies beneath the spines."

This came just three years after the First International Symposium on Cactus Pear and Cactus Pear Fruit in Lagos de Moreno, Jalisco, Mexico. The network was established by four countries – Chile, Italy, Mexico and the United States – with support from the Food and Agriculture Organization of the United Nations (FAO), for the purpose of promoting synergy and cooperation among scientists, technicians, producers and others working with *Opuntia* spp.

High-quality information provides the basis for decision-making and, in the subsequent 20 years the network collated, shared and disseminated information, knowledge and experience worldwide. This led to the decision to hold a second international event entitled International Second Congress on Cactus Pear Fruit and Cochineal in Santiago, Chile, in 1992. This meeting defined the structure and objectives of CACTUSNET. The network was officially established at a Round Table organized for this purpose in Guadalajara, Mexico, in August 1993, providing the stimulus for volunteer participation under FAO sponsorship. The slogan for the meeting was environmentally-sustainable production in arid and semi-arid regions.

Since then, CACTUSNET has grown and currently includes technical specialists and institutions from the following 31 countries: Algeria, Angola, Argentina, Bolivia, Brazil, Chile, Cuba, Egypt, Eritrea, Ethiopia, Germany, Greece, India, Iraq, Israel, Italy, Jordan, Madagascar, Mexico, Morocco, Mozambique, Namibia, Pakistan, Peru, South Africa, Spain, Syria, Tunisia, Turkey, the United States and Zimbabwe.

Knowledge is shared through a letter that circulates among the individuals and institutions in the network. They include the universities of Guadalajara (Mexico), Reggio Calabria (Italy), Palermo (Italy), Sassari (Italy), Santiago del Estero (Argentina) and Chile, and the National Agricultural Research Institute of Tunisia (INRAT). Each contributes before forwarding the letter to the next recipient on the mailing list.

Since the Third Congress in South Africa in 1996, CACTUSNET has been sponsored and organized by the International Society for Horticultural Science (ISHS). The network's institutional memory is published in the ISHS journal *Acta Horticulturae*. The Fourth Congress was held in Tunisia in 2000. The Fifth Congress was held in Mexico in 2004, to coincide with the 150th anniversary of the founding of the Autonomous University of Chapingo. Since then, general meetings of CACTUSNET have taken place alongside the four-yearly International Congress.

In addition to the international congresses, FAO and CACTUSNET have joined forces at a number of technical events worldwide, organizing and participating in projects, courses, workshops, congresses, symposia and working group meetings in Angola, Argentina, Chile, Italy, Morocco, Mexico, Peru and Tunisia.

This improved communication between countries interested in cactus pear production has led to the successful implementation of cactus pear projects supported by the FAO Technical Cooperation Programme (TCP) in Eritrea, Ethiopia and Namibia. Other FAO/TCP projects in Argentina and Iran have included cactus pear within their programme of activities. Additional projects supported by the FAO Telefood programme have been implemented in Argentina, Cuba and Ethiopia. All these projects have been enthusiastically supported by CACTUSNET members in many countries in the form of technical assistance, plant material and information.

This spirit of cooperation and volunteerism among CACTUSNET members has enabled FAO to publish two key technical bulletins on cactus pear: *Agro-ecology, cultivation and uses of cactus pear* and *Cactus (Opuntia spp.) as forage.* These are available in Arabic, English and Spanish. The current technical bulletin focusing on agro-industries and processed products completes the trilogy of cactus pear texts that have taken more than a decade to complete. The importance of this technical bulletin cannot be overemphasized, as it informs and encourages growers, manufacturers and entrepreneurs alike of the potential of the cactus pear value chain, the livelihoods that can be developed and the improved food security that comes from growing this crop.

FAO may have been instrumental in launching the CACTUSNET network, but ownership was quickly claimed by a host of enthusiastic individuals and the institutions they represent. Brief mention should be made of the International Center for Agricultural Research in the Dry Areas (ICARDA), International Plant Genetic Resources Institute (IPGRI), Secretariat of the United Nations Convention to Combat Desertification (UNCCD), Joint Division of FAO and the International Atomic Energy Agency (IAEA), ISHS and ministries, institutions and universities in more than 30 participating countries.

FAO Representations in FAO member countries and the FAO Regional Offices for Europe (REU), Latin America and the Caribbean (RLC) and Near East (RNE) have been instrumental in the success of CACTUSNET. FAO has provided technical assistance and, in some cases, partial funding through the Plant Production and Protection Division (AGP) and the Rural Infrastructure and Agro-Industries Division (AGS).

This book describes some of the main activities and results of work on cactus pear development. However, much remains to be done to advance scientific and technical work in support of cultivation, increase production and introduce the processes and industries required to convert raw materials into higher-value products.

This calls for a global strategy of crop development and exploitation, based on appropriate programmes for every region and country where the crop is grown. Support is available in the form of a wide range of natural parameters and the diversity of sociocultural and historical precedents linking cactus pear back to the ancient peoples of the Americas who once depended upon it. To this day, their descendants continue to enjoy traditional foods prepared from cactus pear – foods that still remain largely unknown in countries around the world where cactus pear grows. A veritable universal horticultural treasure trove remains to be exploited by anybody willing to explore new foods and enrich their diet.

Determined action is required to exploit the cactus pear for agro-industrial use. This book provides the springboard for such action by compiling relevant scientific and technical information and strategies for manufacturing a range of different products from cactus pear. Adding value to raw materials will increase wealth in the community, creating more jobs. We trust that the information provided by the authors, technical coordinators, editor and their supporters will contribute in no small measure to exploiting this "**treasure that lies beneath the spines**".

Abbreviations and acronyms

a_w	Water activity
CACTUSNET	(FAO) International Technical Cooperation Network on Cactus
CAM	*Crassulacean acid metabolism*
CFU	Colony-forming unit
CI	Chilling injury
CIAD	*Centro de Investigación en Alimentación y Desarrollo* (Food and Development Research Centre), Mexico
CMC	*Carboxymethyl* cellulose
COD	Chemical oxygen demand
DM	Dry matter
ECFA	(WHO/FAO) Expert Committee on Food Additives
EDTA	*Ethylenediaminetetraacetic* acid
EU	European Union
EVOH	Ethylene vinyl alcohol
FAO	Food and Agriculture Organization of the United Nations
FDA	Federal Drug Administration (of the United States of America)
G.L.	Gay-Lussac (law)
GMP	Good manufacturing practices
HACCP	Hazard analysis and critical control points
HDPE	High density polyethylene
HTST	High temperature short time
INIFAP	*Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias* (National Institute of Forestry, Agriculture and Animal Research), Mexico
IQF	Individual quick frozen
ITINTEC	*Instituto Nacional de Investigaciones Tecnológicas, Industriales y Normas Técnicas* (Industrial Technology Research and Technical Standards Institute), Peru
LDP	Low density polyethylene
msl	Metres above sea level
NASS	National Agricultural Statistics Service (of the United States of America)
NGO	Non-governmental organization
NTU	Nephelometric turbidity unit
PAM	Polyacrylamide
PE	Polyethylene
PP	Polypropylene
PPO	Polyphenol oxidase
PVC	Polyvinyl chloride
RH	Relative humidity
SAGARPA	*Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación* (Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food), Mexico
TCP	(FAO) Technical Cooperation Programme
UV	Ultraviolet
WAI	Water absorption index
WHO	World Health Organization (of the United Nations)

Chapter 1
Opuntias as a natural resource

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GENERAL BACKGROUND

Interest in *Opuntia* (also known as cactus pear) dates back many thousands of years. Its origin and history are closely related to the ancient Mesoamerican civilizations and particularly to the Aztec culture. Archaeological evidence confirms that these plants were first cultivated by indigenous populations who settled in the semi-arid regions of Mesoamerica (Pimienta, 1990).

Cactus pear and other cacti were probably among the plants and animals brought to Spain by Christopher Columbus as samples of the exotic flora of the New World (Barbera, 1999; Velásquez, 1998). When the Spaniard Hernán Cortés arrived in the Valley of Mexico in 1519 he was amazed at the attractive and delicious fruits of the *nopalli* plant (Náhuatl term for cactus pear plant), called *nochtli* in Náhuatl.

The chroniclers of that era, including Gonzalo Fernández de Oviedo y Valdés, one of the first Spanish writers to describe the Americas, reported in his *General and Natural History of the Indies* in 1535 that the population consumed the fruit of the cactus pear: *"…which they ate with great pleasure as it was the best delicacy that they had all year and would not replace it for anything in the world…"* Nomadic tribes were attracted to areas where *Opuntia* was growing, and access to supplies of fruit became a reason for them to take up permanent residence (Bravo-Hollins, 2002).

Tales of old mention the great variety of *Opuntia* available and their uses. In addition, they described the presence of the cochineal insect that fed on the fleshy green parts of the plant (cladodes), which was cultivated and harvested to produce what is still one of the world's most valuable natural pigments: carmine. The insect and colorant was a secret kept hidden for many years by the Spanish who made great profits from trading the colorant.

In his *General History of New Spain*, Fray Bernardino de Sagahún skilfully described the many ways of using cactus pear. He says: *"There are some trees in this land that are called* nopalli, *which means cactus pear or a tree that produces cactus pears. It is a huge tree whose trunk is made up of the leaves and offshoots from them; the leaves are wide and thick, with abundant juice, and are sticky; the leaves have spines. The fruit from these trees, called cactus pear, is good to eat; it is a valuable fruit. The leaves from the tree are eaten both raw and cooked. Some trees produce cactus pear fruit that are yellow inside, while others are red or pink inside, which are good to eat; other trees have green leaves with red markings, bearing fruit that are purple in colour both inside and out…"* (Velásquez, 1998).

In an order of 1620, King Philip III of Spain states that: *"… one of the most valuable fruits grown in our Western Indies is the cactus pear, produce of equal value to gold and silver …"* (Velásquez, 1998). The plant's medicinal properties were acknowledged from the very beginning, including its value as an anti-inflammatory, diuretic and antispasmodic agent. Exploratory medical research continues to this day.

Opuntias are an intrinsic part of the history of Mexico and Mesoamerica. For example, their natural genetic origin is reflected in the official shield of Mexico, which contains an eagle perched in top of a cactus pear plant. This symbol has lasted to this day in the hieroglyphics of Great Tenochtitlán, a name that means 'Place where the cactus pear grows on stone'. This was the city where the Nahuas made their sacrifices, the capital of the Aztec Empire – nowadays known as Mexico City – where the plant occupied a special place in the economic, social and religious life of the people (Granados and Castañeda, 1996; Flores-Valdez, 2003).

Further evidence of early Mexicans' knowledge and use of cactus pear can be found in the excavations of Tamaulipas and Tehuacán (Mexican State of Puebla), where fossilized seeds and skins of the cactus fruit and fibres from its leaves can be found, estimated to be 7 000 years old (Flores-Valdez, 2003).

Soon after the arrival of the Spanish in Mexico another event involving the cactus pear took place, which highlights the species' suitability for its environment. This was reported in the Náhuatl language in the tract *Nican Mopohua* ('Here it is told'), describing the apparition of the Virgin of Guadalupe. The author, attempting to illustrate the area's transformation in the presence of such sublime beauty, states: *"The mesquites and cactus pear and various other grasses that are often grown there seemed like emeralds, their leaves the finest turquoise and their branches and spines shone like gold"* (Valeriano, 1554).

While today's observations about this species tend to be less euphoric, the plant may nevertheless contain many attractive and valuable compounds, and it is still highly valued for the protection and development of arid and semi-arid zones around the world. Quite literally, the plant is the basis for life for resource-poor people living in these marginal areas. The plant's full potential has yet to be shared as an important option for these populations and for all humankind.

ORIGIN AND DISTRIBUTION OF *OPUNTIA* SPP.

Opuntia spp. originated in the tropical and subtropical Americas and, wild or cultivated, they can be found in a wide variety of agroclimatic conditions across the entire American continent. The plant has spread further – carried by people as they traded and settled – to Africa, Asia, Europe and Australia, where the cultivated and wild plants continue to provide food and materials.

The cactus pear belongs to the *Cactaceae* family. Its taxonomy is highly complex for a number of reasons. For example, its phenotypes show high variability according to the prevailing environmental conditions, polyploidy is common, it reproduces either sexually or asexually and there are several interspecific hybrids.

Authors disagree in their classification of cactus pear in the *Cactaceae* family (e.g. Sánchez Monge, 1991; Scheinvar, 1999; GRIN, 2005). This text follows the classification proposed by the Germplasm Resources Information Network (GRIN) of the United States Department of Agriculture's Agricultural Research Service, according to which the cactus pear belongs to the genus *Opuntia*.

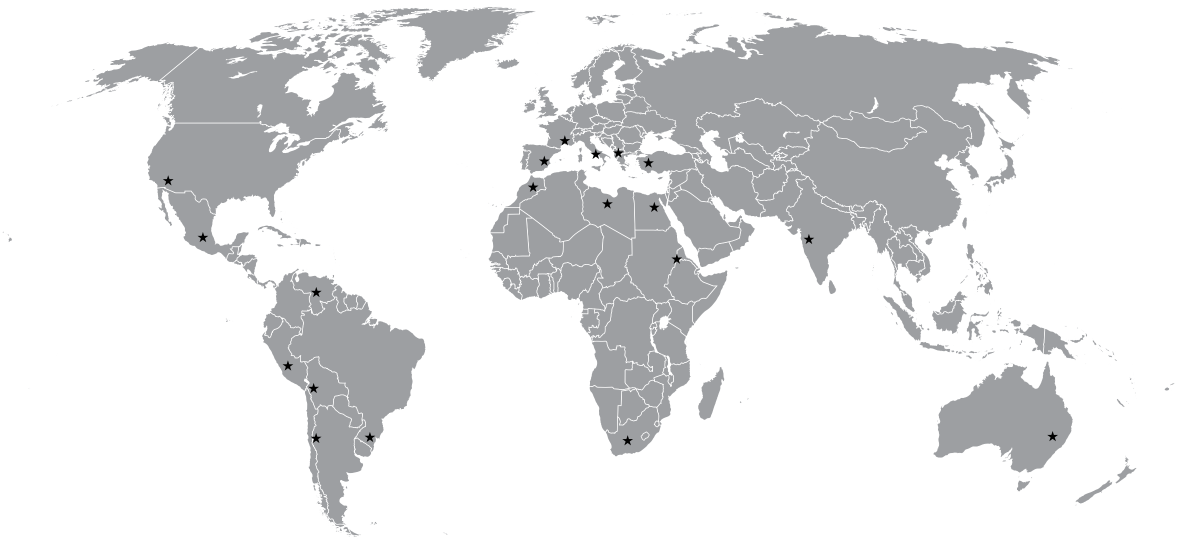
The scientific name *Opuntia* was coined by Tournefort in 1700, in view of their resemblance to spiny plants that grew in the town of Opus in Greece (Scheinvar, 1999; Velásquez, 1998). Once introduced into Spain from Mexico, the species quickly spread throughout the Mediterranean basin. The first *Opuntias* were probably cultivated near Seville or Cadiz, the final destination of many travellers and traders from the West Indies (Barbera, 1999). Today these plants grow wild or are cultivated in southern Spain and around the Mediterranean in France, Greece, Israel, Italy and Turkey. The Arabs took them from southern Spain to northern Africa, where they can be found in Algeria, Egypt, Eritrea, Ethiopia, Libya, Morocco and Tunisia.

Opuntia plants are widely distributed throughout the Americas from Canada to Chile: in the southern United States, all Central American and Caribbean countries and the South American countries of Argentina, Bolivia, Brazil, Colombia, Peru and Venezuela. Wild and cultivated species of *Opuntia* also grow in Angola, Australia, India and South Africa. These countries have more than 5 billion hectares (ha) of arid and semi-arid zones – the most extensive dry lands on of the planet. People living in these environments look for plant species that can adapt, grow and provide food and materials. Figure 1 shows the distribution of *Opuntia* worldwide.

Irrespective of the taxonomic classification used in this document, the name cactus (*nopal* in Spanish) is used to denote the complete plant; cactus pear (*tuna*, in Spanish) to denote the fruit, and cladode to denote the stems (in Spanish *nopalito* refers to the tender cladode and *penca* to the fleshy mature cladodes or 'leaves').

The *Opuntia* species is known by different names in the various countries where it is found. The original name, in the Náhuatl language, is *nochtli*. Notwithstanding, the Spanish renamed the plant *chumbera* and the fruit *higo de las Indias* (Indian fig), which today is known as *higo chumbo* (chumbo fig). In Italy it is known as *fico d'India,* in France as *figue de Barbarie* and in Australia, South Africa and the United States, as prickly pear. This is slowly evolving into the name cactus pear, to reduce the negative connotation of the word 'prickly' (meaning 'with spines'). In Israel it is known as *sabras*, meaning 'spiny outside but sweet inside'. In Eritrea and Ethiopia it is called *beles*. In India it is called in a local dialect *nagphani* or *anda torra* or *chapathi balli* depending on the region. In Brazil it is known as *palma forrageira* because it is cultivated mainly as forage for livestock.

FIGURE 1
World distribution of *Opuntia* spp.



OPUNTIA SPP. AS A NATURAL RESOURCE

Opuntia plants are native to many environments, ranging from desert areas below sea level to high-altitude areas such as the Peruvian Andes and from the tropical regions of Mexico, where temperatures are always above 5 °C, to areas in Canada that can fall to -40 °C in winter (Nobel, 1999). Its adaptability is ample reason for considering this species as a highly valuable resource for a wide variety of ecological zones.

One of the most striking characteristics of *Opuntia* is its anatomy and morphology, which have enabled it to adapt to many highly stressful growing conditions, meaning that the plant can be a viable option in regions where other plants will not survive.

The characteristics that make the plant adaptable to arid conditions are related to the shape of several of its organs. Nobel (1998) suggested that the shallow and extensive root system enabled the plant to exploit scarce rainfall in such environments. On the other hand, isolated rainfall induces the formation of secondary roots, which increases the contact surface with the soil and this facilitates uptake of water and nutrients. At the beginning of a period of drought, the roots contract radially and this helps to reduce water loss.

Scientifically the stems are known as cladodes and commonly referred to as 'paddles', 'fleshy leaves' or 'racquets'. They are succulent and articulated. Photosynthesis takes place in the cladodes, which act as leaves for this function. The cladodes are protected by a thick cuticle, which is occasionally covered with wax or glochids that further reduce water loss. The stems have the capacity to store considerable amounts of water, because they possess abundant parenchyma. This is a whitish tissue in which water is stored, enabling the plants to survive long periods of drought. It is important to highlight the role of plant mucilage. This is a hydrocolloid present in the tissue that has high water binding capacity (Nobel, Cavelier and Andrade, 1992).

Cladodes also have spines. They have few stomas per unit of surface area and feature the peculiar property of remaining closed during the day and open during the night. This helps avoid moisture loss by transpiration during the day and enables the carbon dioxide (CO_2) essential for photosynthesis to be absorbed during the night.

The specific type of photosynthesis that occurs in *Opuntias* is known as the crassulacean acid metabolism (CAM). In these plants the stomata open mainly at night, with subsequent intake of CO_2 leading to gradual acidification of the stem. In conditions of extreme water deficiency the stomata remain closed during both day and night, preventing transpiration and the entry of CO_2.

The water and CO_2 produced by respiration are utilized for photosynthesis, which explains the slow dehydration and degradation seen with cladodes during prolonged periods of extreme drought. The interrelation between the anatomy of CAM plants and their physiology for water storage is crucial for ecological success, and increases the agricultural production potential in arid and semi-arid areas (Nobel, 1998; Sudzuki, Muñoz and Berger, 1993). CAM plants are also resistant to high temperatures, although some species can also withstand low temperatures of -40 °C (Nobel, 1998).

Cactaceae have played a decisive ecological role in slowing down the rate of degradation of deforested soils. The species' agronomic importance is attributed to its suitability for cultivation in arid and semi-arid areas where little or no irrigation is provided.

One of the environmental changes affecting the planet is increased atmospheric CO_2 as a result of deforestation and large-scale use of fossil energy resources. This is affecting all the world's main ecosystems. In view of the environmental changes under way, the cactus pear could be considered an option as a carbon sink, absorbing and holding excess CO_2 in areas where the plant can be established but where nothing else will grow (Pimienta, 1997; Nobel and Bobich, 2002).

In Ethiopia this cactus species is considered the 'Bridge of life' because the stems and fruit store large quantities of water and provide both feed for cattle in times of drought and food for livestock herders, so contributing to the survival of both farmers and their animals (SAERT, 1994). If people in countries such as Ethiopia (and elsewhere) were to be informed of the widespread uses of cactus pear, in Mexico for example, it may be possible to reduce malnutrition and to improve their quality of life.

The properties of the *Opuntia* species make it a promising plant resource for humankind.

TYPES AND CHARACTERISTICS OF *OPUNTIA* SPP.

The taxonomy of the *Opuntias* spp. is complex. It takes a detailed field study to recognize and identify each species, the varieties and the adaptations reflected in their phenotype (Scheinvar, 1999).

Almost 300 species of the genus *Opuntia* are known but, so far, only 10 to 12 species have been utilized for their fruit, tender leaves (cladodes), forage or cochineal for colorant production. The most cultivated species for fruit production are: *Opuntia ficus-indica*, *Opuntia amyclae*, *Opuntia xoconostle*, *Opuntia megacantha* and *Opuntia streptacantha.* Wild species include *Opuntia hyptiacantha*, *Opuntia leucotricha* and *Opuntia robusta.* The most widely cultivated species throughout the world is *Opuntia ficus-indica*. It is the only *Opuntia* cultivated in the Mediterranean basin, where it is used for a variety of purposes (Uzun, 1996).

The characteristics of these *Opuntia* species vary: they differ in the shape of the cladodes, the presence or absence of spines, the size and colour of fruit and other botanical characteristics. For example, the fruit of *Opuntia ficus-indica* is sweet, juicy, yellow, orange, red or purple, full of pulp and with skin of variable thickness, but generally thin. The fruit of *Opuntia xoconostle* is much smaller, acidic, purple-green and pink inside. *Opuntia streptacantha* produces fruit that is purple, juicy and sweet (Scheinvar, 1999). The fruit is fragile when handled, deteriorates easily and ripens quickly, which generally limits large-scale marketing, with the result that it is used to make fermented beverages (López, Fuentes and Rodríguez, 1997).

In Mexico, the tender stems (*nopalitos*) of *Opuntia ficus-indica* are mainly eaten as a vegetable. *Opuntia ficus-indica* and *Opuntia cochenillifera* (or *Nopalea cochenillifera*) are the preferred species for rearing the cochineal insect. In Brazil, Chile, Mexico and elsewhere, *Opuntia ficus-indica* is also used for livestock forage.

DISTRIBUTION AND CONSUMPTION IN SEVERAL COUNTRIES

Opuntias are found in many countries and have been known since ancient times for their wide-ranging uses and properties. Owing to the scarcity of other foods, people found ways to conserve the fruits and to make syrups, which could be kept indefinitely without spoiling. They also made *melcocha*, a toffee made by boiling the fruit juice, cactus pear cheese made from the fruit (*melcocha* that has been further processed) and cactus pear raisins (sun-dried fruit). To celebrate the harvest in August and September, a wine known as *colonche* is made from the cactus pear pulp and *pitahaya* is made by fermenting plants in clay pots in the sun (Corrales and Flores, 2003). These products are still consumed to the present day, although the most popular parts of the plant for food remain the fresh fruit and the fleshy and tender stems known as *nopalitos*.

The plant is found either cultivated or wild in many countries of the world. Barbera (1999) reported that the largest area for fruit production is found in Mexico, with around 50 000 ha available. According to data from Flores-Valdez (1999) cited by Flores-Valdez (2003), an estimated 72 000 ha are cultivated for fruit and 10 500 ha, for vegetables, not to mention the many millions of hectares where wild plants grow. Barbera (1999) reported that Peru has approximately 35 000 ha of wild plants used mostly for cochineal breeding. Brazil has around 40 000 ha for forage. Italy cultivates 2 500 ha for cactus pear production and Chile, around 1 100 ha. There are also smaller areas in Argentina, Bolivia, Israel, Jordan, South Africa, Spain (Canary Islands), the United States and Venezuela. The plant is also important in North African countries, such as Algeria, Egypt, Morocco and Tunisia. In Tunisia, 400 000 ha to 500 000 ha is cultivated (Selmi, Khalfaoui and Chouki, 2002).

As the plant is widely dispersed, there are few official statistics and information on planted areas and their use (e.g. fruit, vegetable, forage and cochineal breeding) is either not available or tends to be unreliable.

Many productive sectors use cactus pear fruits and their fleshy leaves as industrial raw materials for cosmetics, alcoholic drinks and food additives (the latter closely linked to the pharmaceutical industry). The plant is also used as a living fence in gardens and fields and it helps to combat desertification.

GENERAL DESCRIPTION OF THE CURRENT PUBLICATION

Previous FAO publications cover specific aspects of this species (Barbera, Inglese and Pimienta, 1999; Mondragón-Jacobo and Pérez-González, 2001) within the framework of the FAO International Technical Cooperation Network on Cactus Pear (CACTUSNET). The first book described the agronomy of *Opuntias*, including background on possible uses of the fruit (Sáenz, 1999), fleshy leaves (Flores-Valdez, 1999), cochineal breeding (Flores-Flores and Tekelenburg, 1999) and other uses. The second book described the use of *Opuntias* as forage, describing experiences in Brazil, Chile, Ethiopia, Mexico, South Africa and the United States, and highlighting their nutritional value and use as feed for various types of livestock.

This publication examines the possibilities for industrial use of the *Opuntias* for making human food, as well as for other purposes, detailing their properties, characteristics, methods of use and means of consumption. The text covers the processing technologies required to make the various foodstuffs from such parts as the fruit (e.g. juices, dried fruit, colorants) and cladodes (e.g. brine-cured, pickled, flours).

Chapter 2

Chemical composition and characteristics of *Opuntia* spp.

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OPUNTIA SPP. DESCRIPTION

A number of authors have described *Opuntias* (Bravo, 1978; Pimienta, 1990; Sudzuki, Muñoz and Berger, 1993; Sudzuki, 1999; Scheinvar, 1999; Barbera, Inglese and Pimienta, 1999; Nobel and Bobich, 2002). That said, a brief description of the plant is useful as a reminder of the different parts used, the industrial processing required and the resulting end products.

Opuntias are creeping or upright shrubs that can grow to 3.5–5 metres high. The root system is extensive, densely branched and with many fine shallow absorbing roots highly suited to arid zones. The length of the roots is closely related to the prevailing agro-environmental conditions and to crop management practices – particularly the use and application of irrigation and fertilizers (Sudzuki, Muñoz and Berger, 1993; Sudzuki, 1999; Villegas and de Gante, 1997).

The succulent and jointed cladodes (stems) have an oval or elongated racquet shape that can grow up to 60–70 cm long depending on the amount of water and nutrients available (Sudzuki, Muñoz and Berger, 1993). When the cladodes are around 10–12 cm long they are tender and can be eaten as a vegetable. Photo 1 shows several types of *Opuntia* plants.

Cladodes continue to grow in size for about 90 days. The buds (called areoles) can be found on both sides of the cladodes. These are capable of developing new cladodes, flowers or roots depending on environmental conditions (Sudzuki, Muñoz and Berger, 1993).

The areoles have two types of spine in their cavity: small and large. The small ones, grouped in large numbers, are called 'glochids' (*aguates* in Mexico) and the large ones are modified leaves according to some authorities (Granados and Castañeda, 1996). When people come into contact with the plant, spines are released that may penetrate the skin, and this can be a serious impediment when harvesting, processing and eating the fruit. The pads later lignify and become woody stems that crack and turn white to grey in colour.

The flowers, which are sessile, hermaphrodite and solitary, normally develop on the upper edge of the leaves. Colour is variable and includes red, yellow and white. In most parts of the world the plants flower once a year, although in Chile, under certain environmental conditions and with water supplied during summer, there is a second flowering in autumn (March), which explains the origin of the name *inverniza* for this fruit (Sudzuki, Muñoz and Berger, 1993).

PHOTO 1
Different types of Opuntia plants

C. SÁENZ, CHILE (2000)

The fruit is a 'false' berry as it has an inferior ovary that is simple and fleshy. The shape and size of the fruits is variable. Chessa and Nieddu (1997) and Ochoa (2003) described the types of fruit – ovoid, round, elliptical and oblong with flat, concave or convex borders. Colours vary through red, orange, purple, yellow and green with pulp of the same colours. The epidermis of the fruit is similar to that of the cladode, including areoles and abundant glochids and spines, which differ from cladodes in that they remain even after the fruit has over-ripened. The thickness of the fruit peel is variable, as is the amount of pulp. The latter contains many seeds, normally eaten with the pulp. Some fruit show aborted seeds, which increases the proportion of edible pulp. Given the preference in some markets for seedless fruit or for fruit with low seed content, genetic improvement has focused upon identification and multiplication of varieties with this characteristic (Mondragón-Jacobo, 2004).

GENERAL CHARACTERISTICS OF THE SPECIES

Opuntia spp. has, simultaneously, both common and diverse characteristics. A capacity to resist high temperatures and long periods of drought make *Opuntias* highly suitable for production in arid and semi-arid zones.

Some species are widely used for fruit production because of their high quality. This is the case with *Opuntia ficus-indica, Opuntia hyptiacantha*, *Opuntia megacantha* and *Opuntia streptacantha.* Some species produce coloured fruit, which is an additional attraction for consumers. Other species are more suitable for the production of fleshy leaves as a vegetable (*nopalitos*), such as *Opuntia robusta, Opuntia leucotricha* and *Opuntia ficus-indica.* A large number of species are used to produce forage, including *Opuntia robusta*, *Opuntia leucotricha* and *Opuntia ficus-indica*. Other species are used for cochineal breeding.

The fruit is probably the most interesting part of the plant given its differing size, low acidity and useful sugar content. The characteristics of *Opuntia xoconostle* are different and attractive. These are described below.

DIFFERENT PARTS OF THE PLANT: CHEMICAL COMPOSITION AT VARIOUS PHYSIOLOGICAL STATES

In order to utilize the plant industrially it is essential to ascertain the chemical composition of its different parts. This helps in determining the most appropriate processing technologies and the conditions required to achieve safe, nutritious and high quality products. The fruits and cladodes are widely used for food, but the flowers are considered as a vegetable and can be eaten as such (Villegas and de Gante, 1997).

Changes in the pH and the soluble solids and fibre content occur during ripening and must be taken into account when processing fruit or cladodes to produce the best possible products.

Fruit

The composition of the fruit varies with ripening. However, as the fruit are non-climacteric (they do not ripen once harvested) it is important to collect them at the optimal ripened stage for processing and/or marketing and/or consumption. This optimal stage is determined by a number of specific parameters. Inglese (1999) and Cantwell (1999) proposed different parameters to define the best time for harvesting the fruit: size, fill of the fruit, changes in peel colour, firmness of the fruit, depth of the flower cavity or receptacle, total soluble solids content (TSS) and fall of the glochids. As there is no single index for harvest, a number of authors recommend that this should be defined for each type of fruit in each cropping area.

The TSS increases rapidly as the pulp begins to expand (e.g. 40–50 days after fruit set) and when the colour of the peel begins to change (when the TSS is 85–90 percent of the level attained when fully ripe). When the peel coloration is halfway towards that of the fully ripened fruit, the TSS is 12–15 percent, depending on the cultivar. At this stage the fruit is at its best quality for consumption or storage. Although the TSS increases slightly in fully ripened fruit, by this stage the fruit is not in the best condition for storage and is too soft for handling. Table 1 indicates the most significant changes taking place in *Opuntia amyclaea* during ripening (Montiel-Rodríguez (1986), cited by Cantwell [1999]).

The sugar, TSS and vitamin C content increase considerably during the ripening process, while firmness and acidity fall. The changes described for *Opuntia amyclae* are similar to those reported for fruit of other *Opuntia* spp. (Barbera *et al.*, 1992; Kuti, 1992).

However, not all *Opuntias* show the same behaviour during ripening. Silos-Espino *et al.* (2003) studied these changes in three *Opuntias* commonly consumed in Mexico: *Opuntia ficus-indica, Opuntia sp.* and *Opuntia streptacantha*, which are early-, medium- and late-ripening varie-

TABLE 1
Physical changes and composition of Opuntia amyclaea fruits during ripening

State of ripening	Weight (g)	Minimum–maximum diameter (cm)	Depth of receptacle (mm)	Pulp (%)	Firmness (kg cm $^{-2}$)	Total soluble solids content (%)	Acidity (%)	pH	Vitamin C (mg [100 g]$^{-1}$)
Unripe	86	42–44	7.2	44	4.6	7.5	0.08	5.2	12
Green ripeness	102	47–49	3.5	57	3.7	8.8	0.04	6.1	18
Intermediate	105	49–53	1.9	63	2.7	10.1	0.03	6.2	18
Ripe	112	50–54	1.4	65	2.4	11.5	0.02	6.3	26
Over-ripe	108	49–53	1.0	75	2.2	12.5	0.02	6.4	28

Source: Montiel-Rodríguez (1986), cited by Cantwell (1999).

ties respectively. Harvest time (ripeness for consumption) was determined in the field by producers and based on the colour and texture of the fruit.

The pH level evolves as ripening progresses. This is clear in the cases of *Opuntia streptacantha*, *Opuntia ficus-indica* and *Opuntia* spp. The first species shows low pH values (of around pH 3) when ripening is incipient, which later increases to pH 6. The other two species do not show any changes in pH during ripening, with values remaining constant at close to pH 6. The increase in TSS content in all three species reaches similar levels of around 14 °Brix.

Another interesting parameter for which little information has been published is the firmness of fruit, which fluctuates between 1.8 and 3.3 N. *Opuntia streptacantha* is the firmest and has better prospects for post-harvest processing than the other two species (Silos-Espino *et al.*, 2003). The loss of fruit firmness with ripening has also been noted by Nieddu *et al.* (1997) for fruits of cultivar *Gialla* grown in Sardinia, Italy.

The chemical composition of the edible parts of the fruit is generally published by national authorities in tables of the chemical composition of foods, and is typical of the plants that cover the entire country or specific regional zones. However, plant composition varies depending on a variety of factors, including areas of cultivation. In the case of fruit, for example, chemical composition is affected by ripening. It is essential to have some knowledge of the characteristics of the species and its adaptation to local conditions before starting to process it.

The edible part of the cactus pear fruit consists of pulp and seeds. Pulp yield is an important factor to consider for processing and studies by various authors have shown that the quantity of peel varies according to the zone of cultivation. Sepúlveda and Sáenz (1990), working with *Opuntia ficus-indica*

TABLE 2
Chemical composition of the pulp of cactus pear fruit (g [100 g]$^{-1}$)

Parameter	(1)	(2)	(3)	(4)	(5)	(6)
Moisture	85.1	91	85–90	85.6	83.8	84.2
Protein	0.8	0.6	1.4–1.6	0.21	0.82	0.99
Fat	0.7	0.1	0.5	0.12	0.09	0.24
Fibre	0.1	0.2	2.4	0.02	0.23	3.16
Ash	0.4	-	-	0.44	0.44	0.51
Total sugars	-	8.1	10–17	12.8	14.06	10.27
Vitamin C (mg [100 g]$^{-1}$)	25	22	4.6–41	22	20.33	22.56
ß-carotene (mg [100 g]$^{-1}$)	-	-	trace	trace	0.53	-

Source: (1) Askar and El-Samahy (1981); (2) Muñoz de Chávez *et al.* (1995); (3) Pimienta-Barrios (1993); (4) Sawaya *et al.* (1983); (5) Sepúlveda and Sáenz (1990); (6) Rodríguez *et al.* (1996).

TABLE 3
Mineral composition of pulp of cactus pear fruit (mg [100 g]$^{-1}$)

Mineral	(1)	(2)	(3)	(4)	(5)
Calcium	24.4	49	27.6	12.8	-
Magnesium	98.4	85	27.7	16.1	-
Iron	-	2.6	1.5	0.4	-
Sodium	1.1	5	0.8	0.6	1.64
Potassium	90	220	161	217	78.72
Phosphorus	28.2[a]	-	15.4	32.8	-

Source: (1) Askar and El-Samahy (1981). (2) Muñoz and Chávez *et al.* (1995). Sawaya *et al.* (1983). (4) Sepúlveda and Sáenz (1990). (5) Rodríguez *et al.* (1996).
[a)] Phosphate PO_4 mg (100 g)$^{-1}$.

cultivated in Chile, found that the proportion of peel was 50.5 g (100 g)$^{-1}$ of pulp, and 49.6 g (100 g)$^{-1}$ of edible components (pulp and seeds) of which 78.9 g (100 g)$^{-1}$ was pulp and 20.1 g (100 g)$^{-1}$ was seeds. For fruit cultivated in Saudi Arabia, Sawaya *et al.* (1983) found 88 g (100 g)$^{-1}$ of pulp and 12 g (100 g)$^{-1}$ of seeds in edible components for the same species. In Argentina, the percentage of pulp found was 54.7 g (100 g)$^{-1}$ and 42.3 g (100 g)$^{-1}$ of peel and seeds Rodríguez *et al.*, 1996).

A number of authors have conducted studies on the chemical composition of the cactus pear fruit (including Sawaya *et al.*, 1983; Sepúlveda and Sáenz, 1990; Ewaidah and Hassan, 1992; Cacioppo, 1992; Sáenz, Sepúlveda and Moreno, 1995a; Muñoz de Chávez *et al.,* 1995; Rodríguez *et al.,* 1996; Parish and Felker, 1997; Sáenz and Sepúlveda, 2001a). Table 2 shows the chemical composition of the edible part of fruit from plants cultivated in different regions of the world: Argentina, Chile, Egypt, Mexico and Saudi Arabia.

Water is the main component of the fruit, which is valuable in arid and semi-arid regions. Water content is protected by the peel, which is thick and rich in mucilage. The mucilage binds the water strongly and helps prevent fruit dehydration.

Table 3 presents the mineral composition of the edible components of cactus pear fruits cultivated in a number of countries. Variations can be attributed to: the location of plants; the agronomy of cultivation; the application of fertilizers and irrigation use; climate; and genetic differences between the varieties (Muñoz de Chávez *et al.,* 1995).

There are insignificant variations in the chemical composition of the fruit of *Opuntias* of different colours. Results of studies by Sáenz and Sepúlveda (2001a), Sáenz, Sepúlveda and Moreno (1995a) and Sepúlveda and Sáenz (1990) are shown in Tables 4 and 5. The studies explored macro-elements and mineral components of *Opuntias* of different colours: green, purple and orange fruit were considered with pulp of the same colour (Photo 2).

The variations in content of some of the minerals in the fruits can be attributed to their different origins.

PHOTO 2
Cactus pear fruit of different colours

C. SÁENZ AND E.SEPÚLVEDA, CHILE (1998)

TABLE 4
Chemical composition of cactus pear fruit pulps (g [100 g]$^{-1}$ edible part)

Parameter	Green fruit	Purple fruit	Orange fruit
Moisture	83.8	85.98	85.1
Protein	0.82	0.38	0.82
Fat	0.09	0.02	-
Fibre	0.23	0.05	-
Ash	0.44	0.32	0.26
Total sugars	14.06	13.25	14.8
Vitamin C (mg [100 g]$^{-1}$)	20.33	20	24.1
b-carotene (mg [100 g]$^{-1}$)	0.53	-	2.28
Betanin (mg [100 g]$^{-1}$)	-	100	-

Source: Sáenz and Sepúlveda (2001a); Sáenz, Sepúlveda and Moreno (1995a); Sepúlveda and Sáenz (1990).

TABLE 5
Mineral composition of cactus pear fruit pulps (mg [100 g]$^{-1}$ edible part)

Mineral	Green fruit	Purple fruit	Orange fruit
Calcium	12.8	13.2	35.8
Magnesium	16.1	11.5	11.8
Iron	0.4	0.1	0.2
Sodium	0.6	0.5	0.9
Potassium	217	19.6	117.7
Phosphorus	32.8	4.9	8.5

Source: Sáenz and Sepúlveda (2001a); Sáenz, Sepúlveda and Moreno (1995a); Sepúlveda and Sáenz (1990).

TABLE 6
Characteristics of *Opuntia xoconostle* (average from 11 samples)

Weight of fruit (g)	Pulp (g [100 g]$^{-1}$)	Pulp dry matter (g [100 g]$^{-1}$)	Total soluble solids (g [100 g]$^{-1}$)	Ascorbic acid (mg [100 g]$^{-1}$)	Pectin (g [100 g]$^{-1}$)
53.36	69.38	6.27	5.32	76.80	0.799

Source: Mayorga, *et al.* (1990).

There are remarkable differences between some *Opuntias* in terms of their composition, such as between *Opuntia xoconostle* and *Opuntia ficus-indica*. As these differences are important for industrial utilization, the chemical composition of the former is shown in Table 6 according to the description by Mayorga *et al.* (1990).

The fruits of *Opuntia xoconostle* are smaller than those of *Opuntia ficus-indica*. Although highly variable in size, depending on the cultivar, number of fruit per cladode and environmental conditions, *O. ficus-indica* has produced fruit weighing up to 250 g. However, commercial fruit should weigh less than 120 g (Sudzuki, Muñoz and Berger, 1993; Inglese, 1999; Barbera and Inglese, 1992). Comparing this with the data presented above, the proportion of pulp is greater in *Opuntia xoconostle* than in *Opuntia ficus-indica.* The greatest differences are in content of soluble solids, which is much lower (around 5 percent) and in acidity, which is much higher. Ascorbic acid content (76.8 mg [100 g]$^{-1}$) is also higher. Characteristics of this kind would suggest different industrial processes for fruit from these two species.

For example, *Opuntia xoconostle* is considered a spice or condiment in Mexico (Villegas de Gante, 1997). Processing methods applied to *O. xoconostle* with pH 3.5, will be less drastic than those used for *O. ficus-indica* with pH in the region of 6.0 or more. The lower pH of *O. xoconostle* is a protective factor that inhibits the growth of harmful micro-organisms, which makes products obtained from this species safer for consumers. Scheinvar (personal communication)[1] found pH variations ranging from 2.92 to 3.7 in a study of ten types of *O. xoconostle*.

Cladodes

Cladodes are valuable for industrial use. When they are tender stems (10–15 cm), they can be used as a vegetable (*nopalito*) and, partially lignified at 2–3 years, they can be used for the production of flours and other products. When completely lignified they can be burned as fuel. Table 7 shows the variation in composition of cladodes of different ages.

Flores *et al.* (1995) undertook a study of 20 *Opuntia* varieties to analyse lignified stems, mature cladodes and young cladodes, which coincided with the work of Pimienta (1990). The authors found that the protein content was higher in the sprouts and that fibre content increased with the age of the cladode, reaching 16.1 percent in the lignified stems and close to 8 percent in the sprouts. Similar findings were observed by Tegegne (2002) in an experiment carried out in Ethiopia. The ash content did not follow the same trend and the young pads had lower levels of ash than the cladodes or stems. This variation was caused by the number of elements and compounds contained in the ash and their strong relationship with the chemistry of soils, and the complex phenomena affecting their availability to the plant (Bravo, 1978).

Rodríguez-Félix and Cantwell (1988) showed that the chemical composition of fresh young stems was mainly water (91 g $[100\ g]^{-1}$) and 1.5 g $(100\ g)^{-1}$ proteins, 0.2 g $(100\ g)^{-1}$ fats, 4.5 g $(100\ g)^{-1}$ total carbohydrates and 1.3 g $(100\ g)^{-1}$ ash, of which 90 mg $(100\ g)^{-1}$ was calcium. In addition, they found 11 mg $(100\ g)^{-1}$ vitamin C and 30 µg $(100\ g)^{-1}$ carotenoids in fibre content (1.1 g $[100\ g]^{-1}$), which is comparable in value to spinach.

Flowers

Like young cladodes or *nopalitos*, the flowers can be considered a vegetable and eaten as such (Villegas de Gante, 1997). Studies by Jonas *et al.* (1998) indicated that some components are useful in combating benign prostatic hyperplasia because extracts of dried flowers gave beneficial effects.

FRUITS AND CLADODES: NUTRITIONAL VALUE AND FUNCTIONAL PROPERTIES

There has been a recent trend in consumer demand for foods with higher nutritional value, as well as with health benefits, which has spawned a new category of 'functional foods'. The health benefits include disease prevention (Sáenz, 2004).

Fruits and cladodes: nutritional value

According to Sáenz (1999 and 2000), cactus pear fruit has a similar nutritional value to other fruits, although it has a much higher soluble solids content than many popular fruits such as apple, apricot, cherry, melon, peach and plum (Pimienta, 1990; Schmidt-Hebbel and Pennacchiotti, 1990; Sepúlveda and Sáenz, 1990). This characteristic makes cactus pear fruit suitable for processing by concentration or dehydration, taking advantage

TABLE 7
Chemical composition of cladodes of different ages (g $[100\ g]^{-1}$ d. m.)

Age (years)	Description	Protein	Fat	Ash	Crude Fibre	Non-nitrogen extract
0.5	Young stems *(nopalitos)*	9.4	1	21	8	60.6
1	Fleshy leaf *(penca)*	5.4	1.29	18.2	12	63.1
2	Fleshy leaf *(penca)*	4.2	1.40	13.2	14.5	66.7
3	Fleshy leaf *(penca)*	3.7	1.33	14.2	17	63.7
4	Lignified stems	2.5	1.67	14.4	17.5	63.9

Source: López, Fuentes and Rodríguez (1977), cited in Pimienta-Barrios (1993).

[1] Leia Scheinvar, Instituto de Biología, Universidad Nacional Autónoma de México, Mexico (2004).

of the reduced water activity and increased sugar content as a means of preservation.

Most of the sugars present in the fruit are reducing types, with around 53 percent glucose and the remainder fructose (Russel and Felker, 1987; Sawaya *et al.,* 1983; Sepúlveda and Sáenz, 1990; Kuti and Galloway, 1994; Rodríguez *et al.,* 1996). Glucose, the only energetic metabolite in brain and nerve cells, is found in cactus pear in free form and can be absorbed directly by the body.

Fructose helps to improve flavour because it is sweeter than glucose and sucrose and it is easily absorbed by the body (Cheftel, Cheftel and Besançon, 1983).

The contents of protein (0.21–1.6 g $[100\ g]^{-1}$), fat (0.09–0.7 g $[100\ g]^{-1}$), fibre (0.02–3.15 g $[100\ g]^{-1}$) and ash (0.4–1.0 g $[100\ g]^{-1}$) are similar to other fruits (Askar and El Samahy, 1981; Pimienta, 1990; Sawaya *et al.,* 1983; Sepúlveda and Sáenz, 1990; Rodríguez *et al.,* 1996; Muñoz de Chávez *et al.,* 1995).

The calorific value of cactus pear fruit pulp varies between 31 and 50 kcal $(100\ g)^{1}$, which is comparable with other fruits such as apples, oranges, peaches and pears (Sawaya *et al.,* 1983; Muñoz de Chávez *et al.,* 1995; Schmidt-Hebbel and Pennacchiotti, 1990).

The total content of free amino acids (257.24 mg $[100\ g]^{-1}$) is higher than the average for other fruits, although citrus and grapes have similar values. Cactus pear has a relatively high level of serine, g-amino butyric acid, glutamine, proline, arginine and histidine and also contains methionine (Askar and El-Samahy, 1981). A study by Stintzing, Schieber and Carle (1999) found a high level of taurine in fruit of *Opuntia ficus-indica* cultivated in South Africa and Mexico, with values ranging from 323.6 mg l^{-1} to 572.1 mg l^{-1}. The presence of this amino acid is unusual in many plants. It is important for the development of the retina and in the synthesis of biliary acids, which the human body synthesizes in limited quantities.

The fruit has a high level of ascorbic acid, reaching values of 40 mg $(100\ g)^{-1}$, which is higher than in apples, bananas, grapes and pears.

The fruit is a good source of minerals, such as potassium (217 mg $[100\ g]^{-1}$), and is low in sodium (0.6–1.19 mg $[100\ g]^{-1}$), which is beneficial for people with kidney problems and hypertension (Sepúlveda and Sáenz, 1990; Rodríguez *et al.,* 1996). It is also rich in calcium and phosphorus, with levels of 15.4–32.8 mg $(100\ g)^{-1}$ and 12.8–27.6 mg $(100\ g)^{-1}$ respectively (Sawaya *et al.,* 1983; Sepúlveda and Sáenz, 1990).

Calcium and phosphorus are important for bone formation and make up three-quarters of the body's mineral content. Although the cactus pear has potential to deliver calcium in the diet, more studies on bio-availability are required. Phosphorus content is similar to that found in cherries, apricots, melons and raspberries.

Like many other vegetables, cladodes contribute high levels of water to the diet and are valuable for fibre content. They are part of the basic diet of Mexicans and are popular in the southern United States where there are many people of Mexican origin. The vegetable is rich in dietary fibre at levels comparable with other fruits and vegetables, such as mango, melon, apricot, grapes, spinach, artichoke, beet, eggplant, broccoli and radish (Zambrano, Hernández and Gallardo, 1998; Ruales and Zumba, 1998; Schmidt-Hebbel *et al.* 1990). Analysing the plant for food value, Muñoz de Chávez *et al.* (1995) showed high water content (90.1 g $[100\ g]^{-1}$), low content of fat, carbohydrate and protein, and high fibre content of 0.3, 5.6, 1.7 and 3.5 g $(100\ g)^{-1}$ respectively.

The plant is also rich in minerals, especially calcium and potassium, at 93 mg $(100\ g)^{-1}$ and 166 mg $(100\ g)^{-1}$ respectively. It is low in sodium, at 2 mg $(100\ g)^{-1}$, which has health benefits. While high calcium content makes it important in the diet, this is an issue requiring further investigation. In a study carried out with young stems, McConn and Nakata (2004) showed that calcium would *not* be readily absorbed by the body because it exists in the form of calcium oxalate crystals. Furthermore, the young stems contained moderate amounts of carotenoids (30 µg $[100\ g]^{-1}$) and vitamin C (11 mg $[100\ g]^{-1}$) (Rodríguez-Félix and Cantwell, 1988).

Cantwell (1999) described the nutritional value of fresh young stems as comparable with lettuce or spinach, with the advantage that they can be produced fast and abundantly from plants exposed to high temperatures and with little water. These conditions are unfavourable for the production of most other leafy vegetables.

Fruits and cladodes: functional properties

Functional compounds are those that help prevent disease. The fruit and cladodes of cactus pear provide interesting sources of functional compounds, including fibre, hydrocolloids (mucilage), pigments (betalains and carotenoids), minerals, (calcium and potassium) and vitamins with antioxidant properties, such as vitamin C. These compounds are valued for their contribution to a healthy diet and also as ingredients for designing new foods

(Sáenz, 2004). The contents of these compounds differ in fruits and cladodes. For instance, the pulp of the fruit is richer in vitamin C, while cladodes are higher in fibre. Pigments are found mainly in the fruit, and both betalains and carotenoids are present in the peel and pulp of various ecotypes.

These compounds can be included in a new range of foods known as functional foods, which are as foods or beverages that provide physiological benefits. They enhance health, help to prevent or treat disease and/or improve physical or mental performance with the addition of one or more functional ingredients or using appropriate biotechnologies (Sloan, 2000).

Of the functional compounds available, dietary fibre is one of the most widely studied. It has helped to establish nutritional value and the relationships between fibre and health (e.g. cholesterol control and/or prevention of diseases such as diabetes and obesity). Most consumers are familiar with this kind of information (Hollingsworth, 1996; Grijspaardt-Vink, 1996; Sloan, 1994).

Dietary fibre consists of different components such as cellulose, hemicelluloses, and lignin (Spiller, 1992; Periago *et al.,* 1993).

Fibre is classified as either water *soluble* or *insoluble*. The former consists of mucilage, gums, pectin and hemicelluloses, while the latter is formed mainly by cellulose, lignin and a large fraction of hemicelluloses (Atalah and Pak, 1997). These fractions of fibre have different physiological effects. Soluble fibre is associated with reduced glucose and cholesterol levels, and stabilization of gastric emptying. Insoluble fibre heightens water-binding capacity (increasing the weight of faeces), ionic exchange and the absorption of biliary acids, minerals, vitamins and other compounds, as well as interaction with microbial flora.

The fresh fruit is normally eaten with its seeds, which contributes significant amounts of fibre to the diet. Muñoz de Chávez *et al.* (1995) reported variable amounts of fibre depending on the species, within the range 2.73 for *Opuntia streptacantha* and 11.38 for *Opuntia ficus-indica.* Cladodes are an important source of fibre, calcium and mucilage, all of which are valuable in a healthy diet (Sáenz, 2004; Sáenz, Sepúlveda and Matsuhiro, 2004a).

The pigments present in the fruits, such as carotenoids and betalains, are valuable antioxidants. Although the antioxidant power of b-carotenes and flavonoids is well known, that of the betalains has only recently begun to be studied, and eating them may help to prevent tissue ageing (Butera, 2002; Kuti, 2004; Galati *et al.,* 2003). In this respect it compares with fruits such as oranges or red grapes.

TECHNOLOGICAL CHARACTERISTICS AND PROCESSING

Apart from chemical composition and nutritional value, there are other important cactus pear characteristics that present additional challenges when processing the fruit. The high pH values (5.3–7.1) found in many *Opuntias* place the fruit in the low-acid category (pH greater than 4.5). The exception is *Opuntia xoconostle*, with pH 3.5 or less (Mayorga *et al.,* 1990). This necessitates heat treatment to a minimum temperature of 115.5 ºC to achieve good control of micro-organisms. The pH value and high total soluble solids content make the pulp of cactus pear an ideal medium for the growth of micro-organisms (Sepúlveda and Sáenz, 1990; Sáenz, 1999).

Various acids contribute to acidity even in small amounts. Barbagallo, Papalardo and Tornatore (1998a) studied the organic acids present in the juices of three varieties of cactus pear grown in Italy: *Gialla, Rossa* and *Bianca*. They found that citric acid predominated, at around 17 mg $(100\ g)^{-1}$, followed by oxalic, malic and succinic acids in different proportions in the three varieties.

Although found at low levels in the fruit pulp, pectin is partially responsible for viscosity and is a useful ingredient for the production of jams and jellies.

Table 8 shows some of the technological characteristics of cactus pear with green pulp. This is also known as white cactus pear, probably because it has no pigment other than chlorophyll. It is the main species grown in many countries. The percentage of peel, pulp and seeds are similar, although pH, acidity and Brix values vary and this has to be taken into account when processing the fruit.

The existence of cactus pear fruits with different colours expands the possibilities for industrial processing. Table 9 compares the technological characteristics of three cactus pear ecotypes of different colours grown in central Chile. Only green-coloured fruit is grown commercially in Chile at present, but studies have revealed that farmers are interested in planting coloured ecotypes, particularly purple- and orange-coloured fruit.

Green-coloured fruit has better texture and flavour (sweeter) than purple or orange-coloured fruit, which tends to be flourier. Purple or orange fruit is not as attractive as green fruit for eating fresh. Nevertheless, coloured fruit could have

TABLE 8
Technological characteristics of the pulp of cactus pear fruit (g [100 g]$^{-1}$)

Parameter	(1)	(2)	(3)	(4)	(5)
Pulp and seeds	-	-	48	49.6	68.4
Peel	-	-	52	50.4	31.6
pH	5.8	5.3–7.1	5.75	6.37	5.95
Acidity (% citric acid)	0.05	0.01–0.12	0.18	0.06	0.14
°Brix (TSS)	13.2	12–17	14.20	14.06	15.41
Total solids	14.9	10–15	14.50	16.20	15.77
Pectin	-	-	0.19	0.17	0.21

Source: (1) Askar and El-Samahy (1982); (2) Pimienta-Barrios (1993); (3) Sawaya *et al.* (1983); (4) Sepúlveda and Sáenz (1990). (5) Rodríguez *et al.* (1996).

TABLE 9
Technological characteristics of pulps of cactus pear fruit (g [100 g]$^{-1}$)

Parameter	Green fruit*	Purple fruit**	Orange fruit***
Pulp and seeds	49.6	37.9	59.3
Peel	50.4	62.1	40.7
pH	6.37	5.85	6.1
Acidity (% citric acid)	0.06	0.04	0.043
°Brix (TSS)	14.06	14.5	14.8
Total solids	16.20	14.12	14.9
Pectin	0.17	-	0.04
Viscosity (mPa s)	73.9	119.2	45

Source: * Sepúlveda and Sáenz (1990); ** Sáenz, Sepúlveda and Moreno (1995a); *** Sepúlveda and Sáenz (1999).

great potential for processing, perhaps more than the white varieties (with green-coloured pulp), because the chlorophyll pigment is sensitive to heat. During thermal processing there is always risk of unfavourable changes in colour and aroma.

The colour of orange and purple fruit, caused by carotenoids and betalains respectively, is an important reason for processing them, as it opens up the possibility of making different coloured products. However, in recent years there have been an increasing number of studies to test the stability of some of these pigments, both in isolation and in processed products (Merin *et al.*, 1987; Montefiori, 1990; Farías, 2003; Castellar *et al.*, 2003). These pigments, particularly the chlorophylls, affect the results of thermal processing. Sáenz and Sepúlveda (2001b) reported that the colour of juices from green fruit changed easily with degradation of the chlorophyll. This was accentuated with the addition of acid used to ensure the product's microbiological stability. For juices from purple fruit this effect is minimized because betalains display greater stability than chlorophylls under the same thermal treatments and variations in pH.

The viscosity of the pulp is influenced by the presence of pectin and mucilage, owing to their capacity to hold and bind water. Both pectin and mucilage are considered hydrocolloids and are valuable components of dietary fibre. Once extracted from the pulp, these compounds can be used as food thickening agents (Sáenz, Sepúlveda and Matsuhiro, 2004a; Sepúlveda, Sáenz and Vallejos, 2003b).

Other minor but no less important components are the volatile compounds responsible for the aroma of cactus pear fruit and its products. These are mainly alcohols, the most important of which is ethanol. Other more characteristic components of the cactus pear fruit include unsaturated alcohols and unsaturated aldehydes, including 2.6-nonadienal and 2-nonenal found in green and purple varieties. According to some authors, 2-hexenal prevails over ethanol in purple varieties (Di Cesare and Nani, 1992). There are also differences in the aromatic components of the varieties *Bianca, Gialla* and *Rossa,* grown in Italy (Di Cesare, Testoni and Polesello, 1991). The delicate aroma of the fruit can be affected by processing; some products take on the smell of hay or grass when they have been processed by heating. This is an issue that would benefit from further study, although much depends on the processing requirements for the products.

In the tender leaves or stems (*nopalitos*), the presence of polyphenols causes darkening, which leads to problems with preservation (Rodríguez-Félix, 2002). Polyphenols are valuable antioxidants in food.

Furthermore, the acid levels in young stems vary throughout the day as a result of the CAM metabolism. These levels should be taken into account at harvest time, as this acidity can be used to boost preservation and to make the final products more acceptable to consumers.

POTENTIAL USES OF *OPUNTIA* SPP.

The cactus pear plant provides many opportunities for processing fruit and cladodes. Much as with other food plants, the fruit and cladodes of cactus pear can be preserved and processed, using different technologies and practices. A number of traditional foods are prepared from cactus pear, including fruit-based products: jams, juices and nectars; dried fruit; juice concentrates and syrups; and liquors. Pickles, juices, jams and a number of other minimally processed products can be made from cladodes.

A number of functional compounds can also be extracted and used to formulate and enrich new foods. These include natural additive gums and colorants with potential for the food, pharmaceutical and cosmetic industries. Fibre-rich products can be made to help control diabetes and obesity. The plant is also the host of the cochineal insect and thus the basis for producing a highly valued natural colorant.

The integrated utilization of the cactus pear plant provides potential for establishing a host of interrelated industries, small- and larger-scale, artisanal and/or commercial. The key issues are supply and demand, maximizing return on investment and the efficient use of raw materials. This helps increase net returns and avoid waste. Waste that cannot be used directly undermines profitability and, if not treated or disposed of properly, can result in environmental contamination. Table 10 describes options for processing *Opuntias*. Many industrial sectors could benefit from using *Opuntias*. These include the food industry and associated sectors and the construction, pharmaceutical and cosmetic industries. Opportunities for production are:

- food and beverage industry (e.g. various food products and alcoholic and non-alcoholic drinks made from fruit and young cladodes *[nopalitos]*);
- livestock feed industry (e.g. supplements and feed from cladodes and waste from fruit processing, including peel and seeds);
- pharmaceutical industry (e.g. gastric mucosal protectants from mucilage extracts, tablets and capsules of cladode powder and flower extracts);
- cosmetic industry (e.g. creams, shampoos and lotions from cladodes);
- food supplements industry (e.g. fibre and flours from cladodes);
- natural additives industry (e.g. gums from cladodes and colorants from fruit);
- construction industry (e.g. binding compounds from mucilage/cladodes);
- energy sector (e.g. biogas from digestion of cladodes and factory waste streams; alternatively, lignified cladodes burned as fuelwood);
- agricultural inputs (e.g. soils, organic materials and improved drainage from the use of cactus pear plant products);
- tourism sector (e.g. artisan crafts made from lignified cladodes);
- textile industry (e.g. use of natural colorants, such as carmine from cochineal insects).

There is a wide range of possibilities for using the different parts of the plant. Various *Opuntia* species are available with fruit of different colours, and cladodes with many uses, depending on the stage of maturity (either for food or feed). There are many health benefits for people eating these foods: vegetables have been shown to boost the nutritional value of diets. In food-insecure areas, the plant will grow where others fail. In addition, there is the possibility of breeding cochineal on cladodes and harvesting these insects for dyes. There is potential for a range of functional compounds for the food-supplement and cosmetic industries. Compared with other plants, *Opuntias* have the advantage of multiple uses in agro-industry.

TABLE 10
Food products, by-products and additives obtained from cactus pear fruit and cladodes

Products	Products	By-products
Fruit	***Cladodes***	***Fruit and cladodes***
Juices and nectars	Juices	Oil from seeds
Jams, gels and jellies	Pickled and brine-cured products	Mucilage from cladodes
Dehydrated fruits and fruit leathers	Jams and jellies	Pigments from peel and fruit
Sweeteners	Flours	Dietary fibre from cladodes
Alcohols, wines and vinegars	Alcohol	Pulp for animal feed from peel and seeds
Canned fruit	Confectionery	
Frozen fruit and pulp	Sauces	
	Young stems *(nopalitos)*	

Source: Sáenz (2000); Corrales and Flores (2003).

Given the special interest in the value of non-food products from *Opuntias*, a brief summary follows describing some product characteristics. Food production is described in Chapters 4 and 6. Industrial-scale production of certain non-food products is described in Chapter 7.

One of the more active industrial sectors at present is natural additives. Anything natural is highly valued as food because consumers associate it with safe, secure and healthy eating, although this is not always the case. Industries producing additives are always on the lookout for *natural* additives for use in food, pharmaceutical and cosmetic products. For centuries *Opuntias* have been a natural host for the cochineal insect (*Dactilopius coccus*), from which the natural colorant carmine is extracted (Aquino and Barcenas, 1999; Sáenz, Corrales and Aquino, 2002a; Sáenz, Garrido and Carvallo, 2004b). The intense red colour of this pigment is even more attractive because of recent misgivings over the safety of many synthetic red colorants, many of which have been withdrawn by legislation.

The main drawback of the cochineal insect is agronomic: it is a pest to *Opuntias*. The ideal solution is to separate commercial fruit and cladode plantations from those producing the cochineal insect. Crop management is the key to preventing food plantations from insect attack. Commercial plantations for cochineal exist in Chile and the Canary Islands. In Chile, a geographical boundary has been established for the cultivation of cactus pear for cochineal to avoid pest problems in fruit plantations. However, in Peru the same plantations produce both fruit and cochineal insects. Flores-Flores and Teckelenburg (1999), Vigueras and Portillo (1992) and Sáenz, Corrales and Aquino (2002a) describe cactus pear management for the production of cochineal and factors affecting the production and quality of carminic acid and related topics.

The extraction of betalain compounds from red or purple cactus pear was explored some years back. These compounds are water soluble pigments derived from betalamic acid, the stability of which is affected by pH. They are most stable at pH 4–6 (Castellar *et al.,* 2003). They are divided into two main groups: betacyanins (red) and betaxantines (yellow), which have absorbances at wavelengths of 540 nm and 480 nm respectively. There are several compounds within the betacianin group, including betanine, which is mainly responsible for the red colour (Fernández-López *et al.,* 2002). Betanine is also called 'beet red' and accepted as a natural colour for foods that are not heat-treated, such as yoghurts, ice creams and syrups. It is found in the peel and pulp of the fruit and varies in concentration according to species (Odoux and Domínguez-López, 1996; Sáenz, 2004; Sepúlveda, Sáenz and Gómez, 2003a). It would be useful to identify the species with the highest concentration of this pigment. Table 11 shows pigment levels in the peel and fruit pulp of different *Opuntia* species. This analysis is based on species growing in the botanical gardens in Blanes, Spain. Sepúlveda, Sáenz and Gómez (2003a) corroborated the findings shown in Table 11 on a group of *Opuntia* species grown in Chile.

TABLE 11
Betalain content in different parts of the fruit of a range of species of *Opuntia* (mg [100 g]$^{-1}$ fresh weight)

Species	Fruit colour	Peel	Pulp
Opuntia sp$_3$	Purple	72	49.3
Opuntia robusta	Purple	19	58.2
Opuntia robusta-robusta	Purple	40.5	86.1
Opuntia decumbers	Red	22.1	37.3
Opuntia ficus-indica	Pink	1.1	4.1
Opuntia sp$_1$	Purple	118.3	126.8
Opuntia sp$_2$	Purple	44.8	27.6
Opuntia acidulata	Red	1.8	0.3
Opuntia sherri	Purple	8.4	6
Opuntia microdasys	Red	0.9	0
Opuntia curvispina	Red	112.4	99

Source: Odoux and Domínguez-López (1996).

Cactus pear fruit contains variable amounts of seed but quantities tend to be high (10–15 g [100 g]$^{-1}$). Given that seeds need to be removed from the fruit pulp prior to processing most products, over the years various countries have made efforts to find uses for the seeds. Sawaya and Khan (1982) and Sepúlveda and Sáenz (1988), working in Saudi Arabia and Chile respectively, analysed the yield and composition of oil extracted from the seeds of cactus pear fruit. They found high levels of unsaturated fatty acids, high linoleic acid content and low linolenic content, which could affect stability. This suggests that the seeds contain oil that is potentially edible. In 1998, El Kossori *et al.* analysed the seeds of fruits grown in Morocco, which highlighted the oil available and also the fibre content (54.2 g [100 g]$^{-1}$) of cellulose. Earlier, Sawaya *et al.* (1983) had studied the possibility of using seeds as animal feed, and published findings that pointed to the limitations of high fibre content. Yields of edible oils are 6–17 percent which, for a waste stream, compares reasonably with other commonly used oilseeds, and this raises issues of commercial extraction. Oil production is only likely to become viable with integrated processing – using all parts of the plant and taking advantage of the opportunity costs that arise from use (and/or disposal) of low-value materials.

Cladodes have high fibre content and this fibre can be obtained by drying and grinding them (as described in Chapter 6). The resulting powder or flour is used in the food, food supplement and pharmaceutical industries. Tablets or capsules of cladode fibre have been available on the Mexican market for many years where they are used to control obesity and diabetes. In Mexico in the 1980s, a number of studies were conducted on the use of *Opuntia ficus-indica* and *Opuntia streptacantha* for medicinal purposes. A study published on the control of diabetes evaluated the consumption of commercial capsules of dried cladodes of *Opuntia ficus-indica* in patients with diabetes mellitus (FratiMunari *et al.*, 1992). The results showed that the recommended minimum dose of 30 capsules per day required to obtain an effect was impracticable. Studies elsewhere yielded different results depending on the dosage, method of ingestion and type of *Opuntia* used. The best results were obtained with *Opuntia streptacantha*. TrejoGonzález *et al.* (1996) confirmed evidence of the hypoglycaemic action of the cladodes of *Opuntia fulginosa*. Up to 2005, no conclusive studies had been published on the mechanisms involved and/or the value of cladodes for diabetes control.

More recently, new possibilities for pharmaceutical products based on extracts of cladodes and fruit peel have been identified.

In recent years, a number of authors have found other physiological effects, which open up possibilities for new pharmaceutical products based on extracts of cladodes, as well as the fruit peel. Galati *et al.* (2002) undertook work on the protective power of the gastric mucous to prevent gastric ulcers. The anti-inflammatory effects of an extract of cladodes were studied by Loro, Del Río and Pérez-Santana (1999), and antioxidant effects were reviewed by Lee, Kim and Jang (2002). Additionally, Ahamd *et al.* (1996) studied the antiviral properties of an extract of *Opuntia streptacantha.* Finally, a product based on dehydrated extract of peel from the fruit of *Opuntia ficus-indica*, made in the United States and classified as a dietary supplement, has been shown to alleviate the effects of alcohol ('hangover') (Wiese *et al.,* 2004). These studies offer new opportunities for *Opuntias* in medicine.

Another component that has been mentioned for its physiological importance is mucilage. These compounds are found in different proportions in the cladodes and in the peel and pulp of the fruit. Studies by Sáenz and Sepúlveda (1993) showed low yields in all cases: 0.5 percent in peel and 1.2 percent in cladodes. However, these hydrocolloids may be of interest because they can be extracted from mature leaves. This may provide a use for leaves pruned from plants cultivated for fruit production. These hydrocolloids can be used for a wide range of thickening agents for the food and pharmaceutical industries. Viscosity is being studied, with results that may enable them to compete in markets where locust bean gum, guar and other gums are used as thickening agents (Cárdenas, Higuera-Ciapara and Goycoolea, 1997; Medina-Torres *et al.,* 2000; Goycoolea *et al.,* 2000; Medina-Torres *et al.,* 2003; Sepúlveda, Sáenz and Vallejos, 2003b). A major review of these compounds has been published by Sáenz (2004).

Mucilage is also reported to have other properties that may make it suitable as a fat replacement in various foods, and also as a flavour binder according to McCarthy, as cited in Cárdenas, Higuera-Ciapara and Goycoolea (1997).

In Israel, Rwashda, cited by Garti (1999), studied the use of the mucilage or gum of *Opuntia ficus indica* as an emulsifying agent. The author found that the gum:

- reduced the surface and intersurface tension;
- stabilized oil–water emulsions;
- formed small droplets of oil;
- absorbed up to the oil–water interface and did not contribute to the viscosity of the systems;
- prevented the system from flocculating.

Adding to these studies, Espinosa (2000) evaluated the addition of dispersions of this mucilage in different concentrations (0.5 percent and 0.8 percent) to foams formed by egg whites. She showed that the addition of mucilage in these two concentrations increased stability compared with the control (with no addition of mucilage). This resulted in lower syneresis and greater volume after storage for 48 hours.

These types of ingredients are often used for their capacity to develop texture in products, to stabilize emulsions, to control crystallization, as stabilizers for suspensions, to inhibit syneresis and to create edible films. Some have the capacity to form gels.

Not so long ago gums and hydrocolloids were not thought to make a valuable contribution to the nutritional value of foods. They did not increase calorie content or provide flavour or aroma in the products to which they were added. Fashions change as our understanding of health and foods improves, and the value of fibre in foods is increasingly appreciated. Insoluble fibre is not considered to add calories to foods, but soluble fibre does contribute calorific value to a variable extent. For labelling purposes, soluble fibre is deemed to provide 4 cal g^{-1} of food. This insoluble fibre portion can, under certain circumstances, be subtracted from total carbohydrate levels in the food, and the remaining amount can be multiplied by four to give the total calorie contribution from carbohydrates. According to Nelson (2001), adding insoluble fibre to foods is a way of reducing their calorie content.

Without detracting from the possibilities described for utilization of *Opuntias* in the production of food and natural additives and the benefits for integrated use of the plant, many other popular uses have been known for centuries. Some of these are only now being studied scientifically. For example, the use of cladodes: to clarify water (López, 2000); as an adherent for paint when added to lime (Ramsey, 1999); or to increase water infiltration into the soil (Gardiner, Felker and Carr, 1999).

There are many potential uses for *Opuntias*. The plant grows in arid and semi-arid areas with minimum agronomic requirements. It has the potential to provide food, feed and environmental sustainability where other plants would not survive. It can be highly beneficial to local (and typically resource-poor) people living in areas where the plant will grow satisfactorily.

Chapter 3
Field operations and utilization of cactus cladodes

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PRODUCTION

This chapter covers the field cultivation aspects of cactus pear fruits, leaves, pads and stems and of the cactus vegetable (known as *nopalitos* in Spanish). As production, fertilization, pests and diseases have already been covered extensively in the FAO text on agro-ecology, cultivation and uses of cactus pear (Inglese, 1999), only summary information is presented below.

Little worldwide information is available regarding commercial plantations of *Opuntia* for fruit production. Although *Opuntia* is grown for fruit on all continents, no statistics are available from the producer countries: Algeria, Brazil, Colombia, Egypt, Greece, Jordan, Morocco, Peru, Spain, Tunisia and Turkey (Inglese, Giugliuzza and Liguori, 2004).

To establish cactus pear as a crop for fruit production, it is essential to check soil fertility and for the presence of weeds. This will help determine whether weeding and application of fertilizers are required prior to planting. As recommended by Inglese (1999), it is important to determine whether the field has good drainage or, if required, to prepare it accordingly. There is usually little concern about levels of macro-elements in the soil and, according to the same author, only a few over-zealous recommendations exist.

The main species used for fruit production worldwide is *Opuntia ficus-indica*, although other species are grown in Mexico, including *O. streptacantha*, *O. lindhemeiri*, *O. amyclaea*, *O. megacantha* and *O. robusta* (Pimienta Barrios and Muñoz-Urías, 1999).

Planting methods and spacing depend on the growth characteristics of the different varieties and prospects for employing irrigation, even occasionally. The most common method is to plant cactus pear in rows on ridges, which increases exposure to sunlight and makes harvesting and weeding easier. Ridge planting also facilitates the practice known as *scozzolatura*: thinning flowers, cladodes or cactus stems (Sudzuki, Muñoz and Berger, 1993; Inglese, 1999).

Planting material can be obtained from simple asexual vegetative reproduction, from whole cladodes or from parts of the cladode, and also from micropropagation. The plants obtained by the latter (*in vitro)* usually produce roots, and require better land preparation for planting and more reliable moisture (Sudzuki, Muñoz and Berger, 1993). The planting date depends on prevailing climatic conditions for the plants to develop good roots and growth.

Notwithstanding recommendations on how to boost productivity, grow better crops and obtain higher yields, poor crop management is the norm in most *Opuntia* plantations in the Americas and the Mediterranean. However, for reliable fruit production, a certain amount of water must be provided during the dry season to boost yields and to obtain good quality fruit (Mulas and D'hallewin, 1997). The authors also report that, without irrigation, some varieties (e.g. *Gialla, Sarda* and *Bianca*) increase their content of reducing sugars without affecting the content of total soluble solids.

In some countries, there are two well-defined flowering seasons, which lead to summer and winter harvests. In other countries, harvesting takes place during the summer and autumn or only during the summer. The crop can also be managed in such a way as to extend the harvesting period.

Fruit obtained in the summer has a higher number of seeds. Where there is supplementary irrigation, the seeds are larger (Mulas and D'hallewin, 1997). This information follows on from information in the 1990s where irrigation and thinning out of cladodes were recommended to increase and regulate the level of production (Sudzuki, Muñoz and Berger, 1993).

Drip irrigation is used with more advanced cultivation practices intended to produce more fruit than vegetable shoots. For management of this kind, it is necessary to irrigate several times during the year, as is the practice in Israel, for example (Inglese, Giugliuzza and Liguori, 2004).

Cactus plant diseases are classified as infective or biotic and non-infective or abiotic. The former are caused by pathogens such as bacteria, fungi, phytoplasmas and viruses, many of which are unknown agents. The latter tend to stem from damage caused by the environment, atmosphere or soil conditions, and from genetic abnormalities or incorrect use of pesticides. Studies by Granata and Sidote (2002) provide additional information.

Mexico is virtually the only country cultivating *Opuntia* for cactus stem (*nopalito*) production, most of which is sold locally as fresh produce. Supply exceeds demand during the peak season, with consequent saturation of the market, causing losses of up to 60 percent in some periods. Current per capita consumption in Mexico is 5.78 kilograms (kg) year^{-1} (SAGARPA, 2004). *Nopalitos* are part of the traditional Mexican diet and are used as an important component in a wide variety of meals, including soups, salads, stews, sauces, drinks and desserts (Vigueras and Portillo, 1995). *Nopalitos* are a valuable and healthy part of the local diet (Hegwood, 1990; Domínguez, 1995; Stintzing, Schieber and Carle, 2001).

In the United States, the young cactus pads are considered a speciality (Cantwell, 1999) and are eaten mainly by the Hispanic population as a cooked vegetable during the period of Lent and as marinated vegetables during the remainder of the year (Russell and Felker, 1987). However, consumption has increased in recent years and cooking methods have become more varied, with the product now available year round in stores, ethnic markets and supermarkets (McConn and Nakata, 2004).

The fresh vegetable leaf is a living tissue and therefore undergoes a process of continuous change between harvest and consumption. These changes affect its quality and reduce post-harvest life, which can result in considerable losses. Production, physiology, post-harvest processing and quality aspects are discussed below.

Flores-Valdez (1999) reports that, in Mexico, three main systems are used to produce *nopalito*: wild cactus pear, home gardens and commercial plantations. Wild cactus pear covers an estimated area of 3 million hectares (ha), with a range of species including *O. robusta*, *O. streptacantha*, *O. leucotricha* DC, *O. hyptiacantha* Weber and *O. chavena* Griffiths (Pimienta-Barrios, 1993). Tender cactus stems are collected in the spring–summer period for domestic consumption, while the young pads of *O. robusta* Wendl and *O. leucotricha* are marketed fresh or processed. The area of cultivation in home gardens is unknown, but produce is largely consumed in the home or sold in local markets.

In Mexico, commercial plantations of cactus pear for vegetable production cover an area of 9 710 ha, with output of 563 443 tonnes year^{-1}. This puts cactus pear in sixth place by volume of vegetables produced nationally, and eighth place in value after the red tomato, green pepper, potato, onion, green tomato, squash and asparagus. Production is found in 25 of Mexico's 32 states. Milpa Alta, DF is the biggest producer, accounting for 60 percent of national production (SAGARPA, 2004).

Opuntia ficus-indica (L.) Miller is the principal commercial species for vegetable production in Mexico (Pimienta-Barrios, 1993), while *Nopalea cochenillifera* (L.) Salm-Dyck (clone 1308) is the preferred choice in the United States (Mick, 1991). Other commercial varieties of value are Milpa Alta, COPENA V-1, COPENA F-1, Atlixco Jalpa, Esmeralda and Blanco de Valtierrilla (Flores *et al.*, 1995).

Commercial plantations use two types of production system: traditional or intensive (also called the 'microtunnel' system). The traditional system is established by planting mature cladodes (2–3 years old) in rows at planting densities of 15 000–40 000/ha, with plants spaced 30–40 cm apart and a distance of 80–100 cm between rows. The plants grow to a height of 1.0–1.5 metres.

The microtunnel system uses planting densities of 120 000–160 000 plants/ha, with beds measuring 1.2–2.0 metres wide and 40–47 cm long, spaced 1.0–1.5 metres apart. Mature cladodes are planted 20 cm apart, with 20–30 cm between rows. Beds are covered with plastic sheeting in order to reduce the risk of frost damage in winter. This system provides higher yields and output during the coldest months of the year, when production from traditionally grown crops is scarce (Flores-Valdez, 1999; Pimienta-Barrios, 1993).

Production is fast and the first harvest is normally available 2–3 months after planting. Yields from the traditional system are 30–80 tonnes ha^{-1} (Pimienta-Barrios, 1993), while under the intensive system 179 tonnes ha^{-1} and 263 tonnes ha^{-1} have been recorded for the COPENA F1 and COPENA V1 varieties respectively (Blanco-Macias *et al.*, 2002).

Under the traditional system, large quantities of cattle manure (100 tonnes ha^{-1} or more) are applied to the land every two to three years. In some cases mineral fertilizers, such as urea or ammonium sulphate, are also applied one to three times a year. Under the intensive system, cattle manure, nitrogen and phosphorus are applied annually at rates of 100–200 tonnes ha^{-1}, 100–200 kg ha^{-1} and 80–100 kg ha^{-1} respectively (Flores-Valdez, 1999; Pimienta-Barrios, 1993). Rates of 161 kg ha^{-1} of nitrogen, 60.7 kg ha^{-1} of phosphorus and 914 kg ha^{-1} of potassium are recommended for growing *O. ficus-indica* cultivar (cv) C-69 under drip irrigation (Orona-Castillo *et al.*, 2004).

Most commercial plantations are located in regions with summer rainfall of 600–800 mm, meaning that irrigation is needed only during the spring and then 3–4 times in small volumes (Pimienta-Barrios, 1993). However, owing to the expansion of cropping areas, some areas require more regular irrigation. Under some intensive systems, 100 mm is required monthly during the dry season (typically spring), and this boosts production by 10–25 percent (Flores-Valdez, 1999). The use of drip irrigation, including plant establishment, resulted in yields of 108 tonnes ha^{-1}year^{-1} of *O. ficus-indica* C-69, and 65 tonnes ha^{-1}year^{-1} of *O. amyclaea* C-8 (Flores-Hernández *et al.*, 2004) (see Photo 3).

The most important diseases of cactus pear in Mexico are 'enlargement of the cladode' and 'proliferation of sprouts', caused by a mycoplasma and a spiroplasma respectively. Among the most important pests are the zebra worm (*Olycella nephelasa* Dyar) and white worm (*Lanifera cycladea* Druce), while other insects cause damage to the areolas, such as *Cylindrocopturus biradiatus* Champs. The cochineal insect (*Dactylopius* spp.) causes yellowing of tissues (Pimienta-Barrios, 1993).

Harvesting

The *Opuntia* plant blooms once a year in Italy, while in Chile, Israel and the United States it blooms twice. Timing for harvest is an important factor. Harvesting seasons differ according to the variety, agroclimatic conditions and whether forced blooming is used as a production technique (*scozzolatura*).

In Italy, a second blooming is forced by thinning out the flowers and leaves (Inglese, 1999). Schirra, Inglese and La Mantia (1999) observed no differences in soluble solids, acidity and pH with cv. *Gialla* harvested twice a year, in summer and autumn. Ascorbic acid content was higher in summer-harvested fruits, while fruit weight was higher in autumn-harvested fruits.

PHOTO 3
Commercial plantations for vegetables (a) and fruit (b)


(A) A. RODRÍGUEZ-FÉLIX, MEXICO (2005)
(a)


(B) C. SÁENZ, CHILE (2000)
(b)

Fruit harvesting is initiated once the fruit reaches the target size, depending on the variety, and when the soluble solids content exceeds 12 °Brix. It is best to begin harvesting at the lowest possible air temperature, such as early in the morning. This helps avoid the release of spines, and the fruits remain at low temperature, which reduces dehydration and infestation.

A point of note is the confusion in technical literature between spines and glochids. It is correct to refer to large modified leaves as spines, while the glochids are much smaller and grouped in racemes.

There are different ways of harvesting the crop. The commonest method is to collect the fruit with gloves, applying pressure and detaching it with a slight twist, or to use secateurs or knives to cut the fruit from the cladode. This should be done without damaging either the fruit or the cladode. There have been trials with knife-harvesting, leaving a small portion of the mother cladode attached to the fruit. Later this detaches naturally. However, this system may cause problems when handling the cladodes on the plant, and also during the post-harvest period because of the need to remove the attached pieces of cladode from the fruits. Different research studies have favoured one or other of these methods (Cantwell, 1999; Ochoa *et al.,* 1997; Martínez-Soto *et al*., 1999).

Fruit is collected in buckets or trays and left to cure in the sun, drying out any wounds and allowing the glochids to loosen. Typically this is done by laying out the fruit in the field on beds of straw covered with a raschel plastic mesh. Once the fruit is dry – usually the same day if there is sunshine – the glochids are removed by brushing with brooms made from long tender twigs.

Once the glochids are removed, the fruit should be quickly packed and transported to a cool or refrigerated area. This is essential for long-term storage and helps avoid dehydration and the possibility of mould developing on the fruit.

For large-scale harvesting, machinery is normally used to remove the glochids, although rough treatment can shorten fruit shelf-life (Sudzuki, Muñoz and Berger, 1993). Mechanized handling of the crop in the field is described in Chapter 6.

Harvesting of the young cactus pads is done manually, using a knife to cut the base of the cactus pad (Cantwell, 1999). This is best carried out two to three hours after sunrise, in order to avoid high levels of acidity. It should also be done carefully to prevent damage to the base of the pad, which might provide an entry point for microorganisms. Damage can also cause weight loss during subsequent handling (Photo 4).

The young pads are usually harvested when they reach a length of 20–25 cm and weigh 90–100 g (Cantwell, 1999; Pimienta-Barrios, 1993). However, quality standard CODEX STAN 185–1993 describes commercial sizes for cactus stems as anywhere between 9 cm and 30 cm long (FAO/WHO, 1993). Small cladodes (12 cm) or large ones (around 30 cm) are typically used for minimally processed vegetable products (Rodríguez-Félix, 2002). Tender cladodes of *N. cochenillifera* 1308 can be harvested when they reach 11–13 cm in length and weigh almost 40 g (Nerd, Dumotier and Mizrahi, 1997).

In Mexico, harvesting is undertaken throughout the year, although the highest yield is obtained during spring and declines by the middle of autumn and during the winter months. However, with intensive production systems using micro-

PHOTO 4
Harvesting cactus stems or cladodes (*nopalitos*)

A. RODRÍGUEZ-FÉLIX, MEXICO (2005)

tunnels, productivity is high during the coldest months of the year (Pimienta-Barrios, 1993).

POST-HARVEST HANDLING

The cactus pear is a non-climacteric fruit. At 20 °C it has low ethylene production (0.2 nl g^{-1} h^{-1}) and a low respiration rate (20 µL CO_2 g^{-1} h^{-1}), and it is not sensitive to ethylene (Cantwell, 1999).

Early studies on the conservation of cactus pear fruits revealed that the main post-harvest problems are decay and dehydration (Berger *et al*., 1978). Techniques to reduce decay and weight loss, respectively, include the application of fungicides and the use of waxes and plastic packaging. Heat treatment and the use of *natural* waxes and *edible* plastic films have become available in recent times.

There has been increased interest in the use of heat treatment to control post-harvest decay. Physical procedures are being developed or improved in response to consumer demand. These treatments increase the shelf-life of fruits and vegetables and replace the need for fungicides. They provide a viable alternative to the use of fungicides because they reduce fruit susceptibility to pathogens and chilling injury, and slow down post-harvest deterioration (Couey, 1989; Barkai-Golan and Phillips, 1991; Fallik, 2004; Klein and Lurie, 1992; Lurie, 1998a; Lurie, 1998b; Paull and Chen, 2000; Schirra *et al*., 2000; Wang, 1994).

Hot water treatments by immersion for a short time can be used for some fruits to reduce microbial load without damaging the fruit (Shewfelt, 1986). Such treatments are effective in controlling several pathogenic fungi because the spores and latent infections are mainly found on the skin or in the outer layers of the cells of fruits and vegetables. These treatments are normally applied for just a few minutes because only the outer part of the product has to be heated. Many plant products tolerate exposure to water temperatures of 50–60 °C for more than 10 minutes. A short exposure at these temperatures is enough to control many phytopathogens that can develop post-harvest (Lurie, 1998b).

In Italy, pre-storage heat treatment showed potential for extending the shelf-life of cactus pear fruit cv. *Gialla* by at least 4–6 weeks without any prior chemical treatment. This was done either by immersing the fruit for five minutes in hot water at 55 °C or by exposing it to hot, saturated air for 24 hours at 38 °C. This opens up the possibility of supplying good-quality cactus pear fruit during periods when they are in short supply in European markets (Schirra *et al.*, 1996; Schirra *et al.*, 1997a; Schirra *et al.*, 1997b).

In Chile, hot water immersion treatments, combined with fungicides, have been used since the 1970s, reducing the incidence of decay. However, these treatments were eventually discontinued because the fungicides used were not registered for use with cactus pear fruit (Berger *et al.*, 1978). In recent years, these studies have been resumed, using only hot water, without detracting from the firmness, external appearance or acceptability of green and red fruit. Immersion for two minutes in water at 55 °C prolonged the fruit's keeping qualities for 31 days (Berger *et al.*, 2002; Berger and Galletti, 2002).

D'hallewin, Schirra and Manueddu (1999) studied the effects of heat on the epicuticular waxes of cactus pear fruit cv. *Gialla*. From microscopic observation they found that hot air treatments (37 °C for 12 hours, 24 hours, 48 hours or 72 hours) and hot water immersion (52 °C for 3 minutes) caused sealing of the wounds and cracks normally found on the fruits. This left a relatively homogeneous surface from the fusion of the layers of wax, which provided real protection from fungi attack. The use of waxes in *Opuntia* fruits reduces water loss considerably (Cantwell, 1999). In an unpublished study by Berger and Galletti on the use of wax and plastic films, the best treatment was found to be immersion in hot water followed by waxing. This produced attractive and turgid fruits with reduced incidence of decay and spine damage. Similar results were obtained in Argentina by Ochoa *et al*. (1997), who evaluated the effect of wax treatment on cactus pear cv. *Spineless yellow*.

The effect of heat treatment and waxing intensifies fruit colour and shine, improves external appearance, and any symptoms of weight loss are not visible (Berger *et al.*, 2002).

Fruit packaged in plastic film limited dehydration (1.5 percent compared with 3.7 percent) and chilling injury (0.3 compared with 0.9), while improving fruit appearance when compared with control fruit (Piga *et al*., 1996). This treatment also reduced weight loss on cactus pear fruit '*Burrona*' (García-Vite *et al.,* 2003).

The pre-harvest application of calcium chloride (CaCl2) to reduce decay had a detrimental effect because it promoted chilling injury, particularly when combined with hot water treatment. Schirra *et al.* (1997a), working with pre-harvest fruit treated with CaCl2, found that susceptibility to chilling injury in fruit stored at 6 °C was not affected significantly for 42 days but it increased during simulated marketing conditions. This effect was most pronounced when the CaCl2 treatment was combined with hot air treatment prior to storage.

In a later study, Schirra, Inglese and La Mantia (1999) observed that CaCl2 applications promoted the development of chilling injury in fruit harvested during the summer. These authors found a link between chilling injury and the number of applications. Additionally, they observed that fruit harvested during the autumn showed chilling injury during simulated marketing conditions only when the treatment was applied four times during formation of the fruit.

The speed at which *nopalitos* deteriorate after harvesting followed the pattern indicated by Kader (1992), i.e. deterioration is proportional to respiration rate and is temperature-dependent. The respiration rate of the tender cactus pads varies according to the size of the pad: the larger the cladode, the lower the respiration rate. The average rate over a seven-day period for 10 cm-long cladodes is: 16–19 mg kg^{-1} h^{-1} at 5 °C; 38–42 mg kg^{-1} h^{-1} at 10 °C; 52–59 mg kg^{-1} h^{-1} at 15 °C; and 68–79 mg kg^{-1} h^{-1} at 20 °C. These values decrease as the pad size increases, showing values 50 percent lower in cladodes 20 cm long (Cantwell, 2004).

Tender cactus stems produce low levels of ethylene: 0.05 nl kg ^{1} h^{-1} at 5 °C; 0.1 nl kg ^{1} h^{-1} at 10 °C: and 0.22 nl kg ^{1} h^{-1} at 20 °C. These values are comparable with those of asparagus, cauliflower and other leafy vegetables (Cantwell, Rodríguez-Félix and Robles-Contreras, 1992; Cantwell, 2004). Cactus stems are not sensitive to the action of ethylene. However, exposure at high temperatures promoted degradation of the green colour and consequently led to yellowing of the product (Cantwell, 2004).

STORAGE AND TRANSPORT

Storage of the fruit at low temperature is an effective method of reducing moisture loss (Cantwell, 1991, cited in Cantwell, 1999). Without refrigeration, cactus pear fruits senesce rapidly and become susceptible to infection by micro-organisms, especially *Penicillium* spp. and *Alternaria* spp.

The fruit is susceptible to chilling injury (CI). Temperature tolerance depends on the variety, harvest date and field temperatures during the growing period. Symptoms of CI are reddish-brown stains on the surface. In Chile, Berger *et al.* (1978) attributed this discoloration more to damage by spines than to CI (Photo 5). Fruit could be stored under refrigeration for a maximum period of two months at temperatures of 0 ± 0.5 °C and 85–90 percent relative humidity (RH). In Italy, Chessa and Barbera (1984) found that the storage temperature should be 6–9 °C because lower temperatures produced CI and increased the level of decay.

In cactus pear fruit cv. *Gialla*, harvested in summer and autumn in Italy and stored at 6 °C, summer-harvested fruit suffered greater CI than autumn-harvested fruit. In addition, weight loss of summer-harvested fruit was 0.15 percent and 0.27 percent per day respectively during storage

PHOTO 5
Chilling injury in cactus pear cultivar *Bianca*

S. D'AQUINO, ITALY (2005)

and simulated marketing conditions. Findings for autumn-harvested fruit, respectively, were 0.08 percent and 0.23 percent (Schirra, Inglese and La Mantia, 1999).

Martínez-Soto *et al.* (1999) found that the ideal storage temperature for cactus pear fruit cv. *Roja pelona* was 10 °C, which provided conservation for up to 60 days.

There is little information on storage of cactus pear fruit under controlled atmospheric conditions. In Chile, Galletti, Berger and Castillo (1997) stored cactus pear fruit at 0 °C in 2 percent oxygen (O_2) and 5 percent carbon dioxide (CO_2). They found the lowest incidence of decay at 21 days, and that the fruits maintained sensory characteristics for 42 days. In Italy, after storing fruit under similar O_2 and CO_2 conditions and at 5 °C, the fruit quality was much better than that of fruit stored under normal atmospheric conditions (Kader, 2000).

Cactus pear fruits ready for storage or market are generally packed in cartons with a net weight of 5 kg, in which each fruit is displayed separately, wrapped with tissue paper (Photo 6), nested on a celled tray or separated by cardboard bands (Photo 7). Wooden crates are normally used for harvesting and transporting fruit to domestic markets.

There are also standards available in the *Codex Alimentarius* (CODEX STAN 186–1993) relating to quality, presentation, packaging and hygiene for tender cladodes and for cactus pear.

A major problem of tender cactus pads is browning. This typically occurs in fruits and vegetables that have been damaged during transport or cut at time of harvest. This reaction is caused by the enzyme polyphenoloxidase (PPO). The enzyme is widely known for spoiling the colour of foods and is blamed for up to 50 percent losses in tropical fruits post-harvest. High economic losses result when marketing damaged fruits and vegetables. Browning affects appearance and can cause unpleasant odours and decrease the nutritional value of horticultural products (Vamos-Vigyazo, 1981; Whitaker and Lee, 1995).

Differences in susceptibility to browning among fruit and vegetable varieties have been linked to variations in the content and type of phenolic compounds, and to PPO activity (Vamos-Vigyazo, 1981; Whitaker and Lee, 1995). PPO activity and browning susceptibility also vary between varieties. For example, there is high susceptibility with COPENA F-1 and low susceptibility with Atlixco (Rodríguez-Félix, unpublished data).

Total phenolic content in the tender pads differs according to variety and to the stage of development of the cladodes. Tender cladodes from *Opuntia ficus-indica* of commercial size (approximately 20 cm) showed values of 9.19 mg $(100\ g)^{-1}$ for cv. COPENA F-1 and 7.93 mg $(100\ g)^{-1}$ for COPENA V-1 (Rodríguez-Félix, 1986).

Good quality vegetable leaves have a fresh appearance and a brilliant green colour, and are typically thin and turgid. The presence of spines

PHOTO 6
Cactus pear fruit packed in different ways in cardboard boxes

H. BERGER, CHILE (2003)

PHOTO 7
Cactus pear fruit packed in different ways in cardboard boxes

H. BERGER, CHILE (2003)

or glochids is prominent in the early stages of growth in certain species of *Opuntia* (Cantwell, 1999). However, the cladodes of *Nopalea cochenillifera* variety 1308 are almost free of spines and glochids (Nerd, Dumotier and Mizrahi, 1997). The presence of green leaves on the cladode is an indicator of freshness. Thickening of the cuticle and of the cladodes is undesirable and reduces quality. Varieties differ in their physical characteristics such as weight and length of the cladodes (Rodríguez-Félix and Cantwell, 1988).

Codex Alimentarius standards are available for both *nopalitos* (CODEX STAN 185–1993) and the cactus pear fruit (CODEX STAN 186–1993). They describe the requirements for quality, presentation, packaging and hygiene. The quality characteristics required of cactus cladodes describe species (shape and colour), wholeness, firmness, health, cleanliness and freedom from spines and defects (e.g. from parasites and chilling injury). Quality grades included in this standard are: Extra, Class 1 and Class 2. For cladodes, the criteria used to distinguish the different grades are based on appearance, mainly the presence of defects in shape and colour and mechanical damage. Grading is based on the size or length of the cladode, with five categories covering sizes from 9 cm to 30 cm in length (FAO/WHO, 1993). For marketing cactus stems, it is important to apply uniform quality standards in order to ensure competitiveness with other popular vegetables (Caplan, 1995).

The vegetable's shelf-life is determined by several factors, including harvesting, type of packaging, temperature and relative humidity during storage (Cantwell, Rodríguez-Félix and Robles-Contreras, 1992; Nerd, Dumotier and Mizrahi, 1997; Rodríguez-Félix and Villegas-Ochoa, 1997). Weight loss and decay are problems that limit shelf-life in simulated market conditions (20 °C), while CI is the main problem under refrigerated storage (10–12 °C or lower) (Cantwell, Rodríguez-Félix and Robles-Contreras, 1992; Nerd, Dumotier and Mizrahi, 1997; Ramayo, Saucedo and Lakshminarayana, 1978; Rodríguez-Félix and Villegas-Ochoa, 1997).

Cladodes that have been damaged at the base as a result of poor harvesting practices must be marketed within a short time, and should not be stored or sent to distant markets because they can suffer up to 53 percent losses. Losses from decay are caused by *Penicillium* spp., *Aspergillus* spp. and *Alternaria* spp. during storage for 10 days at 15.6–21.1 °C at 50–60 percent RH (Ramayo, Saucedo and Lakshminarayana, 1978). The shelf-life of cladodes (*Opuntia* spp.) when properly harvested was one week at 20 °C and 65–70 percent RH (Rodríguez-Félix and Villegas-Ochoa, 1997). The cladodes of *Nopalea cochenillifera* maintain reasonably good quality for 12 days at 20 °C and 85 percent RH (Nerd, Dumotier and Mizrahi, 1997).

Refrigerated storage reduces the rate of respiration and moisture loss by transpiration, inhibits the growth of micro-organisms and extends the post-harvest life of vegetable products (Mitchell, 1992). The cladodes of *Opuntia* spp. packed in unsealed polyethylene bags maintained their visual quality for two weeks at 10 °C (90–95 percent RH) (1992). Those of *N. cochenillifera*, packed individually in PVC film, maintained quality for three weeks at 12 °C (Nerd, Dumotier and Mizrahi, 1997). However, temperatures lower than 12 °C caused CI in the cladodes and subsequent browning, discoloration of the peel and softening of the product (Ramayo, Saucedo and Lakshminarayana, 1978; Nerd, Dumotier and Mizrahi, 1997). The lower the temperature, the greater the CI. For example, CI symptoms appeared after three weeks at 10 °C (80–90 percent RH), and after two weeks at 5 °C (85–90 percent RH) in *Opuntia* cladodes packed in wooden boxes (Rodríguez-Félix and Villegas-Ochoa 1997).

Some post-harvest techniques that have been shown to reduce CI in vegetable products are temperature conditioning, intermittent heating, modified and controlled atmospheres, chemical treatments and the application of growth regulators. The reduction in damage caused by cold temperatures using these techniques was the result of increased tolerance of the product to low temperatures and delays in deterioration (Wang, 1994).

Packaging in plastic film reduces the symptoms of CI in cactus stems. Results obtained by Cantwell, Rodríguez-Félix and Robles-Contreras (1992) showed that cladodes of *Opuntia* sp. packed in polyethylene bags displayed symptoms of CI after three weeks at 5 °C (90–95 percent RH). Those packaged in wooden boxes showed CI damage after two weeks at 5 °C (85–90 percent RH) (Rodríguez-Félix and Villegas-Ochoa, 1997). Cladodes of *N. cochenillifera* are more susceptible to CI than those of *Opuntia* spp. because the CI symptoms in *N. cochenillifera* appeared after seven days at 4 °C in cladodes without a covering of plastic film. However, packaging in polyethylene bags delayed the onset of CI symptoms until 11 days of storage (Nerd, Dumotier and Mizrahi, 1997). Furthermore, Guevara *et al.* (2001) showed that storing cladodes of *O. ficus-indica* variety Milpa Alta in passive modified atmospheres (up to 8.6 percent O_2 and up to 6.9 percent CO_2) extended storage life and maintained quality for 30 days at 5 °C. This reduced losses of weight and firmness, and changes in colour – benefits arising from the modified atmosphere and *not* from the increase in relative humidity inside the package. Later, Guevara *et al.* (2003) concluded that the storage life of cladodes could be extended to as much as 32 days at 5 °C by applying passive or semi-active modified atmospheres, with an initial concentration of 20 percent CO_2. This level was found to be the maximum that the product could tolerate.

The acidity of cladodes of *Opuntia* spp. and *N. cochenillifera* changes during storage, and these changes are affected by storage temperature and packaging. When stored at low temperatures, the acid content is maintained or increased. By contrast, acidity decreases when storing at higher temperatures (>20 °C) (Cantwell, Rodríguez-Félix and Robles-Contreras, 1992; Nerd, Dumotier and Mizrahi, 1997). According to the authors, these results concurred with those of physiological studies on other CAM plants, which showed that organic acids are the main substrates in the respiration of these tissues when they are kept at high temperatures (Szarek and Ting, 1974). It has also been shown that low temperatures favour the carboxylation of malate, while high temperatures favour the decarboxylation of malate (Brandon, 1967).

Storage temperature also affects the vitamin C level of cactus stems. Low temperatures (5–10 °C) slow down the reduction of ascorbic acid content (Rodríguez-Félix and Villegas-Ochoa, 1997).

Transport and marketing are an important part of the value chain for delivering high-quality goods to the customer (Photo 8). Mexico's main cactus pear production region is Milpa Alta. Cladodes are harvested and packed in baskets for local consumption or in cylindrical bins called *pacas*. These are 1 metre in diameter and 1.7 metres tall, contain approximately 3 000 pieces and weigh 250–300 kg. The bins are transported in trucks to wholesale markets in Mexico City, where they are stored at outdoor temperatures until sold. This normally occurs within three days of harvest. For markets further from production zones, cladodes are packed into wooden crates containing 20 kg or in cardboard boxes holding 5–10 kg, and transported in refrigerated trucks at 10 °C (Cantwell, 1999 and Flores *et al.*, 1995). Cladodes packed in wooden or cardboard boxes are often damaged by spines, which causes the product to brown (Cantwell, 1999).

PHOTO 8
Transport of cladodes and cactus pear fruit

A. RODRÍGUEZ-FÉLIX, MEXICO (2005) AND (2004)

Chapter 4

Utilization of *Opuntia* spp. fruits in food products

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FOOD PRESERVATION SYSTEMS

A large number of fruits and vegetables are seasonal and perishable, including cactus pear fruit. While the fruits of the plant are seasonal, the young stems (*nopalitos*) are not, although they are highly perishable because of their high water content. To make fruits and *nopalitos* available for long periods of the year out of season, it is essential to preserve them to prevent deterioration.

Deterioration of raw materials is caused by several factors: enzymatic changes (which often affect texture); chemical changes (which affect sensory characteristics such as colour, aroma and flavour); nutritional changes (which lead to a loss in nutritional value); and physical changes (such as dehydration). The most damaging of all are biological changes (microbiological attacks by bacteria and fungi or by pests and rodents), which compromise the safety of foods and the health of consumers.

Much can be done to reduce or avoid deterioration and many technologies are available that can be applied to both cactus pear fruit and cladodes. Some have been known and used for many years, while others have been developed recently on an experimental or pilot scale. Many have potential for industrial application.

The preservation systems that can used for *Opuntias* involve technologies based on physical, chemical and biochemical methods. Physical preservation methods include heat transfer, *appertization* (canning), freezing, dehydration and concentration. The latter two methods are based on reducing water activity (a_w). Other more recent developments include irradiation and the application of high pressure and electrical pulses. Chemical methods include salting, adding sugars, acidification and the use of chemical preservatives. Finally, biochemical methods include fermentation, both lactic and alcoholic.

The micro-organism that determines the safety of food packaged in a hermetic container is *Clostridium botulinum* (a sporulating, anaerobic bacterium that produces a highly lethal toxin called botulin, which is controlled by pH because it does *not* develop at a pH level of less than 4.5. Sterilization processes are designed to ensure the destruction of this and other micro-organisms. Table 12 shows the classification of foods according to pH.

In general, foods with a pH level of less than 4.0 require moderate heat treatment, while those with pH equal or higher than 4.5 require more severe heat treatment to ensure the destruction of *Clostridium botulinum.*

Dehydration is another food processing method that has been used for centuries, based on reducing the water content in the raw material or, more specifically, reducing water activity (a_w). The concept of a_w is useful in food preservation and is explained clearly by Barbosa-Cánovas *et al.* (2003). It is well known that each micro-organism has a critical a_w, below which it cannot grow.

TABLE 12
Classification of foods by pH

Classification	pH	Examples
Low acid	≥4.5	Peas, green beans, cactus pear fruit, cladodes
Acid	4.0–4.4	Tomatoes, pineapple, pear
High acid	≤4.0	Lemon, orange

Source: Based on Cheftel, Cheftel and Besançon (1983) and modified by the authors.

For example, pathogenic micro-organisms cannot grow in media with a_w <0.86; fungi and yeasts, although more tolerant to low water activity levels, cannot grow with a_w <0.62. Many deteriorative reactions in foods are slowed down when water activity is low, meaning that water reduction is a safe way to extend the shelf-life of foods.

The close link between a_w and the rate of food deterioration has been described by Barbosa-Cánovas *et al.* (2003): the lower the water activity the longer the food can be preserved. Water itself has $a_{w\,=}$ 1.00 and is a vital element for the growth of micro-organisms, as well as chemical reactions. Fresh fruits and vegetables have a_w close to 1.00, hence their susceptibility to microbial attack and rapid perishability.

A further preservation method based on lowering a_w is evaporation or concentration, which may have a number of effects on the product. The most important is loss of water, although this goes hand in hand with loss of volatile compounds responsible for the flavour and aroma of the raw material. The concentrated product usually has a less intense aroma, which may also differ from that of the original product. However, this can be corrected, for example, by mixing the concentrate with a portion of the fresh or unheated liquid. Either the same fruit or other more aromatic species are used to obtain the desired concentration of solids. It is also possible to correct this effect by recovering the volatile substances by condensation from the gaseous phase with subsequent fractional distillation and reincorporating the aromatic condensate into the product. Another consequence of evaporation is a reduction in the volume of liquid, which is an advantage for storage and transportation of the product. From the consumer's point of view, the concentrated product is useful as it is easier to use, occupies less space, is conserved at normal temperatures and can be consumed in whatever portion is required, while the remainder can be stored safely.

In order to minimize the adverse effects of some preservation methods, there has been concerted development of 'combined methods' of food preservation in recent years. As the name indicates, this system is based on the simultaneous use of different conservation methods. These separately reduce and control microbial load – lowering a_w, lowering pH, mild heating, addition of preservatives and others – and act in synergy; there is no need to use a single process that may drastically alter the quality.

Concentrated juices are obtained by evaporation, usually by boiling the liquid extracted from fruit. Concentrated juices have the advantage that the product remains liquid but it keeps better than the extracted juice because its water activity has been reduced. At the same time, several of its components and characteristics have changed, such as water content and viscosity, while other components, such as acids and vitamins, become more concentrated and some of the organoleptic characteristics, such as appearance or colour, may also change.

Refrigeration is useful for preserving processed foods. Freezing is one of the best methods for conserving the characteristics of food because cooling generally stops or at least reduces the rate of deterioration.

In contrast to sterilization, freezing does not preserve food by destroying micro-organisms; rather it creates adverse conditions for their development. This fundamental difference between the two processes confirms the need for rigorous attention to hygiene and the use of high-quality raw materials. Good quality is essential in all cases and raw materials should always be in good condition, discarding those that are damaged, contaminated or may contain a risky microbial load. These requirements are all the more important when it comes to freezing because micro-organisms are *not* destroyed.

DESCRIPTION OF PRODUCTS BASED ON FRUITS OF *OPUNTIA* SPP.

With the number of technologies available, a wide array of products based on fruits and cladodes can be obtained.

Dehydration is one of the oldest technologies and perhaps the easiest and cheapest to implement. It is not usual for the whole fruit is to be consumed in the dry state but, after removing the seeds, the pulp can be dehydrated in thin films or leathers to produce a chewy natural product. Fruit leathers are popular in the Arab countries and in the United States and are made from a variety of fruits (e.g. apricot, cherry, strawberry and other berries). This is one of the more attractive products made from cactus pear fruit pulp, although it has yet to be manufactured on an industrial scale (Sepúlveda and Sáenz, 1999; Sepúlveda, Abraján and Sáenz, 2003c). In Mexico, there is ongoing research at the University of Sinaloa on thin films of cactus pear fruit pulp mixed with guava, mango and other tropical fruits (Trejo, personal communication).[1] One advantage of dehydrated products is that they do not usually contain additives and for this reason are considered safe, natural foods. A special form of dehydration is the production of candies or glazed products, which can be produced from chopped mature cladodes and/or fruits. In France, whole cactus pear fruits are glazed and eaten as a dessert.

Concentrated products include juices and nectars. They are attractive when coloured fruits are used. In Namibia, an excellent concentrate is made from red fruit. Red-fruit nectars mixed with other juices were available in Californian markets until a few years ago. However, this product was discontinued and now a fresh cactus pear red fruit puree (22–24 °Brix) is offered. In Chile, fresh unprocessed cactus pear juice is widely consumed at home and in ecological restaurants. Some Chilean companies are carrying out trials on processed and frozen cactus pear fruit pulps to supply markets such as ecological restaurants, hotels and ice cream manufacturers.

Cactus pear fruit jams are concentrate products produced in Mexico, the United States, Italy and Argentina. More recently, production has begun in Chile. Jams are also produced commercially from the cladodes, and jellies are made from fruit in Italy, Mexico and the United States. In Mexico, *melcocha* is a traditional product, a type of artisanal jam made from *O. streptacantha* (Corrales and Flores, 2003), although jams are also produced from different types of *Opuntias*. In the United States, chewable cactus pear jelly candies are made commercially from fruit juices of different colours. Syrup products also fall into the concentrate group and are used as a dessert topping. They are produced in Argentina, the United States and a number of other countries.

PHOTO 9
Liquor made from (a) *fico d'india* produced in Italy and (b) O. *xoconostle* in Mexico

(a) (b)

(A) DISTILLERIA F.LLI RUSSO SNC, ITALY (2005)

(B) SÁENZ, MEXICO (2004)

The product known as cactus pear fruit 'cheese' is a juice concentrate that dominates Mexico's artisanal cactus food industries. It is produced from *O. streptacantha.* It is considered as an intermediate-moisture food, which conserves well at ambient temperatures. It is marketed as a pure fruit product or mixed with pine nuts, cashews or other nuts (López, Fuentes and Rodríguez, 1997; Corrales and Flores, 2003).

Fruit-like sauces made from *O. xoconostle* juice and peel are appertized products (in steel cans or glass jars), which are produced in Mexico and in the United States. Some years back, trials were undertaken in Chile with canned cactus pears, with results worth revisiting for today's purposes (Sáenz, 1999).

Of the fermented products, *colonche* is one of the best known in Mexico. It is a low-alcohol drink made from the juice of *O. streptacantha*. Wine and *aguardiente* (distilled liquor) from cactus pear fruit juice have been produced in Mexico for many years. An artisanal factory close to Mexico City produces attractively presented liquors from different coloured fruits. They are obtained by macerating the fruit pulp in high-degree alcohol. In Italy, there are a number of companies producing liqueurs. According to Russo (personal communication),[2] the fruit pulp is macerated in alcohol and left for several days, after which it is filtered and water and sugar are added. The alcoholic content in the finished product is 28 degrees Gay-Lussac (°GL) (Photo 9).

Vinegar has been made successfully from cactus pear fruit by artisanal producers from the Til-Til Region of Chile; a similar experience is reported in Argentina.

FRESH FRUITS

The traditional way to eat cactus pear fruit is as fresh fruit, which has the advantage of maintaining the nutritional value when the fruit is properly

[1] Martín Trejo B., Universidad Autónoma de Sinaloa, Culiacán, Sinaloa, Mexico (2005).

[2] Alessandro Russo, Distilleria F.lli Russo SNC, Italy (2005).

PHOTO 10
Sale of different coloured cactus pear fruit in a fruit market

C. SÁENZ, MEXICO (2003)

stored. The requirements for good storage were described earlier. Photo 10 shows different coloured fresh cactus pear fruit in a market in Mexico.

For home consumption, special care needs to be taken when peeling the fruit because of the spines. Even when the spines have been removed from the fruit at the farm, stray spines always remain, which stick to the peel and cause problems. Before peeling the fruit, hands and cutting utensils should be thoroughly washed. Once the fruit is peeled it should be consumed immediately or stored in a refrigerator for no more than two to three days. The fruit's low acidity and high pH make it quick to ferment, at which point it becomes inedible and can no longer be kept safely. In the home, fresh cactus pear fruit is often consumed as a juice or in desserts, either separately or combined with other fruits.

Changing lifestyles in many countries worldwide mean that there is little time for home-prepared food. This has driven consumer demand for more 'ready-to-eat' products (foods that can be prepared and eaten in a few minutes), and this is reflected in the choice of foods available in supermarkets in many countries. Fruits and vegetables are washed and packed in plastic film and stored chilled, while frozen meals require little more than heating in the home; according to López and Moreno (1994) foods of this kind are called 'minimally processed foods'.

The technologies used when preparing these foods aim to conserve as many as possible of the original characteristics of fruits or vegetables, with manufacturers cultivating a 'fresh, natural, nutritional and safe' image for their product. They do this by both advertising and presentation, using processing to protect the fruit's original qualities. For example, the use of plastic film to wrap products determines permeability and the oxygen and/or carbon dioxide content, which controls the mix of gases surrounding the product. Different plastics have different permeability properties and the most suitable film is chosen for the fruits/vegetables and for the time of year. During storage, the level of oxygen generally falls while that of carbon dioxide rises – a change of atmosphere that reduces degradation of minimally processed fruits and vegetables (Lee, Park and Lee, 1996).

Combined methods of preservation include treatments such as irradiation, refrigeration, modified atmosphere, fermentation and packaging (Barbosa-Canovas *et al.*, 2003).

Hygiene is one of the most important factors in the preparation of any food product. All processing steps should be undertaken in a clean environment with clean air, low temperatures (5–6 °C), plenty of light, ample space and workers who understand and follow personal and operational hygiene procedures. This is important for products that are not subjected to heat treatment to reduce the microbial load.

According to Cantwell and Suslow (2002), some of the more significant factors affecting the quality of minimally processed products are: quality of the raw materials; processing and storage temperatures; conditions of hygiene; types of plastic film used for packaging; temperatures during storage; and period during which the products are kept in storage. Further information describing the technologies involved is found in Chapter 5.

For cactus pear, minimal processing starts with washing the de-spined fruit in chlorinated potable water and then peeling it. A number of studies and treatments have been conducted on food products to determine the requirements for high quality and safety. For example, Coronado (2001) compared the behaviour of cactus pear fruit *O. ficus-indica* sliced and packed in plastic film bags with different gas permeability properties. He found that the slices tended to exude a large amount of mucilaginous liquid, which gave an unpleasant appearance to the fruit. Oyarce (2002) continued this work with *O. ficus-indica*, comparing whole and peeled fruit at different states of maturity and with different colour and firmness. Preservation was evaluated by immersing the fruits in citric acid concentrations of 0.25 percent, 0.5 percent and 1.0 percent. Fruit immersed in water was used as a control. All fruit was stored at 5 + 0.5 °C and 85 percent RH.

Results showed that whole, peeled fruits could be stored for up to 14 days with good microbiological control and fruits retaining much of their original high quality. The final count of mesophilic aerobic bacteria was between 0×10^4 cfu g^{-1} and 5×10^4 cfu g^{-1}, which is within Chilean regulatory limits for prepared foods, so the product is considered safe. As a preservative, citric acid did not affect organoleptic quality, although microbial levels were affected. This was a good result when compared with the control pack with its proliferation of micro-organisms on the product.

Tests for levels of ripeness did not affect the final quality of the product except for flavour, where it was found that the riper the product the better the flavour. Acceptability ratings were generally good, with the highest rating being given to products stored for seven days. In both studies, the packaging material used was provided by the CRIOVAC Company. The material that gave the best results had gas transmission values of 60–160 ml $m^{-2}d$ for carbon dioxide, and for oxygen 3–6 ml $m^{-2}d$ (material BB4) at 1 standard atmosphere (atm) and 5 °C.

In further studies on *O. amyclae,* Corrales *et al.* (2004) used peeled fruits, whole and halved fruits and three types of packaging film: polyolefin 19 micrometres thick (PO19) and co-extruded and bi-oriented polypropylene in thicknesses of 25 micrometres (PPB25) and 35 micrometres (PP35). Packed fruit was stored at 4 °C. It was found that fresh fruit, whole and halved fruit could be stored for up to 20 days without loss of quality. Fruit stored in the PPB25 plastic film showed the least loss in weight, gave the best shine to the fruit and produced the least ethanol. However, these fruit packs also contained the highest percentage of juice drained from the fruit.

Piga *et al*. (2003) evaluated changes in the content of ascorbic acid, polyphenols and the antioxidant capacity of minimally processed cactus pear fruits cv. *Gialla* grown in Italy. They were stored in good condition at 4 °C for nine days. Findings were similar to the other studies; the pH and acidity changed significantly during storage without affecting the sensory characteristics of the fruit for up to six days. Microbial count remained low and no fungal growth was detected.

Corbo *et al.* (2004) carried out an interesting study on the shelf-life of minimally processed *O ficus-indica* cv. *Gialla*. The fruits were cut into slices and packed in plastic bags (nylon/ polyethylene, 102 µm) with permeability to CO_2 of 3.26×10^{-19} mol cm cm^{-2} s^{-1} Pa^{-1} and to O_2, of 9.23×10^{-19} mol cm cm^{-2} s^{-1} Pa^{-1}. The product was packed in ambient air and under modified atmospheric conditions (65 percent N_2; 30 percent CO_2 and 5 percent O_2) and stored at different temperatures: 4 °C, 8 °C, 12 °C and 20 °C. The growth of different types of micro-organisms and sensory quality were evaluated. It was found that the best temperature for storage was 4 °C. Fruit kept well for up to 14 days under all storage atmospheres and had bacterial counts that were within the limits of French legislation for this type of product. However, it was found that the different atmospheres did affect the type of microflora that developed. This led to recommendations to conduct further studies.

JUICES, BEVERAGES AND CONCENTRATES

A common method of conserving fruits and vegetables is to make juice. Juices are appreciated for their high nutritional value, while modern technology and good manufacturing practices (GMP) now ensure their taste remains similar to that of the original product. In some places, people have begun to call them ‘liquid fruits’ (Sáenz and Gasque, 1999; Sáenz and Sepúlveda, 2001b).

Juices provide a good source of sugars, vitamins and minerals, which are an essential part of a healthy diet. Current trends towards healthy eating make juice a natural and important part of the diet, while fruit and vegetable juices can play an important role in improving human health. They are particularly valuable for children and young adults.

In countries such as Chile, cactus pear fruit juice is consumed at home, in ecological restaurants or stores (Sáenz and Sepúlveda, 2001b). This juice is so popular that local producers are always interested in the development of new technologies capable of producing high-quality juices and pulps on a commercial scale. However, some of the fruit’s characteristics, described earlier, can make it difficult to establish satisfactory processing technologies. High pH, low acidity, high sugar content, delicate aroma and susceptibility to deterioration after heat treatment pose challenges for industrial processing (Di Cesare, Testoni, and Polesello, 1991; Di Cesare, Testoni and Sansovini, 1993).

As *Opuntias* produce different coloured fruits – red, green, orange and purple – there are obvious advantages in using processing technologies that will yield different coloured juices.

In Mexico, the first trials to design processing procedures for pasteurized cactus pear fruit juice were conducted more than 30 years ago. Results were inconclusive. Some authors described the pleasant flavour and aroma of the pasteurized juices, while others highlighted difficulties with maintaining microbiological stability and slowing down the acetic fermentation of the juice, which reduced its keeping qualities, even with the addition of lemon juice to reduce pH levels.

Carrandi (1995) evaluated the microbiological behaviour and chemical and sensorial characteristics of the juice of green cactus pear fruit. Treatments included the use of two types of additive: 200 ppm kilol (natural extract of grapefruit seeds) and 500 ppm potassium sorbate, which is approved in most countries' food regulations. The juice was pasteurized in a high temperature short time (HTST) system (98–100 °C for 20–22 seconds [s]) and packed immediately into glass bottles, which were then sealed under ultraviolet (UV) light control. After cooling, the bottles were stored at 0–5 °C for 15 days. Carrindi (1995) concluded that the additives tested were not sufficiently effective to ensure microbiological stability because lactic acid fermentation (produced by *Lactobacillus)* was noted within 2–3 days, regardless of which preservative was used. In another trial aimed at improving the microbiological stability of the juice, a more drastic heat treatment was used (100 °C for 20 minutes), with the juice packed in glass bottles. The results showed good microbiological stability and safety but the final product did not resemble fresh cactus pear juice because of changes in flavour and aroma. In countries where consumers prefer to consume fresh juice that closely resembles the original fruit or juice extracted from it and drunk fresh, care is needed in the choice of processing technologies.

Changes in colour in pasteurized and concentrated cactus pear juices were studied by Carrandi (1995) and Sáenz *et al.* (1993). Heat treatment produced deterioration of chlorophyll and loss of the brilliant green colour of the fresh juice, which became milky white and more opaque. The same was noted with concentrated juices (68.8 °Brix) stored at different temperatures: –2 °C, 10 °C, 20 °C, 27 °C and 37 °C. Again, juices stored at room temperature darkened over time, with an increase in the colour parameter a* (i.e. from –2.84 to –0.57). According to the CIELAB colour scale, this indicates the contribution of green for the negative value and red for the positive value. These results showed that the colour characteristics of green cactus pear fruit juices were clearly affected by the storage period and temperature. This was the same whether the juice was at normal concentration or concentrated. Findings of this kind need to be considered further when choosing a system design for processing and storage of juice concentrates.

In later studies on juices from purple cactus pear fruit, Sáenz *et al.* (1997a) noted the effect of different pH levels (5.2 and 4.0), as well as heat treatment (80 °C for 10 minutes), on the colour of the juice and concluded that the colour was highly stable with respect to changes in pH and temperature – a clear advantage over juices from green cactus pear fruit. The authors tested three treatments: (i) natural juice with no pH modification (pH = 5.2) and no heat treatment; (ii) no pH modification (pH = 5.2) but with heat treatment; and (iii) with pH modification (pH = 4) and heat treatment (80 °C for 10 minutes). They concluded that, for colour parameters a* and b*, the three treatments resulted in colours ranging from reddish-purple to red. Colour parameter b* corresponds to the contribution of yellow or blue colour, depending on whether the value is positive or negative – and this determines the changes in colour of the juices. Although acidification of the juices and thermal treatment used for preservation and microbial stability changed the visual aspect, the juices did retain the reddish-purple colour characteristic of the fruit.

Sáenz and Sepúlveda (1999) conducted tests on mixtures of a refreshing beverage based upon a mix of purple cactus pear fruit juice, pineapple juice, water and sugar. This reduced pH and improved storage life, while at the same time reducing the viscosity of the cactus pear juice. The juice mix received a mixed reception, with some people preferring to drink it diluted. Although the pineapple juice increased acidity, its flavour and aroma affected the delicate flavour and aroma of the original cactus pear fruit juice. A taste panel therefore rated it less highly as a drink than pure diluted cactus pear juice. A more satisfactory result was achieved by adding citric acid to increase acidity. This increased acidity to pH 4.2, with the same acceptability as that of the diluted natural cactus pear juice. Flavour and aroma were not affected.

Other authors have conducted clarification tests in order to increase concentration levels more easily. The use of pectinolytic enzymes was tested in treatments at 40 ºC for 48 hours, with the addition of citric acid for better enzymatic action. The juice was packed in steel cans and glass jars and submitted to different thermal treatments. Both tests showed changes in colour caused by the treatment, which was corrected by adding artificial colorants, according to Yagnam and Osori (1991). Using the enzyme preparation *Pectinex AR*, made from a mixture of pectinolytic enzymes with a high arabanase activity, Sáenz *et al.* (1997b) and Sáenz *et al.* (1998) successfully clarified cactus pear juices, having previously tested a large variety of enzymes from different sources.

Thomas (1998) provided a detailed flow diagram for the production of a natural puree of red cactus pear fruit obtained by rapid freezing. A final product was obtained with <3 cfu g^{-1} of coliforms, lactic acid bacteria and *Escherichia coli* and <10 cfu g^{-1} of aerobic micro-organisms, yeasts and fungi. The same author described the production of a vacuum-dried concentrated puree (65 °Brix), which could be used in the same way as natural puree, for flavouring ice creams and as toppings for fruit and desserts .

Almendares (1992) studied the production of juice concentrates from green cactus pears with lower a_w to protect against microbial growth and extend shelf-life. The juices were concentrated to 63–67 ºBrix in an Alfa Laval vacuum evaporator centrifuge. The stability of the juices against microbial attack was good but the sensory analysis indicated low acceptability by test panellists. They gave the reconstituted juice a score of 5 on a scale of 1 to 9. This was because of colour deterioration and the grassy aroma that developed after concentration (Sáenz *et al.*, 1993 and Sáenz, 1996).

Barbagallo, Papalardo and Tornatore (1998b) produced a slightly concentrated puree of cactus pear fruit cv. *Gialla* (37 percent) and compared it with natural pulp. They found that the colour, aroma and flavour of the concentrate were similar to that of the natural product. Acidity was modified with citric acid up to pH 4. The authors concluded that the slightly concentrated puree could be a useful ingredient for manufacturing confectionery and semi-processed products.

Ruiz-Cabrera *et al.* (2004) conducted tests to produce dehydrated juice by spray-drying juice from *O. streptacantha*. Although they provided no details of the product's storage life or rehydration properties, they noted a significant loss of vitamin C, ranging from 23.65 mg $(100\ ml)^{-1}$ in fresh juice to 10.28 mg $(100\ ml)^{-1}$ in dehydrated juice.

Melcocha is a traditional Mexican product similar to syrup, made from the juice of the fruit of *O. streptacantha.* Originally produced on an artisanal scale, according to Corrales and Flores (2003), manufacturers have become interested in it in recent years owing to its increased popularity as a filling for the small pastries called *empanadas.*

A second well-known artisanal product in some regions of Mexico, which is produced on a small scale, is cactus pear cheese. It may have been given this name because of its characteristic pale colour (at the time of preparation), texture and appearance. It is obtained from the concentrated juice or *melcocha* of the fruit of the wild *cardona* cactus pear (*O. streptacantha*). López, Fuentes and Rodríguez (1997) described how the cactus pear cheese is made. The *melcocha* is kneaded using a large flat round stone that has been previously moistened. The *melcocha* is lifted and dropped onto the stone some 150 to 200 times, until the resulting paste no longer sticks to the stone. The more the paste is beaten, the harder the texture becomes and the paler the paste's golden colour. The paste is then placed in moulds holding 1–20 kg and left for 24 hours. The next day it is removed from the moulds and left exposed to the air for a further 24 hours. At this point the texture resembles a semi-solid gel and the cheese is ready for eating or selling. It is sold in pieces of various sizes and can be conserved for long periods at ambient temperature, according to Corrales and Flores (2003). Flavours and mixed ingredients can be added for variety, such as essence of anise or vanilla, or even pine nuts, cashews, almonds, hazelnuts or other nuts.

As cheese-making is an artisanal industry operating under rudimentary conditions, López, Fuentes and Rodríguez (1997) recommended upgrading to small-scale industrial methods using improved technologies and adoption by producers with a better understanding of good manufacturing processes. Improving the food quality and safety of the cheese could make it more popular with consumers. As yet there are no industrial producers in Mexico manufacturing cheese under proper sanitary and hygienic conditions (Corrales and Flores, 2003).

Alvarado and Díaz (2003) looked at ways of improving the characteristics of the cheese, including a more attractive appearance. They tested cooking equipment (copper and stainless steel vessels) and obtained better results with stainless steel. The cooking temperature was easier to control, preventing overheating and colour changes caused by high temperatures. The concentration of the tested products was similar to that of products found on the market (86–93 °Brix), apart from higher levels of betalains in market products: 4.3–6.2 g $(100\ g)^{-1}$ compared with 2.2–2.6 g $(100\ g)^{-1}$.

FROZEN PRODUCTS

Freezing is one of the best technologies for conserving the colour, aroma and nutritional properties of foods. It has the advantage of fixing the water as ice crystals and so lowering a_w which, together with low temperature, helps to preserve the food. However, freezing is an expensive technology requiring the development and maintenance of a cold chain from producer to consumer (cold rooms, refrigerators, refrigerated transport) at all points in the chain. This is the only way to ensure that product quality and safety are maintained. Power supplies have to be reliable to keep temperatures low.

Sáenz, Sepúlveda and Araya (1988) conducted the first trials on freezing peeled and unpeeled sliced and quartered cactus pear fruit (0.625 mm). Freezing was carried out in a fluidized bed tunnel at –40 °C and the products were stored at –20 °C. The results were unsatisfactory. Although the product had been frozen quickly, a high percentage of drip occurred upon thawing. This, together with loss of texture, resulted in a low quality rating. At the time it was thought that the use of cryoprotector agents, such as syrups or sugar, might improve quality.

In 2000, the use of cryoprotectors (different concentrations of sucrose solutions on freezing cactus pear fruit) was studied in a joint project by the Food and Development Research Centre (CIAD) in Sonora, Mexico, and the University of Chile in Santiago. Findings remained inconclusive: it was *not* possible to achieve a good quality product even with improvements using 30 percent sucrose solution as a cryoprotector. Further studies were recommended to find a more effective cryoprotector that would help preserve product texture.

Bunch (1966), reporting on the production and marketing of frozen purple cactus pear fruit puree in the United States, describes it as a versatile and stable product. The puree can be used in a variety of drinks and meals. The production of frozen puree and juices from cactus pear fruit may offer an interesting processing opportunity, depending on markets. A Chilean company that produces frozen tropical fruit pulps is currently exploring domestic markets and has established a small cactus pear fruit plantation in a fertile valley to the north of Santiago. Manufacturing consists of manually washing and peeling the fruit, sieving out the seeds, packing in plastic bags and freezing the bagged puree in a cold tunnel at –30 °C. The temperature for storage and transport is –18 °C.

There may be a large potential market for the product because a buoyant niche already exists for frozen pulps of other fruits, such as cherimoya and strawberry. Restaurants, health food stores and home-delivery markets could be explored. Typically, many of these outlets tend to purchase fresh fruit and extract the juice in-house and may find it convenient to have good quality pulp immediately at hand in the freezer. It saves time and labour and, if high quality can be maintained, there is the reliability of having juices of known consistency, texture and colour. Convenience in the retail outlet or home is becoming a feature of many modern lifestyles. Stored in the freezer, people have only to defrost, dilute and sweeten it before using or selling it like the original fresh juice. It may also be sold to food manufacturers as a constituent of flavoured drinks, yoghurts, desserts, ice creams, cakes, pastries or confectionery.

DEHYDRATED PRODUCTS AND CONFECTIONERY

There is little information on the dehydration of whole cactus pear fruit. In Mexico, cactus pear 'raisins' or dried cactus pear fruit are produced traditionally from de-seeded fruit. Borrego and Burgos (1986) describe the way they are produced: the fruit is boiled in cactus pear fruit syrup, left to dry in the sun and turned regularly to ensure even drying. Mohamed-Yasseen *et al.* (1996) describe indigenous communities drying the whole *unripened* fruit, before cooking it with meat and other foods.

Dried fruit sheets (also called fruit leathers) are produced in many countries where cactus pear fruits are grown. These foods have a number of advantages: they are made from natural fruit pulps, contain no preservatives, are chewable and make a convenient snack. This makes them attractive to children, which could contribute to a healthier diet in today's 'junk food' culture. Various authors have researched the development of these fruit sheets. In Saudi Arabia, Ewaidah and Hassan (1992) developed fruit leathers from cactus pear fruit cv. *Taifi* and found the most acceptable formula. This helped to expand the culinary tradition in many Islamic countries of eating fruit

TABLE 13
Basic formula for dried fruit leather of cactus pear fruit cv. *Taifi*

Ingredient	Amount (grams)
Fruit pulp	1 400
Sugar	140
Citric acid	15.4
Sodium metabisulphite	2.1
Olive oil	7
Milk powder	140
Flavourings	
Cinnamon	1.8
Ginger	1.4
Cardamom	0.6
Cloves	1
Vanilla	0.6

Source: Ewaidah and Hassan (1992).

sheets made from apricots, particularly during Ramadan. Their formula is described in Table 13.

Sepúlveda, Sáenz and Álvarez (2000) developed dried fruit sheets from cactus pear fruit mixed with different proportions of pulp from quince (*Cydonia oblonga Mill.*) in order to provide natural acidity and avoid the use of citric acid. Several proportions of cactus pear and quince pulp were tested: F1 = 100 percent cactus pear pulp/1.1 percent citric acid; F2 = 75 percent cactus pear/25 percent quince/0.7 percent citric acid; F3 = 50 percent cactus pear/50 percent quince/0 percent citric acid. All other ingredients were constant, i.e. 10 percent sugar, 0.5 percent olive oil, 0.1 percent sodium metabisulphite and 0.1 percent cinnamon. Table 14 shows the characteristics of each formulation tested.

The formulations showed an energy content of 320–327 kcal (100 g) g^{-1}. Some market sectors would prefer lower energy content. This could be achieved by not adding sugar, as this is provided by the fruit. Acceptability of the sheets was rated high for all three formulations but the taste panel found formulation F1 very acidic. It is interesting to note Saudi Arabian consumers' preference for the high-acidity F1 formulation (Ewaidah and Hassan, 1992). This indicated the different taste preferences of people and countries and the need to adjust formulations for different markets.

Sepúlveda, Abraján and Sáenz (2003c) have recently developed fruit sheets from ecotypes of cactus pear fruits with pulps of different colours (purple, orange and green), each mixed with apple pulp. In all cases, results have been promising. Those produced from a mix of orange-coloured fruit pulp and apple received the highest overall rating. This product uses simple technology and could be produced wherever cactus pear is grown.

TABLE 14
Physical and chemical characteristics of dried fruit sheets from cactus pear fruit and quince

Formulation	pH	Acidity (% citric acid)	Vitamin C (mg [100 g] g^{-1})	Colour			Moisture content (%)	a_w
				L*	a*	b*		
F1	3.7a	3.44a	32.65a	36.5a	–0.5a	14.8a	16.0a	0.55a
F2	3.8a	2.81b	24.48b	40.7b	–0.4a	19.4b	15.7a	0.57ab
F3	4.2b	1.32c	15.86c	43.6b	0.6a	21.3b	15.0a	0.60b

Source: Sepúlveda, Sáenz and Álvarez (2000). Different letters mean significant differences (p=0.05).
L*, a*, b*: describe colour components according to the CIELAB colour scale.

JAMS AND GELS

Jam is one of the best known and most popular products of its kind worldwide. It is easy to prepare, available in different types and made from a wide variety of fruits. Jam is obtained by boiling the fruit pulp with sugar, pectin and citric acid to ensure sufficient gelling. It is similar to other dehydrated foods, where preservation is based on reducing a_w. Generally, preservatives are added (e.g. sodium sorbate and/or potassium benzoate) in order to conserve quality after the jam container has been opened.

A number of authors have conducted studies on jam made from cactus pear fruit. In one such study, Vignoni *et al.* (1997) tested two formulations: one included 55 percent sugar, lemon juice and lemon peel, while the other contained just 55 percent sugar. No sensory difference was found between the two formulations.

Earlier, Aguirre, Pimienta and Moreno (1995) had tested different species of *Opuntia* and different jam formulations packed in glass jars. Three fruit treatments were used: with peel, without peel and pulp. Sugar, citric acid and pectin were added to each formulation. Results showed the highest approval rating for jam produced from whole fruit *with* peel, which had the added advantage that peeling was *not* required. As the pulp included seeds, a stone mill was used to obtain an acceptable jam texture, which suggests that jam manufacture from pulp and seeds would probably be best undertaken on a semi-industrial scale.

Corrales and Flores (2003) summarized the general process for making jam from *Cardona* cactus pear fruit (*O. streptacantha*). Fruit without peel was sieved to separate out the seeds and the resulting thick juice was mixed with sugar, pectin, citric acid and preservatives (sodium benzoate). The mixture was concentrated in an evaporator (or open pot) until it reached 65–67 °Brix, when it was packed hot into glass jars to which labels were attached when cooled.

Jam from the acid variety *O. xoconostle* is marketed in Mexico where it is highly appreciated for its attractive colour.

Commercially sterilized products such as canned cactus pear fruit have not generally been a market success because changes in texture and colour reduce the product's sensory quality. Sáenz (1999) recommended exploring these issues further because good colour and texture are difficult to attain. In South Africa, Joubert (1993) studied changes in the texture of fruit of various cultivars and colours after they had been canned. Basically the process consisted of: peeling the fruit and placing it in cans with syrup at 20 °Brix; adding citric acid to reduce pH to 4.2; and boiling the mix at 100 °C for 15 minutes. These canned products lost texture, flavour and colour. Texture deterioration was reduced by adding 0.25 percent calcium chloride ($CaCl_2$) to the syrup. Trials using syrup without citric acid resulted in gas forming inside the cans within a few days, which confirmed the importance of pH control for this type of product and for this particular fruit.

O. xoconostle fruits canned in syrup are currently marketed in Mexico. As it is an acid fruit, it has the advantage of requiring less drastic heat treatment for canning.

Gelled candies or sweets made from fruit pulps and sugar are commonly consumed in Latin America. Several of the products marketed are based on fruits such as quince, Malabar squash (*Cucurbita ficifolia* Bouché), berries and apple. Sáenz, *et al.* (1997c) studied the preparation of gels from the green cactus pear pulp of *O. ficus-indica*. Sugar and the gelling agent carrageenan were added to the pulp (35–40 percent). Two pH levels were tested: pH 3.5 to prevent microbial growth and pH 6.1, the pulp's original pH. Although a significant colour change was seen when pH was reduced by the transformation of chlorophylls into pheophytins, the product retained its chemical, physical and sensory properties for more than 14 days when refrigerated at 4–6 °C. If the sugar concentration is increased, refrigeration can be avoided, which is typical commercial practice.

FERMENTED PRODUCTS

In Mexico, *O. streptacantha* (*Cardona* cactus pear fruit) has been used to produce alcoholic beverages since pre-Hispanic times. *Colonche* is a very traditional product made from this species. According to Corrales and Flores (2003), *colonche* is prepared by artisanal methods in earthenware pots using cultures of *Saccharomyces* spp. as a starter. The juice ferments rapidly and is ready to drink a few hours after decanting. In this state, it has a shelf-life of 2–3 days.

It is a low-alcohol content drink (4–6 percent) that is consumed while it is still fermenting, and it is sweet because of the presence of unfermented sugars. It has a certain viscosity. It is produced only at harvest time and will rapidly decompose owing to bacterial activity if it is not consumed quickly (Díaz, 2003a).

Wine and *aguardiente* (brandy) can be made from cactus pear fruit. Flores (1992) conducted trials to obtain wine and brandy from *O. streptacantha* and *O. robusta.* For wine, an alcohol concentration of 11.6 °GL was obtained by concentrating the juice of *O. streptacantha* to 20 °Brix. Without concentration, the resulting alcohol content was little more than 6 °GL. Wines from both species had a similar aroma: fruity, pleasant and fine. The wine from *O. streptacantha* received higher ratings, with balance and refinement comparable to those of quality wine from grapes. The alcohol concentration of *aguardiente* made from wine obtained from *O. streptacantha* was 56.2 °GL.

The *aguardiente* was rated higher than the wine. The author recommended more detailed studies to explore the development of products with more commercial potential. However, preliminary findings were promising.

Díaz (2003b) conducted tests to find better ways of making *colonche* and wine from cactus pear fruit. A number of different variables were studied, including removal of seeds and skin, as well as the addition of acid, sulphates and yeast. The best treatment came from using fruit with skin, without acidification but with the addition of sulphates and yeast.

Vinegar is another product that can be made from cactus pear fruit but further investigation is required to determine the best processing methods. Pérez, Rodríguez and Martínez (1999) prepared vinegar from orange-coloured cactus pear fruit. Two types of substrate were used for the acetic fermentation: (A) from a previous alcoholic fermentation to 13.5 °GL; and (B) cactus pear juice with sugar added to 22 °Brix. *Acetobacter pasteurianus* was used for (A) and *Acetobacter xylinum* for (B). Table 15 shows the characteristics of both products.

The vinegar produced in both cases had a clean, bright, intense, yellow-amber colour and a fresh, strong, acetic acid aroma. Sensory tests highlighted acidity and a pleasant taste of natural salt. Fast fermentation of substrate B (sweetened juice) was the best option for production.

As cactus pear comes in a range of different colours, different coloured vinegars could be developed. This would provide for diversification of manufacture. Further studies are required to compare the various processes and substrates and to evaluate the products chemically, as well as by taste and appearance.

A wide variety of products can be made from cactus pear. These add value to the raw materials and provide employment and income. Product diversification helps to make the investments required of small-scale agro-industries more viable. These new products provide people with choices and help diversify diets. The outcome is higher consumption of fruit, either fresh or processed.

QUALITY AND SAFETY

The production of high-quality products is the basis for the commercial viability of the agro-industrial sector, particularly for foodstuffs. Consumers continue to demand safe, better quality foods. The earlier concept of 'quality control' has

TABLE 15

Physical and chemical analysis of two types of vinegar produced from cactus pear fruits

Characteristic	Vinegar (substrate A)	Vinegar (substrate B)
Density (g l-1)	1.013	1.0127
Volatile acidity (%)	6.71	9.8
Non-volatile acidity (%)	0.0132	0.0181
Dry matter (%)	5.33	4.27
Ash (%)	0.982	0.832
Alkalinity of ash (%)	0.374	0.567
Chloride (%)	0.768	0.27
Index of oxidation (%)	1 112	1 204
Total aldehydes (%)	0.625	0.0006
Final acetic acid level (%)	6.7	9.8
Fermentation time (days)	183	40

Source: Pérez, Rodríguez and Martínez (1999).

been replaced by that of 'quality assurance', focusing on *prevention* rather than just *control*.

Systems of this kind require a conceptual understanding by the consumer of the foods provided/produced, as well as by the manufacturer (whatever the scale of production), of benefits that reflect on the company and enhance market appeal. It means that everyone working in or associated with the agro-industrial sector (suppliers, distributors and others) must take responsibility for their role within the value chain. Errors, malpractice and faults can be noted quickly and easily and, next time round, they can be prevented. However, to introduce an appropriate quality assurance system in a timely manner, *everyone* involved must be trained and motivated (Fellows, Axtell and Dillon, 1995).

The impact of food-borne diseases has led to improved hygiene practices during processing. This means focusing on workers, water supplies, utensils and equipment, packing, infrastructure and *all* the components of distribution systems.

Cactus pear fruit has characteristics not commonly found in other fruit species, which require additional care when processing: high pH, low acidity (apart from some species) and high sugar content. Cactus pear products should always be of the highest possible quality and sold/consumed within the stated storage period so that they do not deteriorate and become unsafe.

Food safety relates to materials and products throughout the entire value chain. This includes the harvesting and treatment of raw fruits to the point of production (whether home or factory), mode of preparation, storage and transport of finished goods, as well as the chemical, physical and microbiological processes that occur during the food processing phase. It is important, for example, to know which additives can be used in foods, to ensure that raw materials and ingredients are stored separately from hazardous non-food materials, such as insecticides or detergents, and that all working surfaces and utensils/equipment are made of impermeable and easy-to-clean materials like stainless steel or plastic. Wood, for example, is not an appropriate material for processing, preparing or transporting food. Small splinters of wood can easily break off and contaminate the product and wood is a porous material that can be contaminated by micro-organisms. In summary, whatever the scale of processing, good manufacturing practices (GMP) must be adopted and applied at all times.

Foods must be safe, harmless and of high quality. They should not, for example, contain vectors such as *Shigella* spp., *Salmonella* spp., *Escherichia coli* or others with the potential to cause illness or death to consumers. The quality concept encompasses nutritional as well as sensory characteristics, all of which are incorporated into the concept of 'total quality'. Fresh and processed foods offered for sale must meet the levels of quality expected by consumers. Processed foods provide information of this kind on the labels of their containers. This is a fundamental ethical aspect that builds and maintains trust between producers and consumers after the initial purchase. The quality standards developed in each country for a wide range of locally made food products are of special value in this respect. Applied, controlled and policed by national authorities, they give consumers a measure of confidence that the foods on offer are safe to consume. Many of these standards are similar; many national standards follow, or are based on, the guidelines provided by the joint FAO/WHO Codex Alimentarius Commission.

MARKETING

Many of the products described are at different stages of development. Some are already on the market in some countries and manufacturing processes, products and standards can be shifted quickly to other markets. Others are manufactured on a small scale and/or artisanal basis and would benefit from the use of improved technologies with more concern for hygiene and safety. This is the case with cactus pear fruit cheese. Other products, such as fruit leathers, fruit sugar and concentrated juices, remain at the research and development (R&D) stage. Many products already on the market would benefit from strengthening and expanding distribution; these include jams and products derived from *O. xoconostle* sauces, jams, nectars and juices.

For many small-scale agro-industries, insufficient capacity is as important an issue as the more traditional ones of quality, safety and good presentation. There are many small-scale enterprises capable of producing high quality foods at competitive prices but with little experience of identifying and then exploiting markets. This makes market research and the development of effective marketing strategies *essential* for establishing and operating viable food processing enterprises. Market research means identifying sectors of interest, manufacturing to meet expected demand, distributing goods to markets and promoting products (Fellows, 1997).

One move that could improve the marketing of cactus pear foods, whether from small-scale agro-industries or more advanced industrial enterprises, is to differentiate them from any similar products already available on the market, including those made from better-known fruits. Consumers tend to enjoy novelty and are keen to sample attractively presented new products. Differentiating products entails highlighting the different components of the various species: physical (appearance, taste, aroma, texture), nutritional and functional (vitamins, fibre, antioxidants and mineral content).

Rather more challenging but equally important is promoting the source of the raw material (cactus pear fruits) and its origin. This includes elements such as the environment: the arid nature of production areas, clean and uncontaminated atmosphere, value to natural ecosystems, use of fresh water for irrigation (as appropriate), protection of soils and natural flora/fauna, and so on. Special marketing campaigns can be devised or such information can be provided on product labels in the form of simple messages that are easily understood by consumers. These could focus on their valuable contribution, which may extend beyond the product's nutritional value, and the benefit of maintaining *Opuntia* plants in a natural environment.

Chapter 5
Use of cladodes in food products

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DESCRIPTION OF PRODUCT TYPES

According to Corrales and Flores (2003), the chief advantages and reasons for industrial processing of fruits and vegetables are as follows.

1. To preserve their quality long enough to access diverse and distant markets.
2. To obtain higher value-added products with greater marketing potential.
3. To increase a product's shelf-life and availability throughout the year.
4. To stabilize prices in the event of over-supply in the fresh market.
5. To generate employment.

The industrial processing of cactus pear cladodes has potential value for mainstream industries and, equally important, for marginal rural communities in arid regions. The processes available are well known. Profitable production depends on the extent of the markets that can be developed and the services that can be provided.

This chapter covers existing experience with the processing and use of cactus pear in food products, utilizing the tender vegetable leaves or cladodes *(nopalitos)* and mature cladodes. Products available typically include: tender leaves in brine or pickled in vinegar; *nopalito* sauces; pasteurized juices, jams and confectionery; flours; and a selection of less popular processed foods developed for markets in Mexico and the United States.

The main cactus pear products produced by food industries in Mexico and the southern United States are tender leaves prepared in brine or pickled in vinegar, sauces and other foods incorporating tender leaves, including jams, candies, drinks and flour. Leaves preserved in brine or vinegar are the most popular product and have been in production since the 1970s.

Tender-leaf sauces are made from ground leaves, with the addition of various peppers (from the many different varieties available), tomatoes, onions and spices in varying proportions, with an occasional preservative added. The mix is steeped in vinegar. Cooking the leaves is optional, depending on the final product. Ingredients also vary depending on the manufacturer and product, with the addition of white wine, lemon juice concentrate and other ingredients. Sauces can incorporate chopped or ground cladodes, depending on market preferences.

New products recently introduced in Mexican markets include:

- Tender leaves (*nopalitos*) in sauce; these are canned leaves in various sauces, such as chilli or hot pepper (*Capsicum annuum* L.).
- Cladode pâté with soy bean; this is made from a puree of *nopalitos* with texturized soy bean and chicken or beef flavouring, packed in jars.
- *Nopalitos* with tuna fish; this is a salad called '*Azteca*', which contains tuna fish, beans, cladodes and chillies or hot jalapeño peppers. The product is canned for sale. *Nopalitos* in a sauce with tuna fish, mushrooms, sausage or vegetables form a group of tender leaf-based products with other foods added. They have become very popular in Mexico.
- Cereal with cladodes; this is a pelletized product formed from a mixture of wheat flour and bran, with dehydrated cladode powder and maltodextrin added that acts as a water-soluble fibre. It is packed in polyethylene bags and then into cardboard boxes for distribution and sale.
- Cereal flour and cladodes; this is fine flour made from milling dehydrated cladodes with cereal grains, after removing the bran and other components. The descriptor 'flour' is typically given to many finely ground materials in the food industry.

Cladode flour is obtained by dehydrating and milling the de-spined, washed and cut cladodes. The flour has applications in the baking, cookie and pasta industries, and for the production of pelletized dietary fibre. Dietary fibre is a valuable health product for improving the digestion of soluble fibre, which helps people suffering from constipation. Cactus pear leaves provide an important source of such fibre.

MINIMALLY PROCESSED CLADODES

Minimally processed fruits and vegetables, such as *nopalitos*, are prepared and handled to maintain the product's original freshness. This has important benefits for the consumer. Although more expensive than bulk products, minimally processed products have been successful in the market owing to the lack of waste produced when processing; such products are typically cheaper to produce. There are many different descriptors for minimally processed products/foods including 'fresh-cut produce', 'lightly processed', 'partially processed', 'fresh processed' and 'pre-prepared'.

As the descriptors suggest, the preparation of minimally processed products typically includes cleaning, washing, trimming, slicing, cutting into strips and similar related steps, many of which increase perishability. Consumers typically expect minimally processed products to be visually attractive, easy to handle and tasty.

There is a great deal of information available to describe the general characteristics of these products, including: Kader and Rolle (2004); Barbosa-Cánovas *et al.* (2003); Cantwell and Suslow (2002); and Wiley (1997). Below is a brief summary of some of the more interesting applications and technologies available for processing *nopalitos*.

Minimally processed plants generally have higher rates of respiration than the original intact plant, which suggests a higher rate of metabolism and more rapid deterioration. Increased demand for oxygen resulting from higher respiration necessitates packaging films with sufficient oxygen permeability to prevent fermentation and odours. The choice of plastic film for packaging material depends on the balance between the product's demand for oxygen and the permeability of the film. In practice such films are often chosen on the basis of the rate of oxygen transmission (in units of ml m^{-2} day^{-1} atm^{-1}) and other properties, such as the respiration rate of the cut product, the quantity of product involved and the balance of oxygen and carbon dioxide required in the pack. The properties of the film are equally important and include gas permeability, moisture content, thickness of film at specific control temperature, total surface area of the sealed pack and free volume inside the pack.

Physical damage and/or wounds caused by handling increase the rate of respiration and the production of ethylene gas quickly results, with associated increases in the rates of other biochemical reactions responsible for changes in colour (including browning), flavour, texture and nutritional value (sugars, acids and vitamin content). The extent of processing required and the quality of the equipment used (for example, the sharpness of blades when cutting) has a direct impact on the severity of the reaction resulting from the original damage.

To minimize the high rates of respiration and metabolic activity in minimally processed foods, refrigeration with strict temperature control is essential. Generally, these products should be stored at 0–5 °C (32–41 °F) to maintain quality, safety and shelf-life. Where possible, storage should be at 0 °C (32 °F). These conditions apply to all cold-sensitive fruit and vegetable products, including *nopalitos*.

Many of the earlier comments concerning hygiene during the processing of minimally processed *Opuntia* fruits also apply to minimally processed *nopalitos*. Further risks can arise during distribution and display prior to sale if temperatures rise, leading to the growth of dangerous micro-organisms capable of developing under refrigeration and controlled-atmosphere conditions (Corrales-García *et al.*, 2004).

Micro-organisms differ in their sensitivity to controlled-atmosphere storage. Low oxygen levels (1 percent or less) generally have little effect on the growth of fungi and bacteria. For effective control of microbial growth, CO_2 levels between 5 percent and 10 percent are recommended. High concentrations of CO_2 can slow deterioration of the product (i.e. softening and changes in composition) and directly affect cellular pH and the metabolism of the micro-organisms. In general, fungi are sensitive to CO_2 content and yeasts are more tolerant of different concentrations. The packaging material modifies the humidity and composition of the atmosphere surrounding the minimally processed products, including control over microbial profiles. Modified atmospheres can cause changes in the composition of the microflora content. For example, bacterial deterioration can be suppressed by packing in a modified atmosphere. However, this is not possible with certain pathogenic micro-organisms, such as *Listeria monocytogenes,* which can grow at low temperatures and in modified atmospheres.

Modified atmospheres can prolong the shelf-life of freshly cut products by suppressing the deterioration caused by common bacteria. This helps to maintain acceptable/good appearance. Notwithstanding, micro-organisms such as *Listeria* can multiply to dangerous levels in produce packed under modified atmospheres without showing signs of deterioration. This can be dangerous, making it desirable to indicate the recommended use-by date on packaged food products.

Rodríguez-Félix and Soto-Valdéz (1992) studied the behaviour of minimally processed *nopalitos* packed in bags of high-density polyethylene (HDPE) and low-density polyethylene (LDPE), with and without vacuum, and stored at different temperatures (5 °C and 20 °C). The permeability of these films was LDPE 3.367 ml O_2 m^{-2} day^{-1} atm^{-1} and HDPE 3.626 ml O_2 m^{-2} day^{-1} atm^{-1}. Thickness also differed: LDPE 0.057 mm and the HDPE 0.0273 mm. Changes noted in the quality of the cladodes were surface browning, exudation of mucilage and changes in surface colour from brilliant green to brownish-green. This limits shelf-life storage to 1–3 days at 20 °C, and 6–8 days at 5 °C. To improve the storage life of minimally processed tender leaves, Cantwell (1999) recommended keeping cut surfaces clean and dry, and storing materials at 0–5 °C.

Several preliminary studies have been carried out on minimally processed plants at the Department of Agro-Industrial Engineering at Chapingo Autonomous University. These studies included *nopalitos*, cactus pear fruit and pitayas. Results for *nopalitos* are described below.

An evaluation was made of the effect of different refrigeration temperatures (4 °C ± 1 °C and 10 °C ± 1 °C) and three plastic packaging films: polyethylene 35 mm (PE 35), polypropylene 25 mm (PP 25) and polypropylene 50 mm (PP 50) using minimally processed young cladodes (*O. ficus-indica* L.) variety Milpa Alta. Results were as follows.

- Lowest levels of ethanol from fermentation (38.8 mg $(100\ g)^{-1}$ and 12.4 mg $(100\ g)^{-1}$) were found at 10 °C using PP 25 and PP 50, respectively, and at 4 °C using PE 35. The least change in colour (ΔE = 5.6) was seen at 4 °C using PP 25, while the greatest change (ΔE = 32.2) was at 10 °C using PP 50. According to Hunter and Harold (1987) and Calvo (1989), ΔE refers to the total change in colour of a product, so that the initial and final colour values are measured with reference to a control based upon the original product prior to storage, using the formula:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

- Generally the best results (i.e. least ethanol production, least colour change and least change in firmness) were obtained at 4 °C using sealed PP 25 bags.
- Factorial analysis showed that there was no interaction between factors; the type of film had no significant effect on loss of weight, acetaldehyde or hue (colour index). As Table 16 shows, the highest levels of ethanol

TABLE 16
Effect of plastic film type on fresh-cut cladodes refrigerated at 4 and 10 °C

Variable	Type of film: Polyethylene 35 µm	Polypropylene 25 µm	Polypropylene 50 µm	Initial condition
Loss of weight (%)	0.327 a	0.25 a	0.241 a	
Acetaldehyde (mg $[100\ g]^{-1}$)	5.0 a	3.32 a	3.10 a	2.47
Ethanol (mg $[100\ g]^{-1}$)	158.84 a	95.87 ab	90.62 ab	14.67
Change in colour (ΔE)	13.30 b	9.33 b	25.21 a	
Hue (o)	103.7 a	107.36 a	102.3 a	119.17
Lightness (L*)	49.24 ab	51.94 a	41.6 c	57.0
Penetration test in pulp (mm)	6.0 b	5.59 b	10.0 a	6.06
pH	5.53 b	6.18 a	5.97 a	5.2
Titratable acidity (% malic acid)	0.295 a	0.240 b	0.26 b	0.387

Source: Corrales-García *et al.* (2004).
Note: Data with the same letter on each variable are statistically equal.

TABLE 17
Effect of temperature on fresh-cut cladodes after 15 days of refrigeration

Variable	Temperature 4	(°C) 10	Initial condition
Loss of weight (%)	0.130 b	0.459 a	
Acetaldehyde (mg [100 g]-1)	3.88 a	4.05 a	2.47
Ethanol (mg [100 g]-1)	117.12 a	110.69 a	14.67
Change in colour (DE)	9.71 b	20.87 a	
Hue (o)	114.3 a	94.62 b	119.17
Lightness (L*)	48.9 a	46.28 a	57.0
Penetration test in pulp (mm)	7.26 a	7.13 a	6.06
pH	5.68 b	6.10 a	5.2
Titratable acidity (% malic acid)	0.384 a	0.242 b	0.387

Source: Corrales-García *et al.* (2004).
Note: Data with the same letter on each variable are statistically equal.

and titratable acidity were found with the PE 35 film, the greatest change in colour and softening (penetration in texture test) with PP 50, and the greatest lightness with PP 25.

While temperature had no significant effect on the production of acetaldehyde and ethanol, luminosity and softening, the greatest loss in weight, change in colour, yellowing (lower hue) and pH occurred at 10 °C (see Table 17).

The conclusions from these findings are obvious. It is important to use high quality cladodes, have appropriate processing facilities and undertake processing in the most aseptic manner possible.

JUICES AND BEVERAGES

The juice of cactus pear leaves is extracted by milling and pressing. This consists of milling cladodes after removing the spines and chopping the leaves in an industrial blender or home blender. Water is added to facilitate the process and the resulting liquid is filtered to separate out solids in suspension.

One Mexican company mixes cladode juice with guava juice for commercial sale in domestic and export markets. A second product called ‘cladode water’ (*agua de nopal*) is made from cladode juice with added sugar.

Other products of interest are cladode syrups made from sucrose syrups (55–75 °Brix) to which cladode juice has been added. A company in Texas in the United States produces blackberry and bilberry syrups based on cladode mucilage mixtures.

Rodríguez (1999) evaluated several beverages made from cactus pear plant formulations based on tender cladodes previously blanched at 95 ºC, macerated and filtered. The best formulation was macerated pulp diluted in water to 30 percent concentration, with citric acid added to attain pH 3.5 and an aspartame concentration of 1g 335 ml^{-1} as a sweetener. The product was pasteurized at 76 ºC for 15.2 minutes, which slightly affected nutrient and other thermolabile contents.

JAMS AND CONFECTIONERY

Nopalitos jam is prepared from young cladodes that have been ground and cooked with variable amounts of sugar, pectin and preservatives. This is described further in Chapter 6 but processing generally consists of chopping, cooking and grinding blanched material. The material is then heated and sugar gradually added at boiling point. Before all the sugar is added, pectin, sodium benzoate and citric acid should be mixed into the jam. The mixture should then be heated to concentration 65 °Brix. The pectin should be dissolved in syrup before adding it to the mix. If the gel does not form well, the pectin/citric acid ratio should be increased.

Trials on the production of cladode jam have been carried out in Mexico with various proportions of hawthorn (*Crataegus pubescens* Steud.). A 4:1 cladode/hawthorn mixture gave an acceptable formulation with good gelling properties and a_w 0.895. Similarly, jams with aroma, flavour, appearance and texture at 95 percent acceptability ratings were obtained by adding pectin and citric acid to provide an acidity of pH 3.2 and a concentration of 65 °Brix, (Sánchez, Jiménez and Zárate, 1990).

Sáenz, Sepúlveda and Moreno (1995b) undertook trials in Chile where there is no tradition of eating cladodes in any form. Good acceptability ratings were obtained for jam made from cladodes mixed with lemon juice and peel. One-year-old cladodes were used, blanched and pre-treated with $Ca(OH)_2$ to improve the texture and reduce mucilage content. As cladodes possess grassy flavours and aromas, lemon juice and peel were added to the formulation, increasing the acidity of what is normally a low-acid raw material. As cladodes do not contain any pectin and it was impossible to achieve the required consistency for jam, carrageenan was added at a level of 0.3 percent. The jam had 67 ºBrix, pH 3.8, a_w 0.82 and 2.9 cm min^{-1} viscosity. Viscosity is a key parameter of jam. Sensory analysis of the cladode jam yielded a 7.5 acceptability rating on a scale of 1 to 9, which was promising for a new product of this kind. Quality characteristics noted by the taste panel included good appearance, moderate consistency, pleasant flavour and normal colour, acidity and sweetness.

Another type of cladode product, known in Mexico as cladode candies, includes crystallized and candied products. With some variations, these products are obtained by interaction with sugar and by mixing with other foods, such as dried fruits. There are many different ways of producing a wide variety of sweets and candies. Names also vary from place to place for the different products, whether caramels, jellies, gums, sheets and/or candied and nut bars made with mucilage and others mixes.

Chapter 6 provides further details of manufacturing technologies, given the special interest in using cladodes as the basis of sweet products in different parts of the world.

According to Pérez (personal communication),[1] the basic process for making crystallized cladodes is to use the leaves after first removing the spines. The leaves are then washed in water and cut into squares approximately 10 mm by 10 mm. To make the cladodes firmer, prior to processing they are treated with a solution of 5 percent calcium hydroxide for 24 hours, after which they are washed in running water to remove the lime and then drained. This is followed by blanching at 80 °C for two minutes in order to stop enzymatic activity, soften the tissues, eliminate the mucilage and allow for greater sugar absorption. They are then osmotically dehydrated in a 60 °Brix sugar syrup at 20 °C, with fig leaves added (at a rate of about 15 g), which, according to tradition, helps to maintain the texture of the cladodes. This is probably caused by the calcium thought to be present in the fig leaf. The cladodes are added to the syrup, which is then heated at 80 °C for 20 minutes, after which they are removed from the syrup. The concentration of the syrup is increased to 70 °Brix, the cladodes are added and the mix is heated to 50 °C for three hours. At this time, the cladodes are removed from the syrup and dried in a forced-air tray dryer at 75 °C, and then conditioned at 40 °C to prevent exudation inside the pack.

Villarreal (1997) used a similar process but with much slower osmotic dehydration (starting with syrup 40 ºBrix and increasing the concentration by 10 ºBrix/day until a final stage of 70 ºBrix was reached) and tested different mixtures of sugars in 100 g samples of syrups with sucrose/glucose ratios of 80:20 and 70:30. The best treatment was achieved by using syrups with 100 percent sucrose. Cladodes cut into cubes had been treated previously with a solution of 2 percent $Ca(OH)_2$ to improve texture and remove mucilage. The osmotic treatment resulted in dehydration of the cladode cubes to 15 percent moisture content. The final product had the following characteristics: total solids 88.4 percent; moisture content 11.6 percent; 75.6 ºBrix; citric acid 0.27 percent; ash 0.63 percent; and a_w 0.59. The cubes had a strong green colour (L^*= 27.1, a^*= –2,4 and b^*= 3.6). Energy content was high, at 289 kcal $(100\ g)^{-1}$, which was similar to raisins (259 kcal $[100\ g]^{-1}$) and dried figs (250 kcal $[100\ g]^{-1}$). Product acceptability rating was 6.5 on a scale of 1 to 9, and texture was rated 'good' on a similar scale (see Photo 11). Following three months storage at 15–18 ºC, a reduction in product texture was noted, probably caused by a degree of recrystallization as a result of the high concentration of sucrose.

PICKLED *NOPALITOS* AND *NOPALITOS* IN BRINE

Processing of *nopalitos* (whether pickled or in brine) begins with the reception and preparation of the raw materials. Cladodes should be high quality and have their spines removed. Preparation involves basically washing and blanching the cladodes in order to inactivate the enzymes and destroy any micro-organisms present, soften the products and remove mucilage (Sáenz, Corrales and Aquino, 2002a). Blanching can be done by passing the product through a steam cylinder for

[1] Mario Pérez, chemical engineer, Secretaría de Desarrollo Social, Delegación Tlaxcala, Mexico (2003).

PHOTO 11
Crystallized cactus pear cladodes

C. SÁENZ, CHILE (1997)

10 minutes or immersing the product in boiling water for 30 minutes. It is important to adapt the process time and temperature to the characteristics of the *Opuntia* variety used.

Tender cladodes of wild *Opuntia*, such as Tapon (*O. robusta*), are more resistant to higher temperatures and longer cooking times than cladodes from cultivated varieties like Milpa Alta (*O. ficus-indica* L.) (Corrales and Flores, 2003). Finally the product is immersed in clean, cold water, which causes thermal shock, fixes the characteristic green colour of the fresh tender cladodes and removes any surface mucilage (Corrales-García, 1998).

PICKLED TENDER CLADODES (*NOPALITOS*)

Nopalitos are blanched tender cladodes conserved in vinegar and flavoured with spices (maximum 2 percent acetic acid), with or without added vegetables and other condiments. The process consists basically of manually or mechanically cutting or chopping tender cladodes that have previously been de-spined and washed. At the same time, the pickle is prepared in a mixture of vinegar (1.8–2 percent acetic acid), aromatic plants and oil. First the vinegar is heated to boiling point and spices are added directly or in a cloth bag left for about five minutes in the boiling vinegar to provide flavour. Meanwhile, *acitronado* is prepared by frying sliced onion, chopped carrots, peeled garlic and bay leaves in oil. The cladodes are then mixed with the pickle and *acitronado,* to which chillies (*Capsicum* spp.) and coriander leaves are added. The mixture is packed in jars, then sterilized in an autoclave or water bath, cooled, drained and left to dry before finally being labelled (Sáenz, Corrales and Aquino, 2002a; Corrales and Flores, 2003).

A wide variety of pickled *nopalitos* can be found in domestic markets in Mexico. More than 25 different brands are available, made with a variety of spice mixes and packed in plastic bags, cans and jars. Pickled *nopalitos* are also made in Texas, where they are known as ‘sweet and hot cactus’ or ‘kosher dill cactus’. Various commercial products are available labelled with nutritional information. Nutritional information for two popular market brands is shown in Table 18.

NOPALITOS IN BRINE

These are blanched young cladodes preserved in brine solution (maximum 2 percent NaCl). The production process usually uses *nopalitos* that have been prepared for processing. Some companies’ final products have a 12 percent brine concentration. *Nopalitos* can remain in the brine for between 10 days and many months, depending on the product. During this period, it is essential to monitor and maintain the correct concentration of the brine, stir it daily and keep containers well sealed to avoid contamination from foreign matter and discoloration from light.

When brining is complete, the *nopalitos* are desalted by washing, sorted and chopped into strips, cubes or tiny cladode shapes called ‘baby nopalito’. They are packed into glass jars, polyethylene bags, cans or plastic pails, to which are added spices, cover liquid (2 percent brine) and, when required, preservatives. The product is sometimes marketed in bulk, without desalting (Sáenz, Corrales and Aquino, 2002a; Corrales and Flores, 2003). Brined *nopalitos* are typically used in the preparation of many different dishes.

The yield of ready-for-sale brined products using *nopalitos* with spines as the base material is

TABLE 18
Nutritional label for commercial pickled cladodes

Characteristic	Value
Energy	27 Kcal
Protein	1.7 g
Fat	0.3 g
Carbohydrate	5.6 g
Calcium	81 mg
Iron	2.34 mg
Thiamine (vitamin B)	0.02 mg
Riboflavin	0.08 mg
Niacin	0.24 mg
Ascorbic acid (vitamin C)	12.30 mg
ß-carotene	0.25 mg

Source: Salvador Zubirán National Nutrition Institute (INNSZ), Mexico.

TABLE 19
Nutritional label for commercial pickled products

Component	Content	Percentage daily requirement*	Content	Percentage daily Requirement*
	Brand A		***Brand B***	
Energy from fat	0	0	0	0
Carbohydrates (total)	2.03 g	0.67	5	2
Dietary fibre, g	2	18.79	2	8
Sugars, g	0	0	1	-
Protein, g	0.6	-	1	-
Vitamin C		3		
Iron		8		

Source: Prepared by the authors and based on nutritional labels attached to the products.
* The daily values are based on a diet of 2 000 Kcal. The values can be higher or lower depending on individual calorie needs.

around 57 percent, depending on manufacturing processes and performance.

The appearance of the products is highly variable. In many cases the original brilliant green colour is lost as a result of chlorophyll degradation by heat or acid treatments used in the process. According to Montoya *et al.* (2001), some research has been carried out to counter this which has resulted in changes to traditional processing techniques.

Similar markets and products exist for pickled *nopalitos*. More than 20 different brands are currently sold to domestic markets in Mexico, and some companies also manufacture in Texas. The product is sold in glass jars and cans. One of the companies manufactures a cladode puree.

Two Mexican brands include brined and pickled *nopalitos* and feature nutritional information labels, as shown in Table 19.

Brand B also included on its label the sodium content (940 mg or 39 percent recommended daily intake) and cholesterol (0), which is useful for a plant product. Although information on labels varied, the trend is to provide more information about the products and their contribution to the daily diet.

Photo 12 shows a selection of *nopalito* products available on the Mexican market.

As a vegetable, *nopalitos* have high nutritional value but people need to be aware of and try them. The University of Chile, in collaboration with researchers at CIAD in Mexico, set out to explore

PHOTO 12
Pickled and brined tender cladode products

(A, B, C) J. CORRALES, MEXICO (2005), (D) L. C. MONTOYA, MEXICO (2005)

the opportunities for introducing *nopalitos* into Chile where they were previously unknown. Sáenz and Montoya (1999) described the work and preliminary studies undertaken. Brined *nopalitos* were prepared according to recommendations by Montoya *et al.* (2001) (as described in Chapter 6) and were evaluated positively by a taste panel.

The product was presented to the panel as a salad, prepared according to Chilean customs, and the sensory evaluation yielded an acceptability score of 11 on scale of 1 to 15 (Sáenz *et al.,* 2000).

Product appearance and a distinct mucilaginous texture might have downgraded acceptability but, although the taste panel detected them, these characteristics did not differ significantly from the control sample (*nopalitos* cooked at 100 °C for 10 minutes) and so did not influence the acceptability score.

These results were encouraging and hold out promise for many people in food-insecure areas of the world who might benefit from introducing *nopalitos* into their daily diet.

FLOURS

Cladode flour is obtained by dehydrating and milling cladodes of different ages. The age influences the characteristics of the flour. Flour has recently been used in the baking industry and has potential for manufacturing cookies, pastries, soups and desserts, as well as pelletized dietary fibres. The latter application has become important because it increases consumption of soluble fibre, significantly improving the digestion of people with constipation. Cladodes are an important source of this type of fibre.

Sáenz *et al.* (1997d) described the physical and chemical characteristics of cladode flour prepared using a mixture of cladodes of different ages (one, two and three years old), as shown in Table 20. The flour contained 43 percent total dietary fibre, of which 28.45 percent was insoluble fibre and 14.54 percent was soluble. The a_w was low and the colour was shiny pale green, which was easy to change by adding more attractive or acceptable natural colours. It had a high water absorption index (WAI 5.6 ml g^{-1}), which explained its satiating properties.

The calcium and potassium levels in the flour are typically high (3.4 mg g^{-1} and 2.1 mg g^{-1} respectively), while the level of sodium is low (0.02 mg g^{-1}). Although calcium is high considering that the recommended daily intake for an adult is 800 mg, bio-availability needs to be taken into account. Energy contribution is 145.3 kcal $(100\ g)^{-1}$, which is lower than that of wheat and pulse flours, and which, according to Schmidt-Hebbel *et al*., (1990), is typically between 325 kcal $(100\ g)^{-1}$ and 357 kcal $(100\ g)^{-1}$. Total microbiological counts were low, at 3.3 cfu g^{-1}, and the fungal and yeasts count was 4.6 cfu g^{-1}. A

TABLE 20
Characteristics of cactus pear cladode flour

Analysis	Value
a_w	0.53
Colour	
L*	73.37
a*	–5.20
b*	26.1
W.A.I. (ml g)	5.6

Source: Sáenz *et al.* (1997d).

point of note is that the cladode flour is not eaten as it is but is incorporated into other products that are normally heat treated.

Cladode flour has been tested for enhancing the fibre content of products such as vegetable soups, *flan*-like desserts (*flan* is a gelled dessert similar to crème caramel) and cookies. This is of special interest in many countries with low-fibre diets as foods of this kind have potential health benefits.

When incorporating this product into liquid or semi-liquid foods, such as soups or desserts with a degree of gelling, the viscosity or rheological properties of the flour should be taken into account. These can significantly influence the sensorial characteristics of the product to which it is added. In trials to explore this aspect, Lecaros (1997) considered model dispersions of cladode flour with concentrations of 2.5 percent, 5.0 percent and 7.0 percent and pH values of 4.0, 6.0 and 7.0. The pH represented the range generally found in foods. Changes in viscosity were measured at different temperatures (10 °C, 20 °C, 40 °C and 70 °C) because foods are processed or consumed after heat treatment. Some foods are cooled before eating. The biggest effect was caused by temperature and concentration, while pH had little effect. The highest viscosity of the dispersion was found at 7.0 percent concentration, pH 7.0 and 10 °C, attaining a value of 2 307.0 mPa s. Information of this kind is important for food formulation.

A further factor that could influence rheological properties and has been little studied is the effect of cladode drying temperatures. There were indications that drying temperatures of 75–80 °C resulted in lower viscosity of flour suspensions, meaning that a higher proportion of flour would be required in formulated foods (Lecaros, 1997). It is necessary to check these effects on dietary fibre. An additional factor, and one that impacts the agronomic management of growing plants, might be variations in mucilage content. Nobel, Cavelier and Andrade (1992) stated that ambient growing temperature can influence the mucilage content of cladodes; it is also possible that irrigation and rainfall have a similar effect.

When formulating a vegetable cream soup from cladode flour, the same selection of commercial products was used (wheat flour, dehydrated spinach, onion, skimmed milk, sugar, salt, flavourings, etc.), except that 15–20 percent of the wheat flour was replaced by cladode flour (Sáenz, 1997; Sáenz *et al.*, 1999). It was noted that the level of replacement significantly affected the sensory characteristics of the soup, and that a soup with 15 percent replacement received the highest preference rating (7 on a 9-point scale). At the same time, good ratings were received for appearance, colour and aroma but viscosity was judged too high. As this property has a major influence on acceptability, it is essential to improve it. There were obvious advantages in the 5 percent higher dietary fibre and lower calorie content in flour with this level of replacement when compared with similar products already on the market (Albornoz, 1998).

Use of cladode flour in dessert formulations was evaluated by adding different percentages of the flour (16–18 percent) to a base formulation. Other ingredients typically used for cakes or dessert mix powders designed for home preparation were added, such as skimmed milk powders, thickeners, carrageenan and guar gum, sweetener, flavouring and salt (Sáenz *et al.,* 2002b). The addition and choice of flavouring agents is important because cladode flour has a grassy flavour and smell that some consumers find unpleasant.

A powder mix for *flans* had a_w 0.48, which limited microbial activity and offered good preservation properties. The composition of a *flan* mix shown in Table 21 is from Sáenz *et al.* (2002b).

TABLE 21
Chemical composition of a powder mix for flan dessert (g [100 g]$^{-1}$)

Analysis	Average
Moisture	5.72
Protein	27.2
Ether extract	2.0
Ash	12.7
Fibre	9.8
Nitrogen-free extract	42.6

Source: Sáenz *et al.* (2002b).

Of the total dietary fibre, 6.7 percent was soluble and 3.7 percent was insoluble, which would typically be affected by the addition of cladode flour, guar gum and carrageenan. A 100 g portion of reconstituted dessert contained 1.2 g dietary fibre – more than that of similar products on the market. The *flan* was low in calories (40.3 kcal/portion) because it was formulated with a zero calorie sweetener. A similar dessert with added sugar contained 90 kcal/portion – more than twice as much.

The powder is just one of the ways in which cladode flour can be used in food formulations for preparing vegetable soups or desserts. However, as liquid food preparations are more likely to be affected by mucilage, more work will be required to improve the final presentation.

Cookies and biscuits are dried products that can also be made by replacing some of the wheat flour with cladode flour (Sáenz *et al.*, 2002c). These products are already on local markets in many different formulations of 'whole grain' cookies or biscuits, exploiting market niches that promote 'natural' and/or 'high fibre content'. It is a well-known product with a market niche. However it still has to compete with other more familiar products with better acceptance.

Fontanot (1999) conducted studies on various proportions of cladode flour mixed with wheat flour for making cookies, with cladode flour replacing between 15 percent and 25 percent of the wheat flour. The base formulation contained wheat flour, sugar, lard, eggs, milk powder, salt and sodium bicarbonate, together with cinnamon and oats, which provided a flavour similar to cookies already familiar to consumers. Cookies with the highest acceptance rating contained 15 percent replacement flour. Problems noted were grassy flavours and mucilaginous sensation at point of tasting. More effort should be focused on mucilage content, as well as on formulation design, with increased content of oats, cinnamon or other flavourings better able to mask the flavour of the cladode flour.

By 2003, tortillas made from cladode flour or fresh cladodes mixed with traditional maize flour were being sold in local Mexican markets. Tortillas are the country's top staple and a project was undertaken to explore the use of cladode/maize mixtures. Teresa Arellanos[2] reports that the tortillas made with fresh cladodes were well received by consumers. Tortillas made from similar mixtures have since been introduced successfully into many parts in the country (Aguascalientes, Jalisco and Zacatecas). In 2001, the project won Mexico's prestigious National Network for Rural Sustainable Development prize.

[2] Teresa Arellanos, Gente Latina y Desarrollo, S.A. de C.V., Mexico, 2005.

QUALITY AND SAFETY

The importance of maintaining high-quality supplies of raw materials applies equally to manufactured products. A number of extrinsic or intrinsic indicators can be used to determine the quality of these products. 'Intrinsic indicators' are typically those that consumers use for evaluation: their own senses and/or perception. When this is impractical, other indicators, known generically as 'extrinsic indicators', are used. These include health/safety, nutritional value, production method, environmental protection and product source. Typically, these attributes have to be evaluated by indicators such as seals, brands and/or certification, usually provided by specialist third parties (FAO, 2000; and FAO, 2003).

According to Corrales (1994), safety and quality assurance programmes are based on established standards, quality control, inspection procedures, certification and/or accreditation, all of which refer back to original theoretical and laboratory work under the responsibility of the appropriate national authorities.

Standard-setting promotes collaboration between all participants in the value chain. Standardization and the procedures for maintaining standards can overcome obstacles to business development and allow for the differentiation of products, goods and services to enhance consumer protection.

CODEX STAN 185-1993 is the Codex Alimentarius standard for *nopalitos*. It applies to *nopalitos* that have been prepared, packed and marketed fresh. However, there are no international standards for industrially processed *nopalitos*, such as pickled or brined products. Mexico has introduced food standards to provide a measure of guidance and/or reference for such products, including standard NMX-F-121-1982 on human foods (jalapeños or Serranos chillies packed in vinegar or pickled) and standard NMX-F-150-S-1981 on human foods (determination of sodium chloride in brines).

In summary, it is essential to establish high quality foods and safety assurance programmes that will guarantee and certify the attributes required in any and all products. This is based on national standards and regulations, an inspectorate to maintain them and compliance by manufacturers, typically recognized by brands, seals and/or certification (FAO, 2003). Mexico has made a start by grading young *Opuntia* cladodes sold fresh but this has yet to be extended to industrially processed *nopalitos*.

Codex Alimentarius standards cover *all* major foods, whether raw, semi-processed or processed (FAO/WHO, 2003). They also include materials used in the preparation of foods, including raw materials or primary products, as these pertain to the main Codex objectives*:* to protect the health of the consumers and encourage fair practices in food marketing. In the case of cladode-based foods for which there are no Codex standards, available standards for additives and/or other aspects of food processing relating to *Opuntia* cladodes should be used. This provides a better understanding of the issues involved, encourages continued progress and debate and the eventual development of accepted international standards, ultimately benefitting consumers and trade worldwide.

MARKETING: CURRENT STATUS AND PROSPECTS FOR PRODUCTS

Corrales and Flores (2003) have provided a useful summary of the current status of industrial and market development of cladode-derived products, identifying key issues and potential.

A range of pickled and brined *nopalitos* products are produced in Mexico and the United States. The principal varieties grown for human consumption are those of the genus *Nopalea*. These have fewer spines but a thicker peel than *Opuntia* varieties and are generally preferred for processing and consumption.

In Mexico, Corrales and Flores (1996) have described more than 20 companies producing *nopalitos* in brine, and at least three in the United States. More than 25 companies manufacture pickled *nopalitos* in Mexico, with just one listed in the United States. Markets are expanding in line with growing demand for a range of cactus products driven by the increasing popularity of Mexican foods, as well as movements of people. There is novelty value in adding spicy foods to such dishes as salads, and people have become more adventurous in exploring new foods. A similar rising trend has been seen in consumer preference for foods with higher nutritional and health value.

The growing market for Mexican food has not been lost on the commercial sector, and more than 15 branded foods have been identified in the United States (nine in Texas, five in California and one in Arizona), owing partly to the migration and/or resettlement of large numbers of people from Mexico and other Latin American countries who favour such foods. When cooking Mexican dishes, most households prefer to purchase fresh ingredients and prepare sauces on a daily basis. Ready-made ingredients are seldom purchased. This is not the case with recent converts to Mexican foods who have neither the time nor custom of preparing fresh sauces. New markets are selling more factory-made products. Similarly, the amount of hot chillies in processed foods should be reduced to suit palates unfamiliar with highly spiced foods. Marketing campaigns need to tailor both products and approach to people who may be eating Mexican foods for the first time.

When using cladode flour in processed foods, the main strategy has been to introduce into local markets new products containing a mix of cladode flour and traditional flours and to mask any significant changes in taste and/or texture.

Markets for fruit and vegetable juices continue to expand, which presents opportunities for adding cactus pear fruits to mixtures of other fruits to suit the tastes of different customer groups.

Cladode jams are produced by at least four brands in Mexico and two brands in the United States. In Texas, for example, a jam-making company extracts mucilage from grinding and filtering *nopalitos* and uses it to improve the consistency of jams made from a variety of fruits (e.g. cranberry, raspberry, blackberry, strawberry, peach, apple, pear, pineapple and plum). A compote of *nopalitos* and several fruits (pineapple, pear, fig, peach and cactus pear fruits) in syrup has recently been introduced in Mexico.

World markets for *nopalito* jams offer promising prospects for mucilage mixtures with other fruits, especially by emphasizing the additional health benefits of *nopalitos*. Jam markets in Mexico offer limited potential partly because the climate is too hot for most of the year and, not least, because most households have a preference for strawberry jam (more than 85 percent of the jam market). Other preferred jams include pineapple, peach, blackberry and orange. The reality is that there is little demand for *nopalito* jam in Mexico.

Mexico has a buoyant market for all kinds of cladode-based sweets and candies. This includes *nopalitos* in syrup, crystallized cladode pulp, gums, marshmallows and candies. There are exciting prospects for expanding worldwide markets for cladode-based sweets and candies. Well-targeted campaigns in support of high value products will be essential.

Chapter 6
Small-scale food production for human consumption

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DESCRIPTION OF PRODUCTS

There is a wide variety of options for the use of cactus pear fruit, *nopalitos* and mature cladodes, and for processing them into various types of products. Some have been produced in the home for many years and make use of basic, well-known technologies. Some are concentrated products, such as jams, prepared either from the fruit or *nopalitos*. Pickled and brined products are made mainly from *nopalitos*. Dehydrated products are made either from fruit pulp or *nopalitos*. Flours are made from cladodes, and other products can be obtained by fermenting the juice of the cactus pear fruit. Home food production has different objectives to that of small- or large-scale processing industries.

The overall objectives are to: preserve the fruits or cladodes, both of which are perishable; prevent loss through deterioration and/or disease; preserve them beyond the production season, especially in times of scarcity; and provide foods that contribute to a more balanced diet. Little or no capital is required for home preparation of these foods, as the simple technologies and equipment required are typically already available in the home. The ingredients (water, sugar and salt) are inexpensive and readily available.

In some regions where *Opuntias* grow wild or are cultivated, many people have neither knowledge nor awareness of the many options available for using these plants. So, in rural areas, it is logical to begin with uses or processing methods that are familiar because they are *already* used to preserve other plants. It is usually easier to for people to learn how to use, consume or process a ‘new’ species and about its nutritional value and other benefits than it is to learn new technologies. Not only will such technologies be unknown, in some cases so much effort and equipment are required that it might make adoption difficult.

Industrial processing typically differs from home processing, whatever the scale, in terms of the technologies used, the equipment required and the need for facilities and infrastructure. It is usually nothing like home processing, although many of the same principles and activities apply. Industrial processing also has different requirements in terms of labour, the required consistency and quality of materials purchased/used for processing and produce manufactured, as well as the regularity of materials flowing into and out of the factory. Popular manufactured goods always face competition in the marketplace. The skills, equipment and methods required for household production are neither sufficient nor suitable for industrial-scale production.

This chapter covers industrial production of selected foods derived from *Opuntias*. Some of the most promising and attractive products are explored, even though the required technologies may be expensive or complex. Some applications can be implemented without major problems on any scale of production, while others require different infrastructure and more capital.

Figure 2 illustrates the selected products. The processing steps are described below.

One advantage of the selected products is that, in many cases, the same processing steps can be used, with minor modifications, for other types of fruit. As cactus pear fruit is a more seasonal product than *nopalitos*, the infrastructure, equipment and industrial production system required may well be under-utilized, with the resulting economic losses.

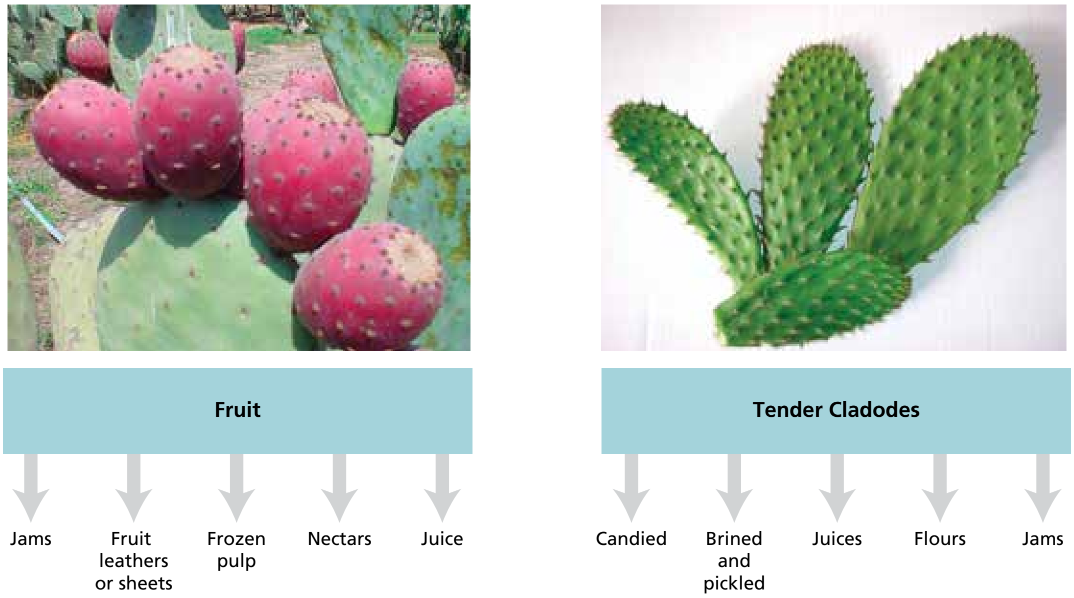
TECHNICAL REQUIREMENTS

Requirements for raw materials, equipment and other elements for the different industrial processes for producing cactus pear fruit and *nopalitos* are described in the next paragraph.

Raw materials

A fundamental prerequisite of any agro-industry is an adequate supply of raw materials to operate the equipment and plant economically over a period of time. Whether fruit or cladodes, these

FIGURE 2
Examples of industrial processing based on cactus pear fruit and cladodes



Source: C. Sáenz, Chile (1997) and E. Sepúlveda, Chile (2005).

raw materials must comply with a number of strict requirements to make them suitable for industrial processing: they must be of sufficient quality for the intended processes; they should be available over the maximum possible period for seasonal supply (or be shipped in from elsewhere); they should be uniform and available in sufficient quantities for factory/process operation; and they should be available in such a way as to enable factory output to match market demand.

Factory managers source inputs from contracted suppliers on the basis of: distance from the factory; assessment of raw materials offered (quality, uniformity, etc.); and extent of pre-delivery damage from poor handling on the farm and during transport. Reliability of supply is also important and contractors must be able to deliver when required. Table 22 identifies some critical quality parameters affecting the different processes that will be used.

All agricultural materials vary, and cactus pear fruit and *nopalitos* are no exception, with variations in composition that impact industrial processing. Much depends on species, ripeness, size and variability, production location (climate and soil) and handling. Some of these differences can be accommodated within the industrial process and by markets. For example, some orange juice is sold with the descriptor 'not from concentrate' on the container, and consumers *can* detect variations in sweetness. Differences of this kind are usually accepted as a natural variation in the fruits used or their origin (location, climate, etc.), provided that no sugar has been added. While this might be thought a disadvantage in terms of consistency in product quality, it has become an advantage in the marketplace (as long as these differences remain within certain limits) because it is reflects the 'natural' state of the original fruits. The juice has *not* been adulterated to provide more uniform sugar content. The type of raw material used therefore depends to a large extent on what the factory produces.

Equipment

A small or medium enterprise will use mechanical and/or automatic equipment in the manufacturing process but may also include a number of manual operations. Mechanical or manual modular systems using portable equipment in different production lines are advantageous because they reduce costs and provide more production flexibility.

The layout of the equipment follows the process flow logic, saving space and avoiding critical points of contamination (e.g. near drains, doors to

TABLE 22
Quality characteristics of cactus pear fruit and cladodes required for industrial processing

Type of product	Characteristic				
Fruit	***Yield (pulp & pieces)***	***Colour***	***°Brix***	***Acidity***	***Texture***
Dehydrated sheets/leathers	x		x		x
Jams	x		x		x
Juices	x	x	x	x	
Nectars	x	x	x	x	
Frozen pulp	x	x	x	x	
Tender cladodes					
Brined	x	x		x	x
Jams	x	x		x	x

washrooms, offices and other places where people may congregate, such as people from outside the plant waiting to see the factory management).

A key factor for the manufacture and production of high quality foodstuffs is routine cleaning and maintenance of equipment. This has to be undertaken carefully according to well-established routines, in such a way as to ensure that the equipment is completely clean and free from all residues of processed materials. This is usually done after the equipment has been shut down for the day to enable the factory to operate normally during working hours. Cleaning routines are established on the basis of manufacturer's recommendations and throughput.

Facilities

Recommendations by Codex Alimentarius (FAO/WHO, 2003) and by Fellows (1997) and many others are confirmed by the authors as useful for choosing which equipment to purchase, where and how to install it and how to prepare it for operation. Recommendations for the installation of food processing equipment are typically based on the hygiene standards required for operations and workers. Many countries have their own regulations concerning the composition and safety of foods, which also govern practices in the processing plant and the conditions for food retail outlets, such as shops and restaurants. Every part of the food chain is covered by regulations. They are usually the responsibility of ministries of health and other official agencies. Standards must be adopted and procedures followed as required. Failing this, the factory, shop or restaurant may not pass inspection.

Ideally the food processing plant and equipment will be constructed specifically for the purpose of food processing. However, food processing equipment is frequently installed in a building that has previously been used for a different purpose. Notwithstanding additional costs for conversion, if this is done carefully the new unit *will* be suitable for food processing. The cost of adapting buildings should be carefully considered because it may be very similar to the cost of a new building, making it preferable to opt for a new purpose-built factory.

The choice of location for the processing plant is vitally important. Points to consider include: access to supplies of raw materials; proximity to markets (e.g. access roads); availability of labour; potable water, electricity and telecommunications utilities; and the condition of the area surrounding the plant (i.e. location of rubbish tips, waste dumps, standing water, odours, insects, vermin, etc.). The alternatives are then to relocate and/or clean up the environment. Cuevas (2004b) reviewed a number of factors for plant location and its effect on product quality and the competitiveness of small-scale food industries.

For a food processing plant, perhaps more than for other types of buildings, external appearance is important, as this is what determines a customer's first impression. Cleanliness and presentation is an indicator of good internal management of the business. However, although the façade is important, a clean exterior is not sufficient in itself. The plant should be clean and painted both inside and out. The plant's immediate surroundings should be clear and clutter-free, with trimmed lawns, equipment and material stored out of sight, rubbish removed and cars and trucks parked well away from the main working areas. The air around the plant should be filtered and dust-free, which is important if the plant produces large amounts of dust.

Inside the plant, the walls should be painted in pastel shades, using water-resistant paint (impermeable and non-toxic) because, like the equipment, the walls must be regularly washed and maintained. For optimum results, the walls should be covered in ceramic tiles to a height of 1–1.5 metres above ground level. If this is too expensive, then tiles should be used around washbasins or wherever walls may be subject to splashing during processing operations. At the very least the walls should be smooth and free from cracks up to a height of 1.8 metres.

A particularly important point for hygiene is the way in which the walls meet the floor. As right-angle junctions are difficult to clean and quickly accumulate dirt, curved junctions are recommended, which can be swept easily. The same applies to windows, which should be constructed to avoid dust and dirt build-up and to prevent them becoming a source of contamination. Window frames should preferably be flush with the wall to facilitate cleaning and provide easy access to windows. Windows should also be fitted with screens to prevent the entry of insects and birds.

Floors should have sufficient drainage to channel away the large amounts of water sometimes used in food processing plants. In purpose-built structures, drainage systems are built into the floor during construction. The floor should have sufficient gradient for water to flow smoothly to a central drainage channel. This should be covered with an easily removable grid to facilitate cleaning of the grid and channel. As such channels may provide access for rodents and cockroaches, they should be fitted with barriers and regularly checked to ensure that they are working satisfactorily.

Apart from the windows, care should be taken to prevent the entry of insects, birds or rodents through other parts of the building's fabric. Vermin can easily gain entry through holes in walls or doors, or gaps where structures have warped or changed shape. Typical entry points are between the roof and walls and at the main entrance doors, particularly where there is damage from road vehicles. Other entry points for pests (typically rats and cockroaches) are service conduits set into the floor or walls for pipes or power or telecommunication cables. It is useful to insert metal discs into such conduits to impede passage and, importantly, to check them from time to time.

Cleaning rooms and washrooms should be separated from food-processing rooms. A washbasin must be placed near the entrance to the plant and at the exit from the toilets, if possible, with taps operated, by the arm or elbow rather than the hands. This helps to avoid recontaminating washed hands before re-entering the plant. A small pool of water set into the floor at the entrance to the processing room, through which all operators must pass (wearing rubber boots), helps to keep boots clean and maintain hygiene.

Raw-material preparation operations, such as washing and sorting, are sometimes undertaken outside the plant. It is recommended to roof over this area to improve working conditions, particularly in hot and/or tropical areas with heavy seasonal rains.

Depending on the site of the processing plant, the plant should be securely fenced to avoid the entry of large animals and/or thieves. Living fences can sometimes be used, including *Opuntia* plants.

Utilities and services

One of the most important requirements for any food processing plant is a plentiful supply of potable water, typically used for:

- maintaining plant hygiene (e.g. washing equipment, floors and walls), which is essential to ensure the safety and quality of the foods produced;
- operators' personal hygiene, which helps ensure food safety;
- washing raw materials (the first step in the production of high-quality products);
- washing other materials and supplies, such as bottles and caps for jars;
- preparing a product to be used as a food ingredient (this is *highly* important because this water will become part of the product).

For these reasons it is essential to have a plentiful supply of clean, good quality potable water.

In many parts of the world, especially in rural areas, a regular supply of clean potable water is not always available, and plant managers need to obtain water by other means. This includes purification to ensure sufficient good-quality water for processing, culminating in a final product that is safe for consumption. Chlorine is used to sanitize water, usually in combination with filters and holding tanks. When water is used in this process as a food ingredient, it must be carefully treated if potable water is *not* already available. This is particularly important if the product is not heated after the water is added. Fellows (1997) reports that water can be treated on a small scale in a number of ways. Boiling and chemical treatment is a first practical option. Other methods use ultraviolet light. Treatment with sodium hypochlorite is a rapid method for sanitizing water. Water used for cleaning should contain 200 ppm chloride, and water used as an ingredient should contain a maximum of 0.5 ppm to prevent the strong odour of the sanitizer passing into the food.

Access to a reliable energy source is essential for any agro-industry, whatever the scale of production. Electricity is required for operating equipment and to provide the thermal energy (heat and steam) required for some processing steps. These can be obtained from a number of sources.

Small and medium agro-industries usually obtain power from the municipal supplies or from an on-site generator. Different fuels may be used, including liquid propane gas, biogas, petrol/diesel, coal, fuelwood or other flammable fuel sources.

Although many micro-enterprises operate with manual equipment that may not require electrical energy, many operations, such as cooking, pasteurization and sterilization, require electricity either from mains supplies or other sources. Cuevas, Masera and Díaz (2004) and Cuevas (2004a) emphasized energy as a strategic to the development of agro-industries, and the availability of reliable supplies should never be underestimated. The better the supply of energy, the more viable the business and the more opportunities there will be for reducing poverty in the local community.

Energy from fuelwood and other sources of biomass are widely used by small and medium agro-industries. If mature *Opuntia* cladodes are left to dry, the lignified skeleton makes an excellent biofuel, which gives *Opuntia*-based agro-industries a built-in energy advantage. However, little information is available on the value, uses, application and yields of *Opuntia* cladodes as fuel, despite the fact that it is used in the home in some African countries. Studies of this kind would be very useful.

Electrical power systems in the processing plant must be protected from water and from rodent attack, and the main circuit breakers/fuses should be located at least 1.5 metres above the ground and well away from wet areas of the plant.

An additional service required by agro-industries is the distribution of products/manufactured goods. Distribution and marketing facilities may be owned by the same company (trucks, sales points, etc.) or be outsourced. Distribution is helped by access to transport services and to a network of good roads linking the plant with the main commercial centres.

The purchasing of supplies (e.g. sugar, packaging, additives), facilities and/or services (e.g. for plant/equipment maintenance, especially if this is sophisticated) and other requirements to operate agro-industrial plant/equipment, has to be considered when planning and establishing facilities. Failure to foresee requirements and/or to contract reliable services may lead to operational inefficiency. The more complex the plant and its equipment and manufacturing processes, the more varied will be the services required. This will ultimately determine ease of operation, costs and profitability (Cuevas, 2004a; Cuevas, 2004b).

Labour

A supply of high-quality raw materials is essential for the production of high quality, safe foods. However, it is the people involved in the production process that are critical to the industry: skilled technicians, managers and labourers are the ultimate resource. In industry, as in all walks of life, it is people that matter most. The availability of highly qualified staff determines the sustainability of the plant and the business over time. If qualified staff cannot be recruited because they are not available at the plant location, or if the enterprise is too small to pay for full-time specialists, then the firm will need to contract people in for services. However, as the enterprise expands, pragmatic choices usually result in one or more people in the company/family being trained in key specialist skills.

Training is an essential part of the longer-term development of the business. Ultimately, everyone at the plant should undergo some form of training, even for apparently quite simple tasks. It is important to remember that food production is part of a chain and that quality assurance requires conscientious work by *everyone* in the company. All workers should be aware that they are playing an important role in ensuring that processing operations produce high quality, healthy foods that are safe for their customers to eat. This sense of ownership should be nurtured over time and all workers made to feel responsible for their small part in the overall process. At the same time, as workers demand quality in the items they receive at their stage of the process line, they are effectively acting as internal customers who are either satisfied or dissatisfied with the goods delivered. This leads to the development of a chain of responsibility for quality and encourages everyone involved to work as well as they possibly can.

Training efforts should be directed at the technical aspects of each production worker's job: hygiene, personal relations, responsibilities and other values (e.g. honesty, work ethic, loyalty, commitment), which make the work and the workplace safe and pleasant, given that most people will spend many hours each day and many days each year at the plant. Contented workers are likely to remain with a company for much of their working lives.

Numerous publications provide information on operating plant and equipment, some of which were used as the basis of this summary. Operator hygiene reporting is covered by Fellows, Axtell and Dillon (1995), Fellows (1997) and Enachescu (1995). Codex Alimentarius international food standards (FAO/WHO, 2003; FAO/WHO, 2004) are recommended reading. FAO/WHO (2003) and Chile (1997) are recommended for hygiene standards on the plant, staff, processing and sale of food products. Goleman (1999) is useful on interpersonal relations. All countries have national regulations governing the operation of food-processing enterprises. These should be scrutinized, if necessary with the assistance of local specialists, as part of industrial planning and *prior to* investment or construction.

Working capital

Working capital is generally essential whatever the scale of the agro-industry; and, it is usually investors who determine the cost of borrowing sufficient funds for establishing the business and operating it prior to selling any goods. Consideration must also be given to the operational costs/cash flow of the business on the basis of earnings. Financing is usually required for raw materials, supplies and services, as well as for building the plant, purchasing equipment and installing services. As funds required for purchasing differ from those required for operation, so the financial costs involved and loan/credit terms will also be different.

Investment funds will be required to purchase land, construct buildings, purchase and install machinery, equipment and parts, and to pay the costs of preparing the plant for operation, such as troubleshooting. This can usually be borrowed from commercial sources, although small-scale agro-industrial investment in developing countries is sometimes available from donor/grant funding.

Working/operating capital will be required to cover the costs of raw materials and supplies, labour and basic services (energy, water, etc.), sometimes before any revenues have been generated from sales of processed products. Funds will be spent during the early months of plant operation and prior to the sale of products. Estimations of the funds required will help to determine the amount of operating capital required, and this can also be borrowed. Once the plant is up and running, working capital usually finances the inventory and incoming invoices, should these exceed the company's credit from suppliers.

In a modern economy, several sources of finance can sometimes be combined in order to reduce the requirements for working capital (and hence the cost of borrowing). This may be shared with others, again at a cost. Apart from bank financing, factoring, for example, will enable a company to receive payments early, potentially reducing the need to make further personal funds available as working capital.

A number of criteria are generally used to differentiate between types and levels of enterprises. They include: the number of workers and their skills; technologies used; capital invested (in relation to staff numbers); scale of investment; scale of operations; annual capacity; systems organization and so on.

Scale is often determined by the number of workers. Micro-enterprises are those employing 1–5 workers, small-scale enterprises are typically those with 6–20 workers, and medium-scale enterprises are those with 21–100 workers (Higuera, 2004).

PRE-PROCESSING

Operations undertaken prior to processing are of special interest for processing cactus pear because post-harvesting and handling of fruits or *nopalitos* have a direct impact on the quality of the final product. Cactus pear fruit or *nopalitos* must be harvested carefully to avoid damage and/or contamination and to ensure quality from crop/field to the first stage of the processing line.

Supplies of raw materials to the plant are secured in cooperation with producers to ensure that the crop meets factory input requirements and that harvested materials remain in good condition when stored prior to delivery. Storage in the open air and/or the field is *not* appropriate once these materials have been harvested. If there are no refrigerated storage facilities available, raw materials may be kept in the open air under a roof or shaded mesh screen for short periods prior to processing. Raw materials should be packed and delivered in open boxes that can be handled easily

PHOTO 13
Cactus pear fruit arriving at the processing plant

C. SÁENZ, MEXICO (2004)

by one or two people. This 'non-bulk' packaging minimizes the risk of damage from crushing (see Photo 13). At no time should the fruit or cladodes be left in a pile on the ground awaiting transport in the field or before delivery to the factory.

Once the raw material has been delivered to the processing plant, it is formally received and checked for quality on the following points:

- cleanliness and ripeness of the fruit;
- uniformity of size and freshness of cladodes;
- uniformity of the varieties of fruit received;
- weight of the fruit or *nopalitos* received (indicating source, names of producers contracted, company farms, etc.).

Depending on the type of fruit to be processed, it is sometimes useful to perform routine laboratory analysis (e.g. acidity, °Brix and pH). Sugars (°Brix) can be controlled easily using a manual refractometer.

After harvesting, *nopalitos* do not generally receive any conditioning or preparation prior to delivery to the plant. Whatever the means of transport, crops should be delivered carefully to prevent damage prior to arrival at the processing plant. They should therefore be transported in boxes. In Mexico, they are transported to local markets in *pacas*. These are cylindrical structures about 2 metres high and 1 metre in diameter, into which 2 500–3 000 *nopalitos* are packed. This method of transportation is described by Corrales and Flores (2003) (see Photo 14).

The *paca* is a useful container given the large number of cladodes that can be moved. However, the *pacas* should not be left for more than a few days at room temperature before unpacking because, like all plants, changes will occur as a result of respiration. If the cladodes are transported loose in wooden boxes they can be damaged from knocks and broken spines. The colour of the cladodes darkens and processing quality is lost.

PHOTO 14
Types of transport systems for tender cladodes (wooden box and paca)

A. RODRÍGUEZ-FÉLIX, MEXICO (2005 AND 1999)

REMOVAL OF SPINES

Spines can be removed from cactus pear fruits manually or mechanically. Manual removal is typically undertaken in the field immediately after harvesting, as shown in Photo 15. A bed of straw is prepared on the ground (sometimes a net or plastic sheet is used) and the fruits are laid out on it. A worker with a broom removes the spines by brushing the fruits back and forth to rub them against the straw. Care is required to avoiding damaging the skin of the fruit and to prevent soil contamination. Soil and/or straw contaminants have to be removed at the processing plant.

Mechanical removal of spines is usually undertaken in the open air, before the fruits are delivered to the plant. In hot countries shade is provided with a *raschel*-type plastic mesh spread over the de-spining equipment to make the working area pleasanter and to prevent the fruits from warming.

Different equipment designs have been developed for removing the spines. The same equipment can be used either on the farm or as the first stage of processing at the factory. The aim is the same: to remove the spines from the fruit.

Spines are removed by running the fruits over rollers covered with hairs or brushes that are sufficiently hard to remove the spines without damaging the fruit (Photo 16). Brushes are typically made from nylon bristle, horsehair or cloth that is thick and firm but not rough. The spines from cac-

PHOTO 15
Brushing cactus pears to remove the spines

C. SÁENZ, CHILE (2002)

PHOTO 16
Mechanical removal of spines of cactus pear fruit

SÁENZ, MEXICO (2004)

PHOTO 17
Mechanical equipment for removing the spines of cactus pear fruit with air-suction device

C. SÁENZ, MEXICO (1991)

tus pear fruit are fine and small and can stick to the skin, eyes and clothing, sometimes causing severe irritation. Once removed, the spines are captured by an air-blower and deposited in a container attached to the equipment. This prevents contamination problems for people working nearby.

Photo 17 shows a different type of equipment used for the removal of spines from cactus pear fruit. The air-suction unit can be seen on top of the equipment.

The fruit is sorted by hand before the spines are removed by the de-spining equipment. Operators typically use gloves to protect their hands. Spines are removed from *nopalitos* manually using sharp knives as they arrive at the processing plant.

SORTING AND WASHING

Fruit is sorted and washed as it enters the plant. Fruit that is damaged, spoiled, overripe, green, miscoloured, misshapen or not uniform in any way is rejected at this stage. Photo 18 shows a simple table with workers sorting by hand.

After sorting and before processing, the fruit must be washed with clean water that has preferably been chlorinated (200 ppm). This can be done by immersing the fruits in tanks made from plastic or a similar, easily washable, non-contaminating material. The choice of equipment depends largely on plant throughput and the scale of production. For example, the production line of a micro-enterprise will contain equipment that is typically modular, simple, small-scale, manually operated and easy to clean. Wooden equipment or utensils should *not* be used for handling the fruit because of the safety and hygiene requirements of food processing. Plastic or stainless steel equipment and utensils are preferable.

Depending on the quantity of fruit washed, the water should be changed frequently to keep it clean and avoid contaminating the fruit. This is the final procedure before peeling the fruit, which is usually done by hand using sharp knives. The easiest way to peel cactus pear fruit is to cut off the ends, make a slit lengthwise and remove the peel in one piece. This also removes the section of inner skin under the fine epidermis. However, the inner skin is incorporated into some processes to boost yield without affecting the product's flavour

PHOTO 18
Sorting cactus pear fruit manually

C. SÁENZ, MEXICO. (2004)

or aroma. It is difficult to remove the thin outer epidermis any other way and most plants remove it along with the peel.

Peeling, and all other operations involving direct contact with the fruit, should be done using clean hands, as shown in Photo 17. Gloves are also used. At this stage, workers should wear masks and caps. Over time workers develop great skill and dexterity with peeling and are able to work quickly and precisely.

Work continues to develop peeling equipment for the cactus pear. For example, the University of Chile tested equipment similar to that for peeling potatoes but was unsuccessful. The potato-peeling equipment used rotating corrugated rollers covered with abrasive material, with flowing water to remove the skins.

The spines of *nopalitos* are removed manually using sharp knives as part of the cleaning process. Over time workers become highly skilled at spine removal and work quickly without damaging the *nopalitos*.

After the spines have been removed, depending on the process, the edges are trimmed with a knife and the remaining material is chopped into different-shaped pieces (Photo 19). The pieces are washed in chlorinated water to protect tissue from oxidation, remove any dirt and prevent browning. The product is then ready for processing.

PROCESSING CACTUS PEAR FRUIT

The diverse food products that can be made from cactus pear are reflected in the products found in markets worldwide. On the mature markets of Central America, the full range of products is available. This contrasts with markets in Africa, for example, where few such products can be found. The success or otherwise of products and markets depends ultimately on customer demand and, for new markets, this will have to be developed. Any of the products can be made, although the processing is more demanding for some than for others.

In some cases, the food formulations based on *Opuntia* fruits and the processing required are protected by patents. Although these products and their manufacture cannot be described in detail, below are the broad outlines of the required approach. Before manufacturing a new product in a new market, it makes sense to undertake trials to confirm that the fruit available is suitable for the formulation that will be used, and that the product will be acceptable to consumers. Culinary tastes vary from one country to another and what is accepted in one place may be rejected in another. Market testing is essential.

Most of the processing technologies used for cactus pear fruit can be used for other species of fruit with varying degrees of success. Some of these are shown below.

Cactus pear jams

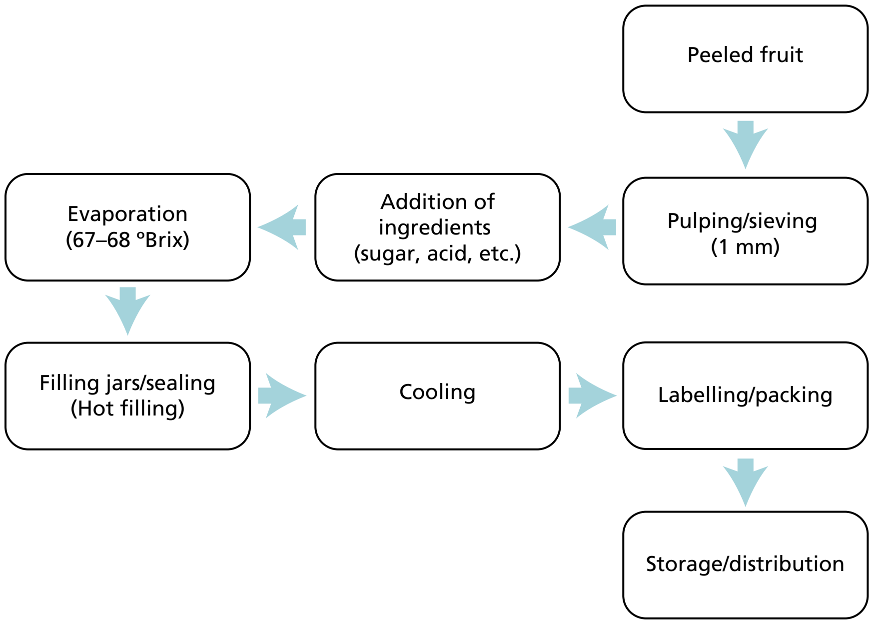
There is a range of variables and formulations suitable for producing jams from cactus pear fruit but Figure 3 shows the main operations involved in this type of processing. Before beginning processing, it is sensible to perform routine laboratory analysis to determine the main physical and chemical characteristics of the raw materials. This will help determine whether any changes to the formulation or process are needed. For example,

PHOTO 19
(a) Removal of spines and (b) chopping cladodes

(a) (b)

(A) C. SÁENZ AND E. SEPÚLVEDA, MEXICO (1999); (B) SÁENZ, CHILE (1999)

FIGURE 3
Flow chart for the production of cactus pear fruit jam



Source: A. Rodríguez-Félix, Mexico (1999 and 2005).

pectin may have to be added (depending on how much is already in the fruit) and/or colouring agents to strengthen colour. Ideally, only natural colorants should be used.

Processing begins with peeling the fruit. The peeled fruit is then milled using a sieve with 1 mm diameter perforations. Mills can be operated manually or mechanically, depending on the level of production at the processing plant; both are used in practice (Photo 20). Several types of manual sieve are used to separate the seeds from the pulp. The types of sieve used for separating tomato seeds from pulp are useful and, for small-scale applications, a centrifugal sieve typically used for home preparation of juices can be used.

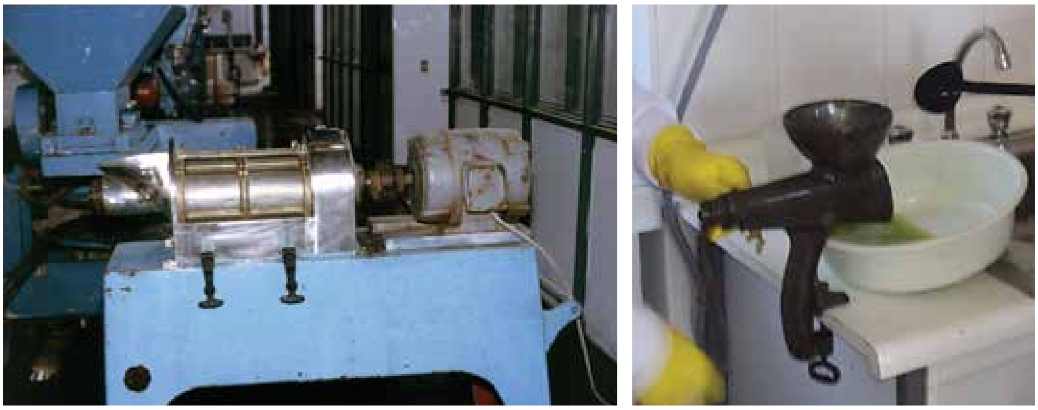
The seedless pulp is placed in a tank and the dry ingredients are added: sugar 55–60 percent, citric acid 0.8–1.0 percent and pectin, if required, depending on the characteristics of the fruit being used. Preservatives are also added, such as sodium benzoate (1 g $[kg]^{-1}$) and others in accordance with the dosage permitted by national regulations. From here the pulp is pumped into a second steam-jacketed tank and, depending on the plant's production volume and equipment, it is transferred to a vacuum evaporator or concentrated in the steam-jacketed tank with steam at atmospheric pressure until it reaches 67–68 °Brix. The vacuum evaporator operates at lower temperatures to protect the product's organoleptic characteristics. If steam lines are not available, the pulp can be concentrated by direct heating, taking care to prevent the product from sticking to the vessel walls and burning. The concentrated product is discharged into the hopper, which feeds into the filling machine.

The product can be packed in washed and sterilized glass jars of different capacities (300–500 g), or in plastic bags holding from 300 g to 1 kg or more. The jars are capped while they are hot (85–90 °C) using twist-off or similar caps. The caps are self-pasteurized by inverting the jars containing the hot product for 10–15 minutes.

When plastic bags are used, heat-sealing is carried out in specially designed equipment. This can also be done manually or, alternatively, the equipment can be located at the exit of the filling machine to form a continuous line for packing, filling and sealing to increase the process speed and reduce contamination and handling points. This choice will typically depend on the plant's production volume.

After filling, the jars pass through a cooling system to prevent overheating and associated organoleptic and nutritional deterioration of the product. Cooling is by water spray until the temperature

PHOTO 20
(a) Mechanical sieving and (b) manual sieving used to separate seeds



(a) (b)

(A) C. SÁENZ, CHILE (2005); (B) F. MIÑO, CHILE (2005)

drops to 30–40 °C, which is sufficient for the jars to dry before passing to the final operations.

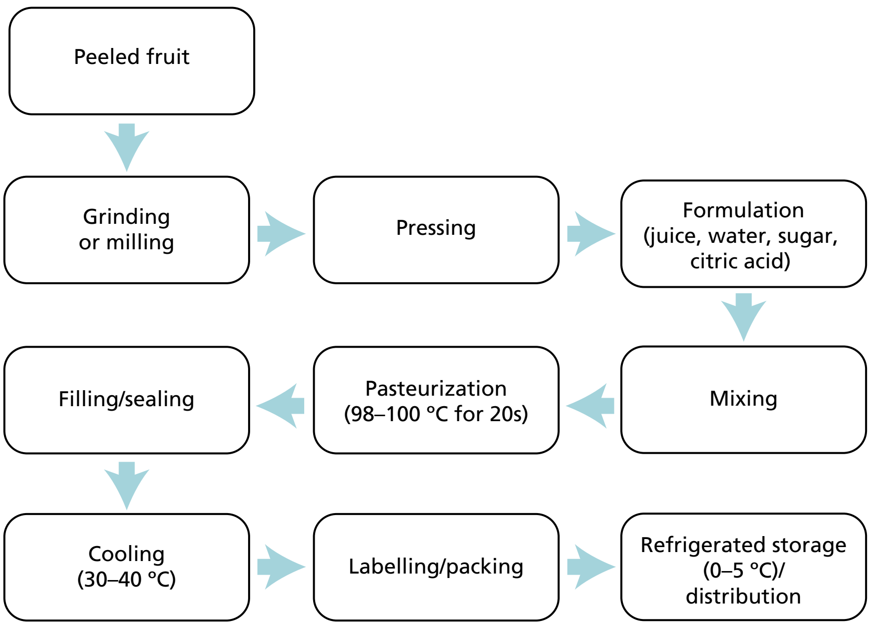
The jars are labelled, packed in cardboard boxes and stored in a specially designed room until ready for sale. In hot countries, it is essential to ensure that storage temperatures do not exceed 20–22 °C because higher temperatures can damage the products, accelerating biochemical reactions and the growth of micro-organisms and resulting in loss of quality. Storage conditions vary for different products and it is essential for producers to follow recommended procedures and not to treat all products in the same way.

Juices, syrups and nectars

Similar production technologies are used to prepare the cactus pear juices and nectars commercially available in a number of countries. The production technology for cactus pear fruit juice is more complex than for acidic fruits and those with a less delicate flavour and aroma. Close control of pH and heat treatment (temperature and timing) is required to ensure preservation and high quality in the final product. A flow chart for processing cactus pear fruit juice is shown in Figure 4.

The whole fruit is milled to reduce the size of the fruit. The seeds can be removed or retained,

FIGURE 4
Flow chart for the production of cactus pear fruit juice



Source: Carrandi (1999).

PHOTO 21
Juice extraction presses: (a) Frame hydraulic (b) Tube hydraulic (c) Filter press

(a) (b) (c)

C. SÁENZ, CHILE (2005)

depending on the process. Sometimes it is convenient to leave the seeds in place to make the cake press less compact and the operation more efficient. Fruit is then pumped into the extraction system for pressing. Many different types of presses are used, including: a hydraulic press inside a frame into which the fruit is placed wrapped in cloth with an appropriate mesh size; a hydraulic press with tube membranes of variable porosity; high capacity belt presses and so on. Photo 21 shows three types of juice extraction presses.

After pressing, the juice is pumped into a tank where it is diluted with water (20:80 ratio of water to juice). Depending on the *Opuntia* species, acidity may need to be adjusted up to 0.1 percent. Sugar (up to 12–13 °Brix) and preservatives are added (sodium benzoate and/or potassium sorbate, or a mixture of both, at 500 mg $(kg)^{-1}$ or to levels set by national regulations).

The juice is then heat treated in either a tubular or a plate heat exchanger, depending on the proportion of pulp in the juice. Treatment timing and temperature is determined by the product's characteristics and the type of pasteurizer or heat treatment system used. It is usually best to use HTST equipment, which is least damaging to the product. In the flow chart in Figure 4, a plate heat exchanger is used for pasteurization at 98–100 °C for 20 seconds. This is similar to the equipment shown in Photo 22.

When juice with few particles in suspension is required, the juice should be filtered prior to heat treatment. A centrifuge, decanter, filter press or other type of separator is typically used.

There are two approaches to bottling: heat-treating the juice prior to bottling, as described earlier; or bottling the juice, then heat-treating juice and bottle together. Under the first approach, all subsequent operations need to be carried out under aseptic conditions to avoid contaminating the product. The second approach has the advantage of avoiding contamination following heat treatment because there is no further handling of the product, which is completely protected inside the container. Under the second approach, a more severe heat treatment is generally used because the heat has to be transferred to the centre of the container. For example, as glass bottles take more time to heat to a given temperature and then to cool, this can adversely affect the sensory and nutritional characteristics of the juice. In contrast, if a heat plate exchanger is used, the juice is treated as a thin film or layer and heat is transferred more efficiently. Damage to the product is less likely.

Cactus pear fruit juice has a delicate aroma and flavour, so, while effective heat treatment is required for microbial control and product safety,

PHOTO 22
Heat plate exchanger

C. SÁENZ, CHILE (2005)

PHOTO 23
Juices produced from different coloured cactus pear fruit

C. SÁENZ, CHILE (1996)

care is needed to ensure that the juice's sensory and nutritional properties are retained.

Following pasteurization, the juice is hot-bottled (Figure 4). Filling is typically performed under ultraviolet light with forced air to prevent contamination. Both bottles and caps need to be sterilized before use.

Once sealed and packed, the bottles are cooled by placing them under a cold water jet or on a belt under cold showers. The product is cooled to a temperature that enables the bottles to dry in the ambient air. The bottles are then labelled, packed in boxes and kept in storage rooms until shipped to market.

Different *Opuntia* varieties produce different coloured fruits, providing options for marketing different coloured juices. According to research undertaken at the University of Chile, this has not been done commercially despite the attractive appearance and taste of some of these alternatives (Photo 23).

Other products, such as syrups, toppings and nectars, can be made from cactus pear juice. Syrups or sauces are sometimes also called toppings and are served with desserts, added to fruit or diluted with water to serve as a beverage. They are prepared either by concentrating the juice directly or by adding sugar to a level of 40–75 °Brix, depending on the type of product required. Photo 24 shows a variety of products from around the world

Similar procedures to those described earlier are used to prepare fruit nectars, the key difference being their content: sucrose syrup or corn syrup is added, less fruit is used and additives are incorporated to increase body or consistency and to add flavour. Gums such as locust bean gum or carboxymethyl cellulose are typically used as additives. Standards for nectars are controlled by each country's food legislation, many of which follow Codex Alimentarius standards. This specifies the fruit content of the juice and/or nectar required for each product (FAO/WHO, 2004).

Nectars can be produced from cactus pear fruit or from a blend of fruits such as cactus pear, pine-

PHOTO 24
Cactus pear fruit juice concentrate products – syrup, *arrope* and juice concentrate

C. SÁENZ, CHILE (1998 AND 2002); (B) E. CHESSA, MEXICO (2004)

(a) Argentina, Namibia and South Africa (b) Mexico apple or berries. When green cactus pear juice is used as the base material, blending it with pineapple juice improves not only appearance and colour but also stability, by increasing the juice's acidity.

Sweeteners

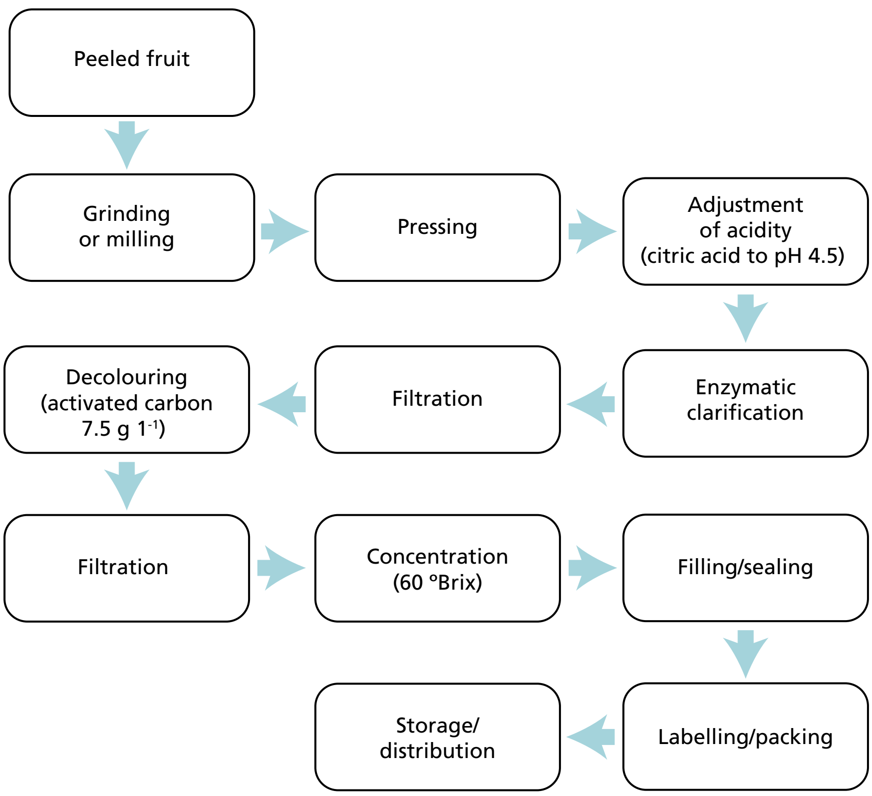
Technology similar to that for making juice can be employed to produce natural sweeteners, using enzymatic treatment of cactus pear fruit juice. This is a product similar to corn syrup and is widely used in the soft drink industry. Cactus pear has advantages in terms of sugar composition, with near equal parts of fructose and glucose. A flow chart for the production of natural sweeteners is shown in Figure 5.

The juice is placed in a double-bottomed tank and acidity is adjusted to pH 4.2–4.5 by adding citric acid (amount dependent upon the acidity of the juice). This is an optimum pH level for the enzymes, which are then added to separate the pulp from the liquid fraction. There are several suitable enzyme preparations available on the market. Sáenz *et al.* (1998) developed Pectinex AR (5 000 ppm for 22 hours at 50 °C). This is an enzyme with strong arabanase activity capable of degrading the insignificant pectin content of cactus pear juice, as well as the mucilage, which is resistant to the conventional enzymatic treatments used to clarify other industrial fruit juices (apples, pears, etc.). Further R&D work is required to identify other enzymes and to lower the dosage and treatment times required.

Following enzymatic treatment, the juice is separated from the pulp using a filter press or similar. The juice is then placed in a vessel for decolouring by adding activated carbon (7.5 g l^{-1}). The juice is filtered again and the decoloured and clarified product is vacuum evaporated until it reaches 60–62 °Brix, when it is bottled. In the home, 1 kg glass jars are typically used. Bulk packaging is in large cans (2–5 kg) or plastic drums (50 kg) prior to plastic wrapping. The final product is moved into storage at 22–25 °C before being shipped to market.

As the liquid sweetener market in most countries is highly competitive, it is essential to

FIGURE 5
Flow chart to obtain a cactus pear fruit sweetener



establish the economic feasibility of any new enterprise based on cactus pear extracts before investing in manufacturing.

Dehydrated sheets

Fruit leathers or dehydrated sheets are simple products that are easy to make at different scales of production.

In countries with plenty of sunlight, manufacturing can be undertaken on a small or medium scale using solar dryers. Many designs are available with varying levels of complexity. It is essential to avoid rehydration of the product when relative humidity is high. Where drying time exceeds 18 hours, care should be taken to prevent water absorption at night.

Figure 6 features a flow chart for producing dehydrated cactus pear sheets, which are normally called ‘cactus pear leather’ or ‘cactus pear sheets’ in the marketplace. The product can be prepared using a variety of formulations and from fruit of different colours to make it attractive to consumers.

The process begins with milling and screening peeled cactus pear to remove the seeds. Ingredients are added in line with the recipe, for example, a mixture of 75 percent cactus pear and 25 percent apple pulp. Apple is frequently used as an extender for many food products because of its ability to increase volume without affecting the flavour of the food to which it is added. At other times, a pure cactus pear formulation is used. Typical added ingredients include: 10 percent sugar, citric acid to boost the acidity of the mix to 0.4 percent, and 0.1 percent cinnamon, based on the recommendations of Sepúlveda, Abraján and Sáenz (2003c).

After mixing, the product is ready for drying. The pulp is spread in thin sheets on trays coated with non-stick plastic (Teflex™) (see Photo 25).

Enachescu (1995) recommended making dehydrated fruit bars in stainless steel trays covered with glycerine (40 ml m^{-2}) to prevent the pulp sticking and make it easier to remove the sheets after drying. Oil can be used instead of glycerine.

Trays (36 cm^2 × 36 cm^2) are then placed in a low-capacity dehydrator, as shown in Photo 25, or a medium-capacity dehydrator, such as the forced-air tunnel shown in Photo 26. Drum dryers can also be used. The recommended drying temperature is 58–60 °C for 8–10 hours depending on: available equipment; load or batch size; air velocity; air recirculation; and thickness of the pulp on the trays. The load in each tray is typically 2.5–3.0 kg m^{-2}.

Once drying has reduced the moisture content to 10–15 g $(100\ g)^{-1}$, the 10–20 mm thick dried sheets are removed from the trays and placed on a clean stainless steel or plastic surface (board or table) for packaging. The sheets are cut into

FIGURE 6
Flow chart to prepare dehydrated sheets from cactus pear fruit

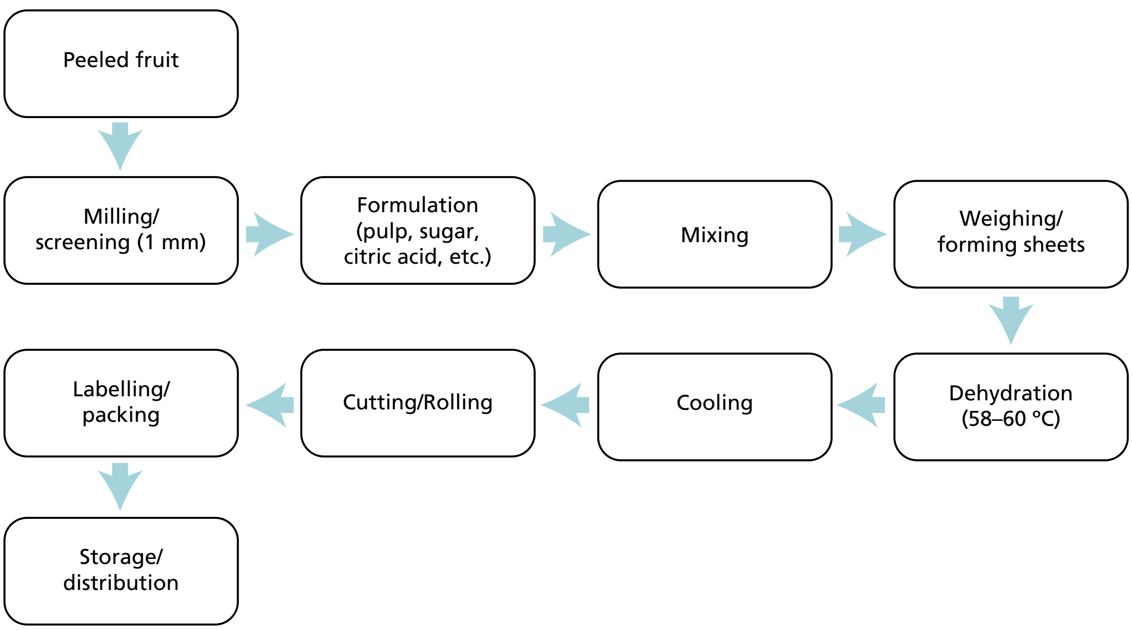


PHOTO 25
Electric tray dryer for making sheets

E. SEPÚLVEDA, CHILE (2004)

PHOTO 26
Forced-air drying tunnel used to obtain dehydrated sheets of cactus pear pulp

C. SÁENZ, CHILE (2004)

rectangles 12–15 cm × 3–4 cm, rolled in cellophane paper and packed in a material suitable for a dried product. Polypropylene sheet is popular, cheap, widely available, easy to handle and, importantly, impermeable to light and moisture. Another variant is to package the sheets flat without rolling, maintaining their original shape.

For storage, the product is placed in cardboard boxes and stored at room temperature, ensuring that the relative humidity of the storage area does not exceed 60–65 percent. Photo 27 shows dehydrated sheets or fruit leathers made from cactus pear fruits of different colours.

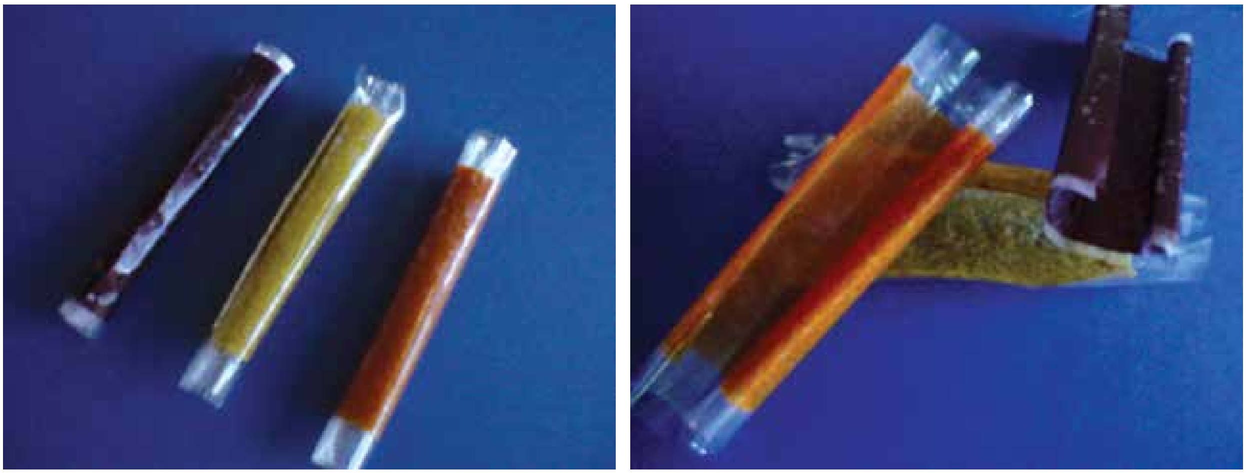
The fruit bar concept developed by Amoriggi (1992) for fruits such as mango and banana is similar, except that fruit bars have a slightly higher moisture level of 15–20 g $(100\ g)^{-1}$, are thicker (30 mm) and have a different texture. However, fruit bars are easy to hold and eat and make a convenient snack with market appeal.

One interesting variation on conventional dehydration, which is sometimes used commercially, is a mix of solar and electrical drying equipment to provide 24-hour drying. Care is required when transferring products between units, and with controlling temperature regimes. For example, this may include daytime drying at 55 °C for 10 hours, followed by night-time drying at 70 °C for 16 hours. The tray load in this case would typically be 12.5 kg m^{-2}.

Frozen pulp

Fruit pulp freezing has been recognized as one of the more promising recent systems for the production of high-quality products. Freezers are available everywhere, and frozen pulp provides a

PHOTO 27
Dehydrated sheets of cactus pear fruit pulp



E. SEPÚLVEDA, CHILE, (2003)

convenient means of preparing refreshing drinks, pastries, ice creams, liquors, jams and other confectionery foods.

Frozen pulp is not widely available, except in California where a red cactus pear pulp sweetened to 22–24 °Brix is made. Frozen products have demanding requirements for handling, preservation and infrastructure for cold chain distribution and marketing. Nevertheless, opportunities for frozen products are being developed. Pilot plant studies are under way at the University of Chile, with follow-up interest from cactus pear producers and frozen fruit pulp processors.

Given the many years of success with frozen foods and freezing processes using most other fruits and vegetables, frozen cactus pear products are likely to become available in most places in the next few years. Manufacturing operations are described below and outlined in Figure 7.

Peeled, pulped and de-seeded fruit is required, and the pulp's homogeneity is improved in a stirring tank before being pumped to the packaging line. The pulp is packed into high-density polyethylene bags (typically holding 1 kg), sealed and set on trays that are then placed on mobile carts or trolleys. These carts are wheeled into a freezing room at –30 °C where the bagged pulp is frozen. When freezing is complete, the bagged pulp is stored in refrigerated rooms at –18 °C. Frozen green cactus pear fruit pulp that had been prepared in this way at the University of Chile maintained its original green colour, aroma and other organoleptic properties (Sáenz, unpublished data).

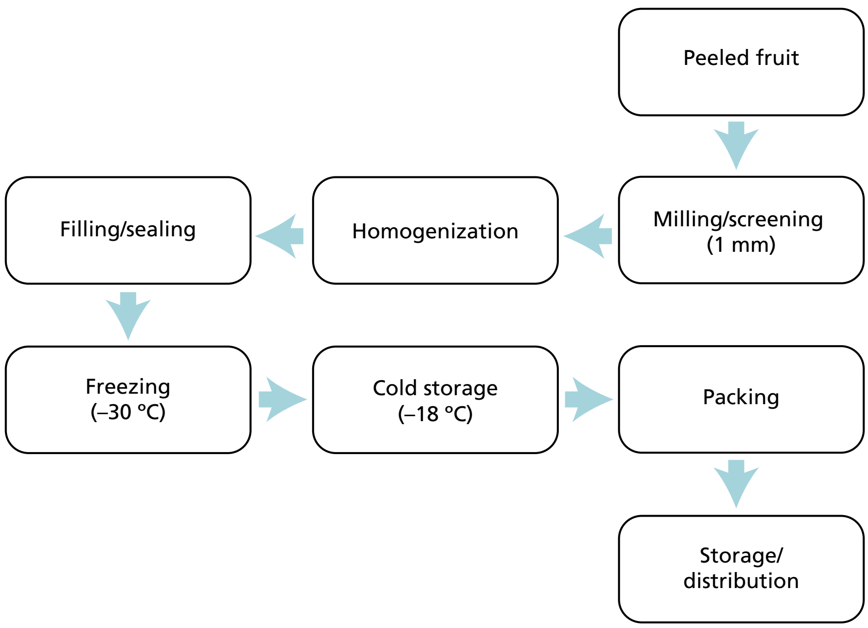
Access to a cold chain is essential for producing and selling frozen pulp. Frozen pulp is not a sterilized product because it has *not* been pasteurized before freezing. If it defrosts it can easily spoil. Storage, distribution and transportation must be in refrigerated containers/vehicles (–18 °C), and the product should *not* be left at room temperature at any time. Retail stores must store and display frozen pulp for sale at similar temperatures in order to maintain the original quality.

Once defrosted, the product is ready to eat or use, at which point it should be treated as a fresh product, kept refrigerated and used within three days of opening. If these products are to be used in other manufacturing processes, such as pastries or ice cream, the same health and safety handling precautions should be followed. However, it is more practical to defrost the pulp prior to use.

Oil from seeds

Seeds are normally considered a waste product of pulp, juice and jam manufacture. However, the seeds contain small quantities of edible oil that can be extracted. Oil extraction is only practical if sufficient seeds are obtained to make the process

FIGURE 7
Flow chart for frozen cactus pear fruit pulp production



economically feasible. Cactus pear seed oil has similar characteristics to other edible oils such as grape seed and corn oils and, if prices are competitive, it can compete with these oils on the basis of culinary use, neutral flavour and composition.

Once the seeds have been separated from the fruit pulp, the small quantities of pulp sticking to the seeds can be removed by heating the seeds for two minutes in a solution of 2 percent NaOH at 90–95 °C. The seeds are then washed with water until all traces of the NaOH have been removed, before being drained and dried at room temperature or in an artificial drier at 55–60 °C. After drying, the seeds are milled (in a hammer mill or similar) to reduce particle size and make it easier to extract the oil.

Oil can be extracted using a solvent such as hexane. In this case, the ground seeds are immersed in the solvent for 16–18 hours, with regular stirring to stimulate the oil extraction process. To separate the solvent from the oil, the mixture is vacuum-evaporated and then distilled. The solvent is driven off and the resulting oil is filtered and settled before being canned or packed into glass or plastic containers. Packaging is the same as for other edible oils, using materials that reduce the action of ultraviolet light, prevent oxidation by light and maintain high quality. The oil should be stored at room temperature.

Oil yields from cactus pear seed are low and production is only feasible in association with other processing activities, such as manufacturing pulp, juices or similar products that produce large amounts of seed. Oil extraction is a means of adding value to what is essentially a waste product (for which there is an opportunity cost). Stand-alone oil production is less likely to be economically viable.

The products described can be manufactured by small-scale agroprocessors. They are representative of the immediate product derivatives (fruit pulps, juices, etc.), as well as those used as a basis for other product formulations, such as jams. Although the basis of these foods and industries is *Opuntia* fruits, the level or scale of investment for processing needs to be studied carefully before taking practical action.

There is potential for home-based production of *Opuntia*-based foods and products in places such as Africa, the Near East and elsewhere in the world where the plant grows but remains underutilized, thereby helping to mitigate food shortages.

CLADODE PROCESSING

Tender cladode or *nopalito* consumption is part of the traditional cuisine of a few countries, such as Mexico and the southern United States. Although the potential exists to introduce these culinary traditions into other cultures and countries, success will depend upon the approach taken, the way in which these foods are introduced and the ease with which they can be manufactured or prepared locally. People need to become familiar with both aspects, but first the food needs to be introduced.

In some countries, a range of cladode products and brands are available on the market. These include *nopalitos* in brine, pickled *nopalitos*, sauces, jams, candied fruits, juices and flour used in breakfast cereal. There are also many artisanal products (cheese, *colonche* and others). This section describes some of the different industrial processes used for manufacturing food and non-food products from cladodes.

There are differences between preparing *nopalitos* for home consumption and for industrial manufacture. Mature cladodes that are not consumed at home may have industrial uses, and cladode products are marketed in many countries.

Six flow charts have been prepared showing the products made and the technologies used for a range of existing products. These are shown below.

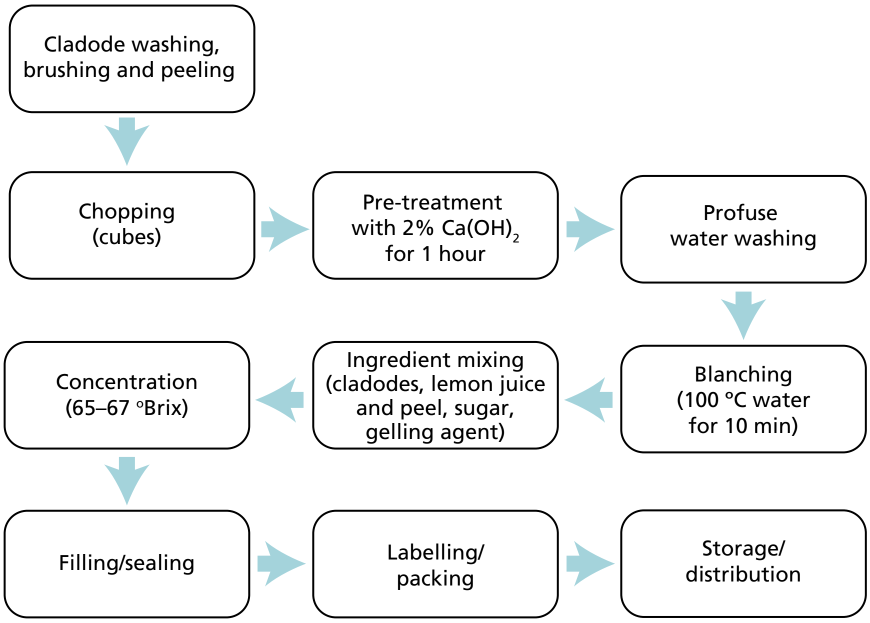
Jams

Jams can be made from *nopalitos* and/or mature cladodes. It is more difficult to make jams from cladodes than it is to make them from the cactus pear fruit. Several steps are required for preparing and pre-treating cladodes for processing. The main challenge is mucilage and ensuring that it does not adversely affect the quality of the final product.

Mucilage is a high-viscosity hydrocolloid that plays an important physiological role in the growing plant. It affects the sensory characteristics of some products and makes them less attractive to some people. It has to be removed before manufacturing the majority of food products made from cladodes.

A flow chart for jam production is shown in Figure 8. There are numerous formulations for making jam in a number of countries, including Mexico and the United States. The production of jam from cladodes and lemon, developed at University of Chile, is described below (Sáenz, Sepúlveda and Moreno, 1995b). Although Chileans do not generally eat *nopalitos* or mature cladodes, the jam was highly rated by a local taste

FIGURE 8
Flow chart for jam production from *Opuntia* cladodes



panel. Findings suggest that a well-made, tasty jam such as this would find a niche in competition with similar jams in local markets.

Jam requires cladodes less than one year old with the right texture and lower fibre content than older cladodes. They are collected fresh and delivered to the factory, then steeped and washed in chlorinated water (80 ppm).

Following removal from the water tank, they are brushed to remove spines and any remaining soil. Working on stainless steel table tops with sharp knives, workers peel away the green outer skin. This is easier if the thicker and harder upper and lower edges are removed first. The cladodes are then chopped into small cubes measuring around 1 cm^3 × 1 cm^3 × 1 cm^3. Pre-treatment with 2 percent $Ca(OH)_2$ for 1–2 hours helps to eliminate the mucilage using a ratio of solution to cladodes of 1.5:1. The tank should be deep enough to ensure that the cladode pieces are totally submerged in the $Ca(OH)_2$ solution. The mix should be stirred from time to time.

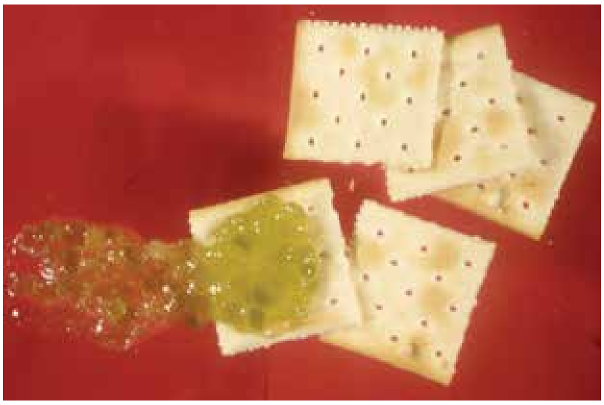
The cladode cubes are then washed with copious quantities of water and an indicator is used to check that all the calcium hydroxide has been completely removed. Phenolphthalein is typically used as an indicator. The cubes are blanched in boiling water for 10 minutes to soften them and then drained. A ratio of 1.5:1 water to cladodes is recommended.

The pieces are place in a jacketed vessel for mixing with the other ingredients in the formulation. Added to every 10 kg of chopped cladodes are: 8 kg sugar; 0.7 litres of lemon juice; 0.6 kg of chopped lemon peel; and 5–6 percent of carrageenan as a gelling agent, or else 2–3 percent pectin, depending on the required consistency. The lemon peel should be chopped to the same size as the cladodes and blanched in the same way to remove any bitterness. Consistency is one of the most important factors determining the quality of jam. Quality is affected by the degree of concentration of the mix and the content of pectin or gelling agents, as well as the size and quantity of particles in suspension in the final product. The mix is concentrated by boiling to 65–67 °Brix, and the jam obtained is shown in Photo 28.

Following concentration, the jam is packed in 500 g glass jars in much the same way as fruit jam. The jars are labelled, packed in cartons and stored ready for distribution and sale.

The proportions shown here should be taken as a guide; for example, less sugar can be used. It may also be necessary to thicken the mix further because cladodes do not provide any soluble solids for the jam. At this point other fruits providing solids can be added. Lemon or orange pulps are good options, given the solids content of these fruits and the additional pectin and acidity pro-

PHOTO 28
Cladode and lemon jam



C. SÁENZ, CHILE, (1996)

vided. When *nopalitos* are used, pectin and acid have to be added because cladodes do not contain enough of them.

Successful trials have been carried out in Mexico using fruits such as hawthorn (*Crataegus pubescens*), the yellow fruit of an indigenous Mexican plant with a bitter-sweet flavour similar to plums.

Candied products

Candied products were already being prepared in ancient Egypt, where fruits were preserved in honey. Ancient Egyptians and their Arabian successors were the first to use sugar syrups and honey to preserve dates and other fruits. This section explores these technologies as they apply to cladode products.

Technologies for making candied products are based on a process of replacing the cellular and intercellular liquids in the plant tissue with sugar syrup through diffusion and osmosis. This should result in a highly preservable final product because a low a_w is achieved. Syrups with increasing concentrations of soluble solids (40–75 °Brix) are used, with at least 60–65 percent sucrose, glucose and fructose. The tissues must be made permeable to enable osmosis and diffusion to take place. This is done by blanching in a water solution with citric or lactic acids. By replacing the cellular liquids, this solution enables the sugar to penetrate the tissues and maintain the volume, appearance and original quality of the chopped plant material.

Candied products are usually made from fruits because the soluble solids content facilitates processing. At first sight, cladodes may not seem to be appropriate for candying but opportunities have been identified for substituting cladode materials for the watermelon skins currently used. These are cut, flavoured and coloured to look like other fruits (in miniature form) and used as decoration in bakery products and on cakes and other foods. The texture of mature, 2–3 year-old cladodes is well suited to making candied products.

A flow chart for producing candied cladodes is shown in Figure 9 (Villarreal, 1997). It begins with the reception of mature cladodes, which are transferred to a work station where workers sort them by appearance, size and weight (usually around 2 kg) on stainless steel/plastic table tops. Irregular, damaged or diseased cladodes are rejected. This maximizes the yield of uniformly sized pieces.

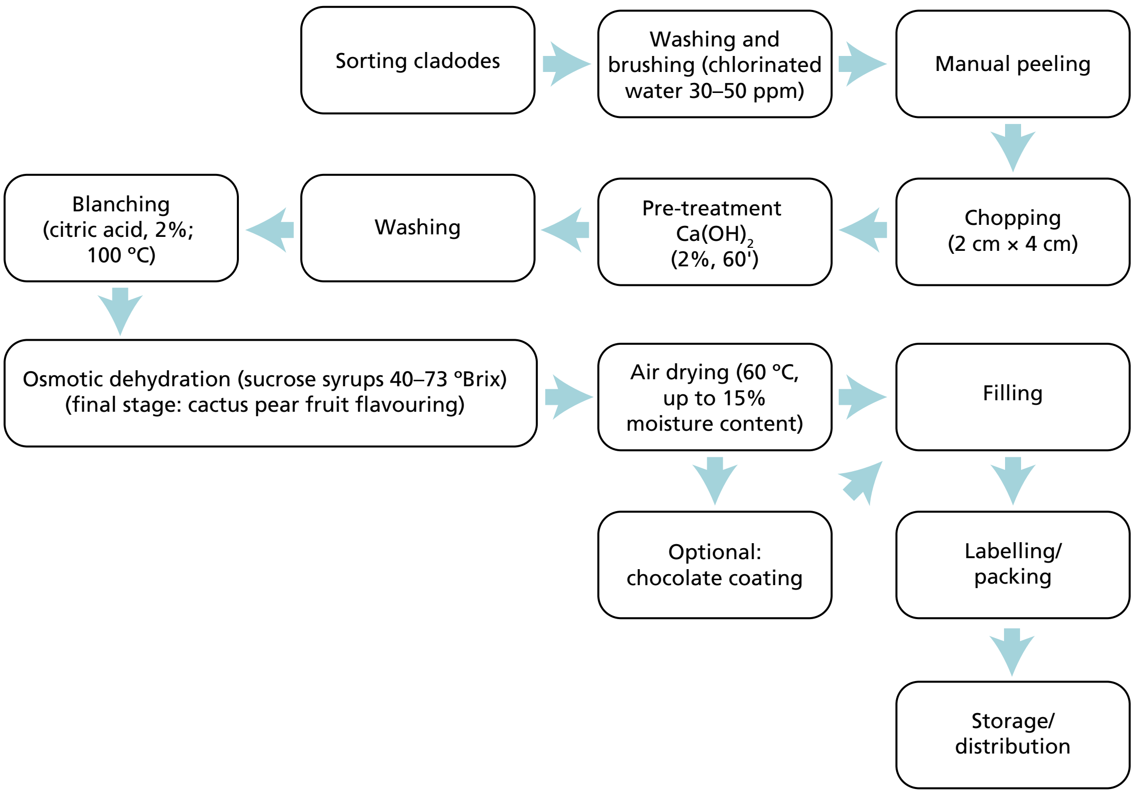
After sorting, the cladodes are washed in chlorinated water (30–50 ppm), then brushed to remove dust, micro-organisms and spines. The cladodes are hand-peeled to remove the thick fibres. Again, worktops are made from stainless steel or plastic. After cleaning, the cladodes are chopped into small cubes using sharp knives or specially designed equipment. The pre-treatment required to remove the mucilage is performed in the following three stages.

1. *Immersion:* The chopped cladode is placed in a jacketed tank with 2 percent calcium hydroxide solution for 60 minutes to remove the mucilage and improve product texture. The ratio of solution to cladode is 1.5:1.
2. *Washing:* The calcium hydroxide solution is emptied from the tank and the cubes are washed in potable water to remove all traces of mucilage and hydroxide. This is shown with a phenolphthalein indicator.
3. *Blanching:* A solution of 2 percent citric acid is added to the cladodes in the same tank and the mixture heated to 100 °C for 10 minutes. The ratio of solution to cladodes is maintained at 1.5:1, with the cubes remaining fully submerged.

Once pre-treatment has been completed, candying operations begin with osmotic hydration. The concentration of the sugar syrup is increased. This starts at 40 °Brix and is increased by 10 °Brix each day until 73–75 °Brix is reached. Each time the solution concentration is increased, the syrup containing the cladode pieces is boiled for one minute and then left for 24 hours to allow the cladodes to cool in the syrup. The flavouring agent is added in the final syrup treatment: essence of cactus pear fruit is incorporated at 0.5 percent concentration to heighten this flavour in the final product and to reduce the cladodes' typical 'grassy' flavour .

The candied pieces are left to drain on plastic mesh trays and dried in a forced-air dryer (or

FIGURE 9
Flow chart for the production of candied cladodes



Source: Villareal (1997).

similar) at a constant temperature of 60 °C until their moisture content drops to 15 percent. This is sufficient for good preservation because a_w will be around 0.59.

Packing can be done in a number of ways. One method is to place the candied product on expanded polystyrene trays. Operators use stainless steel tongs to handle the pieces or they can do this manually wearing gloves to avoid contamination. The candied products are then placed in polypropylene film bags.

Photo 29 shows preparation prior to osmotic dehydration and some of the end products.

Depending on the target market, one alternative is to add a chocolate coating to the candied product after drying. Candied cladodes can be marketed as sweets. They are similar to candied orange peel or other chocolate-coated fruits, which are well known and eaten in many countries.

The delicate operation of applying a chocolate coating adds value to candied products but also increases production costs. A special chocolate is used for coatings (containing 6–8 percent cocoa solids) that enables thinner coats to be applied and improves product appearance. Chocolate is heated to 28–31 °C and applied to the cladodes at the same temperature. The coating can be applied manually with simple hand tools. The chocolate-coated product is then placed on trays, covered with polyethylene and chilled in a refrigerated room at 10–12 °C for 24 hours to harden the chocolate coating. The finished product has an attractive, glossy appearance.

Finally, the product can be packed in the same way as uncoated products, taking care to trim any excess chocolate to optimize the appearance of the final product.

Storage and distribution of this product are more problematic than for similar uncoated products because the temperature must be controlled to prevent the chocolate from melting. Storage below 25 °C is recommended.

Nopalitos pickled or in brine

Brined and pickled *nopalitos* are popular in Mexican food markets. Some examples are shown in Photo 30.

PHOTO 29
Cladode peeling, cutting and chopping; and candied products with and without chocolate coating

C. SÁENZ AND SEPÚLVEDA, CHILE (1997)

Processing required for brined and pickled *nopalitos* begins with the preparation of raw materials described earlier at the point of delivery to the factory. Special preparatory activities then follow. Processing has been described by Corrales-Garcia (1998) and Corrales and Flores (2003). Figure 10 shows a flow chart for the production of tender cladodes in brine describing typical industrial processes.

Nopalitos normally arrive at the processing plant with the spines removed but, if this is not the case, the spines have to be removed before processing. Cladodes are sorted by hand on stainless steel/ plastic surfaces, discarding damaged, undersized and diseased material. Selected cladodes are transferred to a wash tank and washed with chlorinated water (50 ppm). After draining, they are manually or mechanically chopped into pieces. *Nopalitos* are chopped into strips (1 cm × 10 cm) or cubes (1 cm × 1 cm × 1 cm) using knives or moulds to produce 'miniature' shaped cladodes about 5–7 cm long. These are called *penquitas* (mini-cladodes) and have a thickness of 50 mm or less. Another option is to harvest and use small cladodes (6–8 cm), which are tenderer than the *nopalitos* normally used for industrial processing. This is a more delicate product and prices are correspondingly higher because of the lower yields obtained.

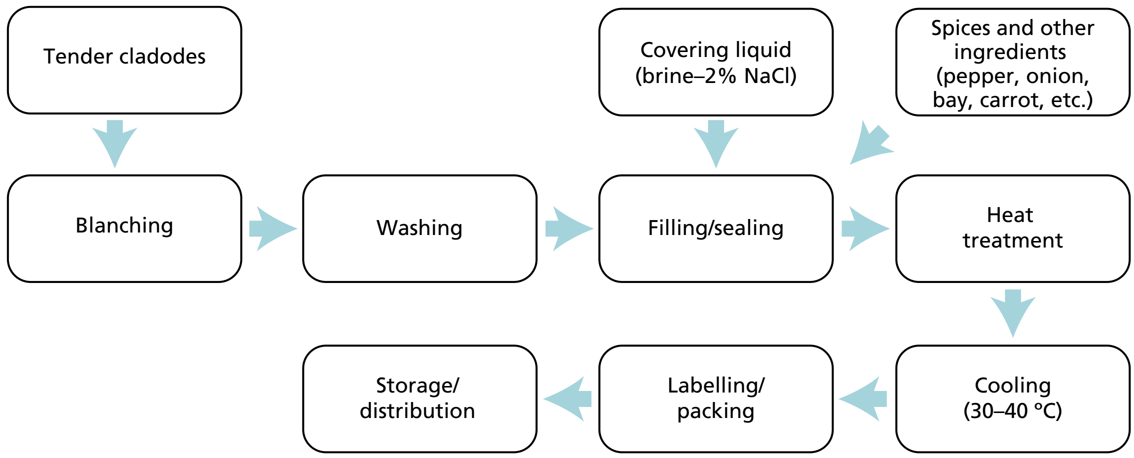
Spines are removed, the cladodes are washed and chopped, and the cladode pieces are blanched in hot water (95 °C) or steamed before being cooled quickly with cold water to prevent colour damage. This is important when steam is used. The lengthy period required for hot water treatment means that it is sometimes difficult to prevent colour deterioration. The product is then packed into steel cans or glass jars (0.3–1 kg). This is the point at which the various mixed spices and

PHOTO 30
Sale of tender and pre-cut cladodes in the market

C. SÁENZ AND E .SEPÚLVEDA, MEXICO (2001)

RODRÍGUEZ-FÉLIX, MEXICO (2001)

FIGURE 10
Flow chart for traditional production of tender cladodes in brine



other vegetables may be added (onion, carrot, bay, pepper, etc.) to provide additional flavouring. Finally, the hot liquid (90–95 °C) is poured over the contents to completely cover them and fill the jar or can to overflowing.

The hot liquid comprises 2 percent NaCl/brine with the optional addition of preservatives such as sodium benzoate. These should be added at rates established in the home country or recommended by Codex Alimentarius. Typically a maximum of 1 g kg^{-1} of product is used.

Before sealing, the jars or cans are passed through an exhauster tunnel in order to release any trapped air and create an effective vacuum once the recipient is sealed. Depending on the material used, recipients are sealed either manually or mechanically. This is followed by sterilization in autoclaves. Although temperature and time are based on the type of recipient used, 100–110 °C for 15–20 minutes is typical for 200–250 g jars or cans. After sterilization, the recipients are cooled to 30–0 °C and left to dry before being labelled, packed and stored until dispatch to markets.

The flow chart in Figure 11 shows variations on traditionally produced brined *nopalitos*, according to the recommendations of Montoya *et al.* (2001). These modifications help improve the green colour of the cladodes and reduce the stickiness caused by mucilage. In the market, it is common to find products of an olive green, almost brown colour, which does not affect safety but looks rather unattractive. People generally prefer to purchase green-coloured cladodes. The brown colour is the result of chlorophyll degradation to pheophytin, which often happens with green vegetables subjected to heat treatment.

The modifications are based on two operations: the first to reduce mucilage levels by pre-treatment with 2 percent $Ca(OH)_2$; and the second to reduce discoloration by blanching with 0.3 percent $NaHCO_3$) The final result is a much more attractive product with a green colour much closer to that of fresh cladodes.

Manufacturers are always on the lookout for innovative methods to enable them to improve the quality and/or appearance of their products, helping them to maintain a competitive position in the market and, on occasions, to explore new and sometimes more demanding markets.

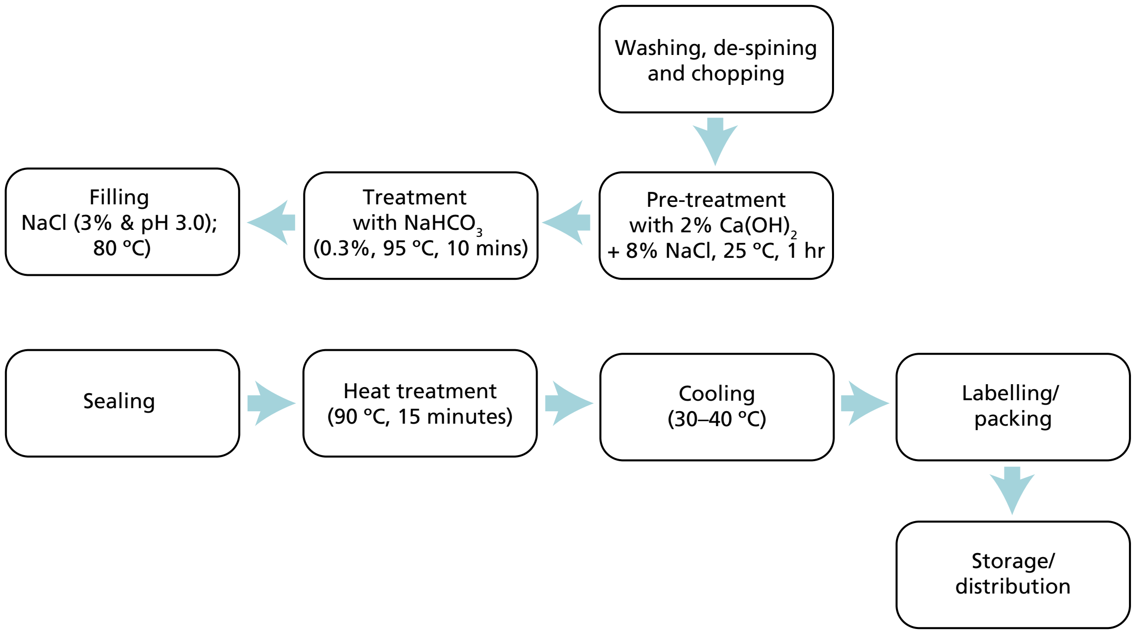
Basic methods for producing pickled *nopalitos* were described in Chapter 5.

Cladode juice

Cladode juice is a relatively new product that has been produced for only a short time by a Mexican company. Development and promotion of new fruit and/or vegetable products is useful, because consumers are always in search of new flavours and there are always opportunities for foods offering health benefits. Cactus cladode products contain soluble fibre and minerals and are low in sugar, which makes them attractive to health-conscious people, particularly diabetics. The flow chart for cladode juice production is shown in Figure 12.

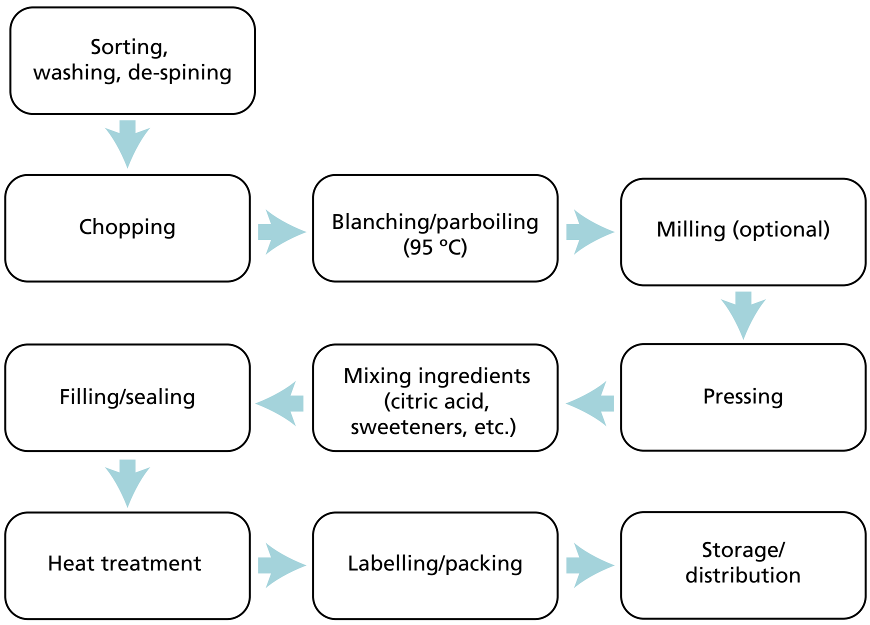
Once *nopalitos* have been sorted and de-spined, they are transferred to the chlorinated water tank (30–50 ppm) for washing. They are then chopped and reduced in size to increase the surface area of

FIGURE 11
Flow chart for the production of brined cladodes



Source: Montoya *et al.* (2001).

FIGURE 12
Flow chart for cactus pear cladode juice production



the pieces. This helps with blanching and pressing operations. Chopped *nopalitos* are blanched in hot water at 95 °C, drained and then milled. Milling can be carried out in different types of equipment fitted with knives or rotating blades. The milled material is then pumped to a press. Various types of press are available: filter press, screw press, belt press or similar design.

Liquid from the press is then pumped to a tank and ingredients added according to the required formulation. Uniform mixing is achieved by stirring in a stainless steel vat with a rotor. Rodriguez (1999) suggests increasing acidity by adding citric acid until pH 3.5 is reached, then mixing 30 percent *nopalito* juice with water and aspartame to obtain a sugar-free product. This drink can be marketed to diabetics.

The juice can be poured into glass bottles to be pasteurized or it can be heat treated using a plate heat exchanger prior to being bottled. Aseptic conditions always apply. Finally, bottles are labelled and sent for storage at room temperature until ready for distribution and marketing.

Flours and powders

Flours and powders can be produced from both *nopalitos* and mature cladodes. These products have been used for many years in the pharmaceutical industry for manufacturing capsules and tablets. However, cladode flour is rich in dietary fibre and other components with a high nutritional value, attracting increased interest from the food industry because of its potential for blending, extruding and filling. Some examples of production processes are described below.

A product on the Mexican market incorporates cactus pear cladode flour into cereal in an extruded form used as a breakfast food (Photo 31).

The company that developed the breakfast cereal uses 3–6 month-old *nopalitos*, which are a more intense green colour and have a higher soluble fibre content than older cladodes. The resulting flour is also greener than that from older cladodes. Older cladodes may contain impurities arising from lignification and are more difficult to grind once dried. Flours made from older cladodes also contain lower fibre and mineral levels than younger cladodes (Pedroza, personal communication).[1]

Cladode flours are used to make baked goods and biscuits, replacing a proportion of the wheat flour in the recipe. This is done for a number of reasons but primarily to obtain additional fibre and/or reduce production costs; a lower shop price leads to higher sales (Sáenz *et al.*, 2002c). The same has happened with tortillas, which are traditionally made from 100 percent maize: tortillas are now available on the Mexican market in which a portion of the maize has been replaced by cactus pear cladode flour.

There are many companies making cladode flour but the precise formulations and processes are usually not made public by the manufacturers. The flow chart for cladode flour/powder production shown in Figure 13 was developed by Sepúlveda, Sáenz and Moreno (1995).

Prior to processing, the cladodes are sorted and material that fails to meet the required processing standards is discarded. The selected cladodes are washed in chlorinated water (30–50 ppm) and hand-chopped into strips or cubes on a stainless steel/plastic surface. Chopping can also be performed using mechanical equipment, such as a meat cutter or similar. Chopped cladodes are then placed on trays and transferred to a tunnel dryer for drying. Drying begins at 80 °C for two hours, followed by one hour at 70 °C until a moisture content of 7–10 percent is reached.

Once dried, the small pieces of material are milled to a fine powder using a knife mill or stone mill: final particle size depends on the intended use. The powder is packed into impermeable con-

PHOTO 31
Breakfast food product based on cereals and cactus pear cladode flour

G. PEDROZA, MEXICO (2005)

[1] Gerardo Pedroza, Cactu Fibra, San Luis Potosí, Mexico.

PHOTO 32
Cladodes chopped and drying for flour and powder production

C. SÁENZ AND E. SEPÚLVEDA (1995)

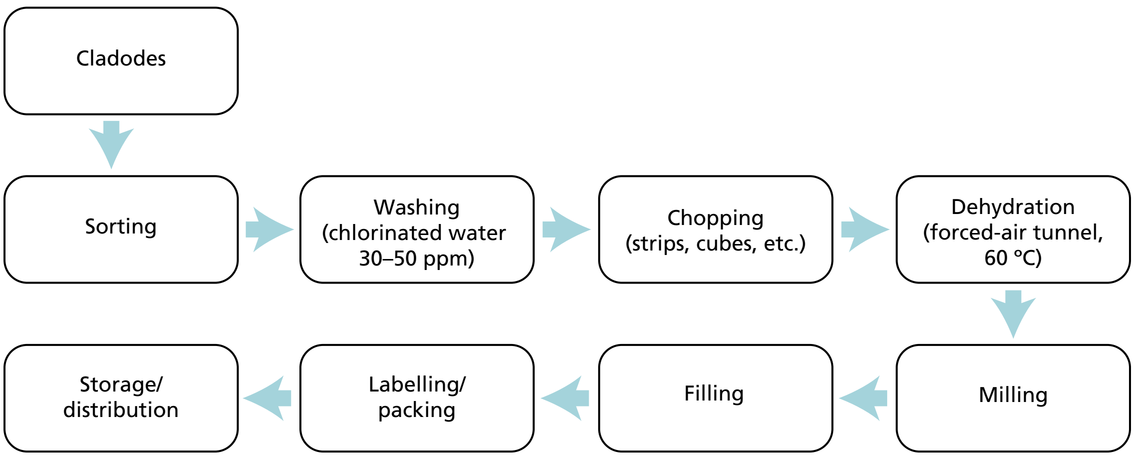
tainers and moved to an insect- and rodent-free store with relative humidity below 60–65 percent.

Photo 32 shows some of the operations required to produce cactus pear cladode flour.

Variations can be made to the flow chart in Figure 13 depending on the production volume and final use. For example, the chopping system can be completely mechanical and the batch tunnel dryer can be replaced by a continuous drying system (which usually achieves a much higher throughput).

The way in which cactus pear foods are eaten is as important as the way in which they are harvested, processed and preserved. There may be little advantage in making these foods available out of season if they are not already an attractive

FIGURE 13
Flow chart for the production of cactus pear cladode flour



Source: Sepúlveda, Sáenz and Moreno (1995).

part of local people's daily diet. There is much to be done before novel foods can be introduced into new countries, which could start by taking the innovation, processes and ideas of Mexican firms and sharing them more widely.

Appendix 1 lists a number of Web sites providing information and ideas on different ways of using cactus pear and cladodes as food, either alone or in combination with other foods. This helps promote new ideas and encourages people to experiment with novel foods. There may be opportunities for helping people to sustain themselves by consuming plants that are already familiar to them but are not part of their traditional diet. If this increases food/nutrition security, as well as processing and trade, everyone in the community may stand to gain.

FILLING, PACKAGING AND STORAGE

Filling, packaging and storage are an important part of the manufacturing system for any product. Although *Opuntia* products are produced in much the same way as the other products described earlier, there are key production issues stemming from *Opuntia*'s special characteristics. Whatever the product or manufacturing processes involved, the final stages in the production of safe, high-quality foods can be wasted if care is not taken with filling, packaging and storage.

Many different packaging materials can be used. It is essential to choose the most appropriate option for the products and processing systems involved. The two most widely used packaging materials are glass and tinned steel plate, with their respective well-known advantages and constraints for food preservation. Both materials are used to pack heat-treated foods (commercial sterilization). While glass has the advantage over tinned steel plate of being inert and transparent, the latter is more resilient, more robust, more resistant to thermal shock and handling and, crucially, cheaper than glass. The major disadvantage of steel plate is corrosion but, if the original materials are of good quality, sufficiently well protected and stored in dry conditions, then corrosion is not likely to be a problem.

There are many packaging alternatives on the market using both tinned steel plate and glass. Containers are available in a variety of sizes, shapes and colours. For glass, there is a variety of caps providing hermetic sealing. Glass jars can be opened and closed easily and used as a container until all the contents have been consumed, sometimes over long periods. As glass jars and bottles can be filled hot, they are used widely for sweets, jams and juices. Tinned steel cans have to be emptied and/or used at the time of opening and cannot be used to store left-over food.

Plastics are also widely used in the food industry. Many technical advances have been made in plastic food packaging in recent years, and there are many suppliers and a great variety of materials available. For food packaging, materials are either flexible (plastic films of different thicknesses and combinations of polymers) or rigid (pots, jars, trays and bottles). Films may be formed from layers of different polymers (e.g. polyethylene [PE] and ethyl vinyl alcohol [EVOH]), which provide for different levels of gas permeability. Plastic films are frequently used to pack fruits and vegetables that have been minimally processed prior to sale or use. This includes cactus pear fruit and *nopalitos*.

Laminated plastic films (e.g. plastic/paper/aluminium) are also popular. These provide a more robust barrier (permeability to gases) for packing powdered products such as cladode flour. Plastic films metallized with aluminium can also be used to pack dried sheets and bars made from cactus pear pulp. The shine of the aluminium layer of these films is particularly attractive. Flexible plastic films can be sealed easily using simple machines. They cost less than tinned steel plate or glass, are cheaper to transport and mean less dead weight has to be carried.

While flexible plastic films are not normally considered appropriate for use with high-quality products, this could be a misconception in many cases. Rigid plastic containers are useful for sweets and jams and, although they cannot be hermetically sealed, they are widely used for this type of product.

An important feature of packaging materials is their ability to be recycled, given that millions of containers are used every day and most are eventually discarded. Large quantities of materials are wasted. While all materials are recyclable, some need to be returned to collecting centres and converted into new materials for re-use. Not only can glass be recycled, it can also be re-used in its original form. While packaging is important, it is beyond the scope of this text on cactus pear utilization. Further information on packaging materials and systems can be found in Rees and Bettison (1994) and Coles, McDowell and Kirwan (2004).

Storage requirements depend on the type of product. Some require refrigerated, frozen and/or cool storage, while others can be stored at room temperature.

Whatever the case, there are general standards for ensuring good storage, maintaining product quality and safety and storing them securely prior to delivery. Storage facilities for finished products should be separate from the processing room and from stores containing non-food materials such as detergents and waste. Food storage rooms *must* be vermin free. Ideally, there should be temperature and relative humidity control, with ease of access for people and/or pallet-handling equipment. Stores should also be securely lockable to prevent tampering with stored goods and/or theft.

QUALITY AND SAFETY

When a new processing enterprise is established or a new plant is constructed, it is essential to adopt the highest possible standards of manufacture and to produce high-quality foods. This helps develop a reputation for both the foods and the manufacturer, building consumer confidence and markets. Most manufacturers adopt a specific approach to manufacturing known as a quality assurance system. The system covers all the successive steps in processing: purchase and handling of raw materials; pre-plant processing; addition of ingredients and additives; manufacture and storage; sale; and final consumption. Although by the time of sale and consumption, the goods will have left the factory, trading agents, markets and shops will continue to provide feedback to the manufacturer with shared responsibility for the care and security of the original goods.

Quality and safety are important aspects. It is essential to maintain product safety. One way to do this is to implement what is known as a Hazard Analysis Critical Control Point System (HACCP). This system has been designed to prevent problems arising, rather than solving them (or trying to solve them) after they have arisen. The manual by Fellows (1997) and the Codex Alimentarius guidelines (FAO/WHO, 2004) provide a useful guide to implementing an HACCP system.

Many managers of small-scale enterprises may take the view that an HACCP system does *not* apply to them owing to a number of perceived constraints: it is unsuitable for implementation; it will raise costs; it will be impossible to engage the required staff or to train them all, and so on. This is simply not the case. HACCP systems can, and should, be introduced whatever the scale of production. New ideas should be welcomed when the end result helps boost quality and reputation. The worldwide trend in agro-industrial activities, sectors and manufacturing is towards management systems that boost productivity, health and safety. Consumers and markets require this approach wherever foods are produced, processed and sold.

Although it has long been recognized that implementing HACCP systems in small-scale enterprises will always be challenging, in the long term it is not an option to ignore the principles of responsible management. Despite the challenges, increasingly national food laws and customers are prevailing and demanding more transparency from manufacturers; in the end, all enterprises, large and small, will have no alternative but to adopt recommended practices or to close down.

The challenges will be seen differently by governments, non-governmental organizations (NGOs) or the private sector. Governments encourage good manufacturing practices (GMPs), NGOs provide non-profit services in support of industries, growers and rural communities, and the private sector carries the main investment, manufacturing and trading risks. The three sectors are essentially interdependent. Sound GMP strategies help to determine markets and then help the manufacturer retain them. With challenges of this kind, small and medium enterprises often need technical assistance from experts – in ministries, universities, standards agencies, business associations or elsewhere – to help them understand what is required, which practices/systems to adopt and how to implement and maintain them.

Numerous factors require attention at the different stages of industrial processing. Figure 14 shows the most important of these.

The industrial production of food is governed by standards that vary from country to country. Many countries choose to adopt FAO/WHO Codex Alimentarius standards, which are a bare minimum for countries selling to international markets. Standards are becoming stricter as markets develop. This is of benefit to consumers, whether products are fresh or processed. The health of the population at large is a universally accepted public good and remains a top priority in the production and sale of foods to the public. People have a right to assume that the foods they eat will be beneficial. When foods are labelled, the general public trusts that the manufacturer's information on the bottle or can is true, reliable and honest. People do not wish to be misled by false advertising. In every production process there are ethical standards that manufacturers are obliged to adopt, which means that they must follow proper procedures and best practices from beginning to end of the production chain.

FIGURE 14
Factors affecting product quality from processing to distribution

Cuevas (2004a) analysed the complexity involved in implementing total quality systems in small-scale agro-industries. One of the criticisms was the lack of commitment by many of those responsible for a ensuring a systematic approach to food safety management as the *basis* for food processing. There was a failure to recognize that this extended beyond control of function. To be effective, *everyone* involved in manufacturing in the food chain must assimilate such technologies, not just those supervising the technical teams and the equipment used to make the product. This calls for a multidisciplinary approach within the factory, plant and/or industry to provide continuous and effective results-based management over time.

MARKETING

A cactus pear fruit and cladode processing industry should only be established after conducting market studies to confirm that the future product will find markets. This is essential for continuity and when developing a business. Market studies help identify which market sector to target. The guidelines provided by Shepherd (2003) may be useful. For example, dried fruit sheets or bars from cactus pear fruit pulp could be targeted at children, schools and sports people, or sold to fast food companies, wherever there are people who like healthy snacks. Frozen pulp may be targeted at middle- and higher-income customers, or else sold retail in supermarkets or in bulk to other industrial manufacturers. Frozen pulp may be sold as an ingredient to food manufacturers, to the hospitality trade and to institutional authorities, such as the military, prisons and schools.

Cactus pear products may find a valuable niche in consumers that make healthy lifestyle and eating choices, including vegetarians, health centres and hospitals, where diet and medical care demand high-fibre, high-vitamin content, antioxidants, sugar-free foods and similar attributes.

Whichever segment is targeted, it is critical to ascertain: whether any competitors exist for the product and, if so, how many; whether they are well-established or newcomers; whether they are successful and, if so, *why*? A number of other questions must be answered. What are the weaknesses of the products and markets? How best should the product be presented to the market?

What is the most suitable launch campaign? It is expensive to launch a new product and, if it fails, this usually indicates poor market appraisal.

Occasionally, consumer studies are required, especially if the product is being introduced onto a market where it is unknown. It is not easy to change and/or modify diets and eating habits and a special marketing strategy may be required.

Market studies traditionally follow the famous 'four Ps' of marketing: product, price, place and promotion. These recognize the value of good packaging and labelling, which are important for advertising the product inside the bottle or can and for educating consumers about the value of the product (and the company). Market studies may also explore distribution, bulk or retail alternatives, depending on the product (e.g. juices, pulps and jams), selling through the company's own stores or in supermarkets, as well as the preferred location of stores: on busy roads and/or near the factory and/or selling directly to the customer, for example, door-to-door in the city.

Advertising and media options will have to be evaluated in order to choose the most appropriate communication channel: newspapers, radio, television, supermarket offers, free samples to motorists in cities or in retail shops, or personal contacts. As the challenges always evolve quickly and will change after the product is on sale, managers will need to continue monitoring consumer quality and price expectations as part of the company's marketing strategy.

One important aspect of selling is product appearance. This affects how the consumer first perceives the product: packaging, size and labelling. A logo identifying the company helps consumers to find (and perhaps purchase) the product. The quality of the label (paper, colour, printing, use of words/pictures, etc.) will influence consumers and help them to recognize the product, or to perceive a familiar product as well made and high quality. Poor appearance will give precisely the opposite impression: the product will be less attractive to consumers and may not sell.

In many countries, national regulations stipulate the minimum information that must be provided on labels. A good label is simple, the colours are harmonious, it attracts they eye, is truthful and creates a 'feel-good' or 'familiar' impression in the buyer. Good labels are usually produced by experts in this field.

In summary, agro-industrial production encompasses the entire value chain from field to consumer (*the farm to the table*), representing a changing vision where the consumer is the most important focus, partner or stakeholder within the value chain. This reinforces the importance of consumers in markets: consumer needs and tastes determine the types of product manufactured and hence the role of agro-industries in producing goods to satisfy consumers.

ECONOMIC ASPECTS

Technical and economic feasibility studies are crucial to making appropriate decisions on whether or not to invest in a particular industry and/or processing plant. This is the only way to reduce the risk of failure. Many such initiatives fail, but this does not have to be the case. The key is risk assessment, and risks can always be minimized with good information.

Feasibility studies will usually cover: the funds required for infrastructure, equipment and supplies; scale of production and operating costs; the products to be made; availability and cost of raw materials; equipment and supplies; and services available (electricity, water and energy). Human resources are expensive. What trained professionals are available? What are the market rates for the professionals required? What are the production costs? What technologies should be used? What demand is there for the selected products? How big is the target market? And there are many more questions to be answered.

It is important to understand and accept that agro-industrial *products* are derived from agricultural *materials*, which are typically seasonal. This is the case with cactus pear. As there will be times when raw materials are unavailable, alternative options need to be identified for producing foods from other species/materials in order to make use of the factory and its equipment. It may not be logical to close the factory for more than six months each year. Diversification needs to be included in the decision-making and planning process. Marketing studies should be carried out by marketing experts, with help/consultation from those responsible for industrial development, those familiar with the crop and the associated foods, and those selling the equipment required for the plant and/or providing the finance with which to build and operate it. Further information on planning is provided by Fellows (1997), Shepherd (2003) and Cuevas (2004b).

Chapter 7
Industrial production of non-food products

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PRODUCT DESCRIPTION

Few plant species are as versatile as *Opuntia* for processing into food for human consumption. However, the industrial opportunities for *Opuntia* extend beyond food products, making the species valuable for both cropping and utilization.

One of the more attractive indirect products made from *Opuntias* is carmine from the cochineal insect (*Dactylopius coccus*). This is the best and safest natural red colouring agent for foods. Its use is permitted by most food regulators worldwide, including the United States Food and Drug Administration (FDA) and the European Union (EU) coded as E120 in EU regulations. FAO/WHO (2000) reports that it is also in the list of additives authorized by the Joint FAO/WHO Expert Committee on Food Additives (JECFA). Carmine pigment is an interesting natural alternative to synthetic red colouring agents and is widely used in the food and cosmetic industries. Peru is the leading international producer of dried cochineal and exports processed cochineal in the form of carmine, carminic acid or solutions.

The cochineal is an insect of the Hemiptera order and parasitic to the *Opuntias* on which it feeds, with the result that production is largely a parallel agrobiological activity. The plants must be managed differently from those used for the production of fruit or cladodes. In addition, the insect has to be cultivated, harvested and processed to produce the colorant. This is totally different from harvesting and processing food products, additives or by-products. *O. ficus-indica* is usually the host plant on which the insect grows and develops. It is collected, killed and processed to extract the pigment. The female insect is processed for making carmine. The plant simply serves as a medium for cultivating the insect (see Photo 33).

PHOTO 33
Commercial cactus pear plantation for cochineal production

C. SÁENZ, CHILE (1998)

Agro-industries are typically more efficient when they use all the materials delivered to the factory or processing centre. For this reason, they always try to make use of waste to provide additional income and/or reduce costs for the enterprise. This is the case with *Opuntia* fruit seeds and peel, which are often separated from the pulp when making juices and other products. Seeds may contain good quality oil. The peel is rich in hydrocolloids (mucilage), which can be extracted and used as a thickener in the food industry. The peel of red and purple varieties contains large quantities of pigment (betalains) that are used as natural colorants. The idea of extracting pigments from cactus pear fruits of other colours has not been explored, although the orange-coloured fruits are known to be rich in carotenoids.

The production of flour and powders as the basis for a range of different foods from cladodes has been described earlier. The use of these products as food supplements and/or in the pharmaceutical industry is described in this chapter, given the extensive experience available. Their use as an ingredient in medicinal products has only recently begun to be more widely accepted. Their popularity with customers is changing the market position of products such as tablets and capsules of powdered cladode or flours in suspension for medicinal purposes. This popularity stems from the curative properties traditionally attributed to *Opuntia* plants in popular medicine. Work is under way to substantiate traditional practices in modern scientific terms.

Closely linked to these are products known as nutraceuticals or functional foods. These possess both nutritional and medicinal properties that consumers expect to provide added health benefits (and not simply nutritional value). Other products recently introduced into Mexican markets contain fibres from cactus pear and other vegetable materials, e.g. *Psyllium plantago* L. They are sometimes marketed as liquid products to be mixed with water and used, for example, in clinical treatments requiring intravenous feeding.

Purified mucilage can be extracted from the cladodes, which contain greater quantities than the peel. These compounds are of interest to the food and catering sector where they are used as the basis for stabilizers in foams and emulsions for non-alcoholic and dairy products (Garti, 1999; Stintzing and Carle, 2005). Their potential as an emulsifier remains to be explored.

The properties traditionally attributed to certain plants, including *Opuntia,* such as benefits to skin and hair, mean that they have potential for the cosmetics industry. A number of Mexican companies make cosmetics from *Opuntia,* including creams, lotions, gels and shampoos. Cactus stems are not used as an ingredient for manufacture and, according to Corrales and Flores (2003), *Opuntia*'s properties are not widely known, limiting demand. In the short term, therefore, cosmetics are unlikely to absorb large quantities of plant material.

The tourist industry offers opportunities for exploiting *Opuntia* products, including the artisanal manufacture of a number of traditional products. For example, the lignified cladodes are used for making baskets and similar items.

Another quite different but no less potentially important sector is construction. Recent interest has been shown in the anti-corrosive properties of mucilage. Studies are under way on the use of cladode extracts as adhesives in paints and for water clarification.

TECHNICAL REQUIREMENTS

As there are such differences in the processing and production methods of some of the products described, such as cochineal and peel for colorants, hydrocolloids and cosmetics for skin treatment, each will be considered separately.

Many non-food products derived from cladodes and cactus pear fruits offer potential for a variety of uses in the chemical industries, for the manufacture of cosmetics and as agricultural inputs. The technical requirements for processing vary, with different equipment and processes involved, and the raw materials need to be harvested, treated and used differently.

Each industrial sector requires appropriate facilities, equipment and procedures, as well as skilled workers capable of undertaking the work. For example, the safety standards of an enterprise in the chemical industry using solvents will differ markedly from those of a firm producing foods, powders or flours. Depending on the type of product to be manufactured, the appropriate standards and regulations for the particular industry must be adopted and followed.

Requirements for services, labour and working capital will be similar to those described in Chapter 6.

COLORANTS FROM COCHINEAL

Numerous reports describe production of the cochineal insect, its biological cycle and the most suitable hosts among the wide range of species

PHOTO 34
Cochineal insects ready for harvesting and the harvesting operation

(a) (b) (c)

(A) AND (B) CARMÍN DEL ELQUI, CHILE (2005)
(C) A. VIGUERAS, PERU (1999)

and varieties available. Similarly, harvesting and processing of insects and the markets for insects and colorants have also been well covered. Leading authors include Flores-Flores and Tekelenburg (1999) and Sáenz Corrales and Aquino (2002a). Portillo (1995) showed that *O. ficus-indica* is a preferred host plant for the cochineal insect. Given the ample scope of these reports, the following description begins with harvesting the cochineal insect. This should be considered as a *pre-processing* operation.

Preparation

Mature and ovipositing female insects contain the highest quantity of pigment, at around 19–22 percent carminic acid. Younger cochineal insects contain 16 percent or less carminic acid. Harvesting can be undertaken three or four times a year. This is done by hand, taking care to avoid damaging the insect and losing pigment from leakage. The insect is carefully brushed from the cactus plant cladode and deposited in a flat tray. Photo 34 shows cochineal insects ready to be harvested, and the sequence of harvesting operations.

After harvesting, the cochineal insects are sorted to separate the mature insects from the remainder. The insects are then killed. Different methods are available but perhaps the easiest is that described by Flores-Flores and Tekelenburg (1999): leaving them to die naturally in the shade. A natural death of this kind allows for complete oviposition and provides high levels of carminic acid of around 26 percent.

The dead insects are dried by natural air-drying methods. Using a solar dryer, for example, insects can be dried for 4–5 hours over a period of six days. Alternatively, they can simply be left in the open shade for 20–30 days. Artificial drying can be undertaken during periods of rain or high humidity or when time is short. The insects can be dried in hot air at 50–70 ºC, 60 percent RH for 3–4 hours, until the moisture content has dropped to 7–10 percent. Artificial drying provides greater control and results in more uniform drying, less contamination and higher quality raw material. Photo 35 shows cochineal being dried in an artificial dryer.

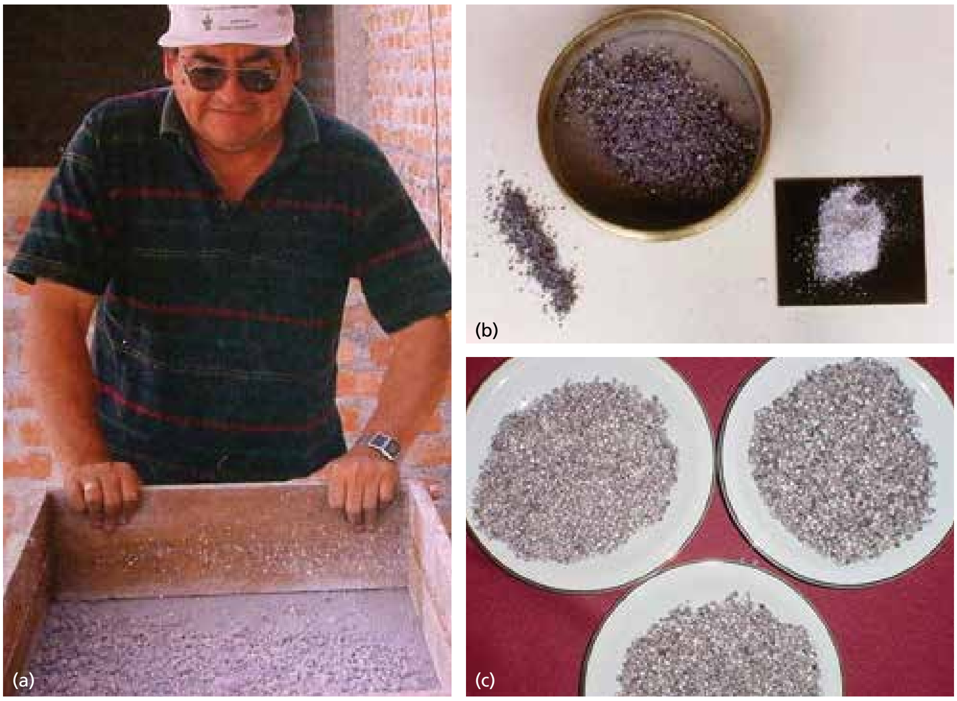
After drying, the cochineal insects are cleaned and all impurities, such as *Opuntia* spines, sand and silica, are removed. This is a semi-manual operation using an air jet and sieves (Photo 36). The dried insects are screened and graded using different mesh sizes, with the highest quality grade retained by a 2 mm screen.

Quality is also determined by carminic acid content, moisture content and contamination from heavy metals. Insects that produce carminic

PHOTO 35
Artificial drying of cochineal

FOODSAFE, CHILE (2005)

PHOTO 36
Cleaning, sorting and dried cochineal



(A) L. PORTILLO, PERU (2000); (B) L. PORTILLO, PERU (1997); (C) C. SÁENZ, ARGENTINA (2005)

acid levels of more than 22 percent are considered good quality, although the market typically demands a higher carminic acid content. Genetic improvement is reportedly in progress to boost the production of insects with higher carminic acid content (Anonymous, 2000).

Cochineal are graded and packed into jute sacks, impermeable plastic sacks or 50 kg drums made from pressed cardboard with metal frames to protect the product and prevent damage. Storage is best at temperatures below 20 °C and relative humidity below 50 percent. The cochineal product is then sent to the processing plant for the production of different types of colorant.

Processing

A range of commercial products is extracted from cochineal, including cochineal extract, carmine and carminic acid. These are available as solutions, crimson lake and powders, and have multiple uses in the food, cosmetic and pharmaceutical industries, as well as for the preparation of laboratory dyes and for dyeing paper, textiles and ceramics (Photo 37).

The commonest uses and limitations of each type of product depend on factors such as:

- pH of the final product or changes during processing;
- temperature before and after addition of the colorant;
- shelf-life of the final product and packaging and storage conditions;
- concentration of the colorant for the tone required;
- agents that might come into contact with the colorant before, during and after use.

Figure 15 provides an indication of the operations involved in producing a variety of cochineal products. As many of these processes are protected by industrial patents, the flow chart has been taken from the study by Carvallo (2000). It summarizes the experience of numerous companies, research centres and researchers, including Pérez (1992), and is supported by information from Peru's Industrial Technology Research and Technical Standards Institute (ITINTEC, 1990).

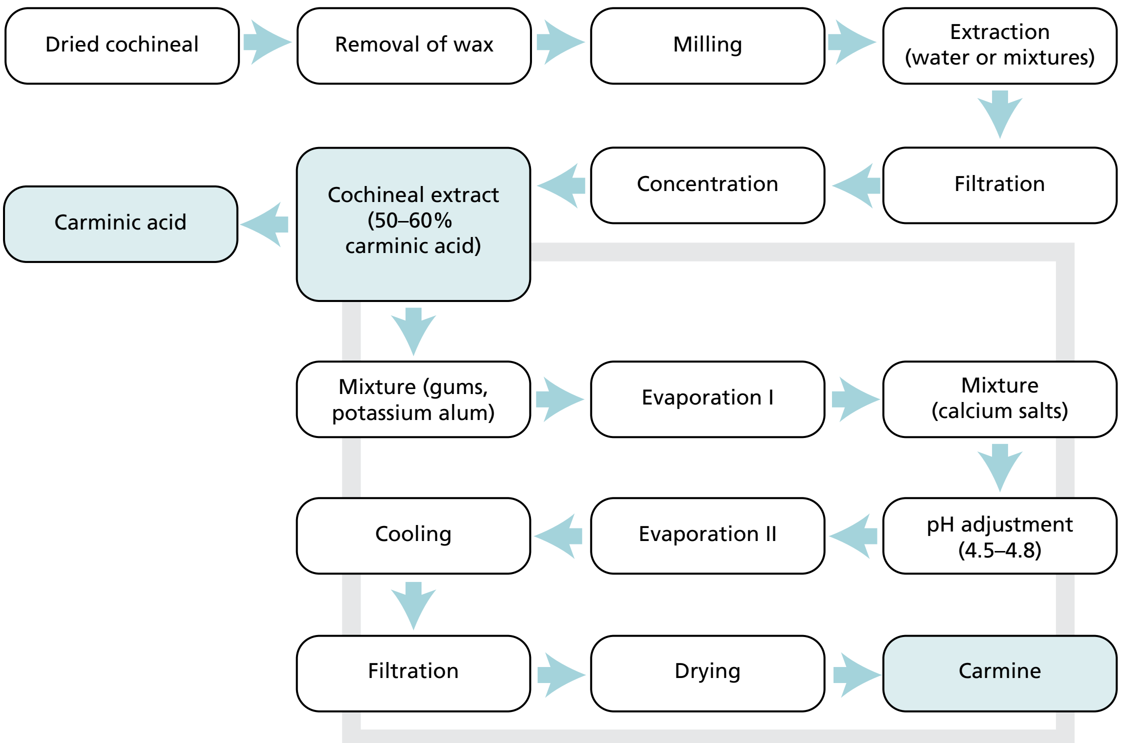
On arrival at the processing plant, the wax coating is removed from the dried cochineal. This is an important first step because subsequent operations require the cochineal to be completely wax-free as this determines the brilliance of the final product. The cochineal is placed in a stainless steel vessel and the solvent is poured over it. When the solvent has completely dissolved the wax, it is filtered through a mesh. Although acetone or hexane solvents are the norm, other types of organic solvent may be used, such as those for extracting vegetable oils.

PHOTO 37
Products derived from cochineal

(A) FOODSAFE, CHILE (2005); (B) C. SAENZ, CHILE (1999)

The cochineal is then milled to allow easy extraction of the colorant. For this, the insects must be dry and clean. Milling produces a totally pulverized material and, depending on the type of mill used, this may involve a single pass through one mill or two mills in series. The powdered cochineal meal is used as the basis for extracting the colorant. Different extraction methods are employed. Some use solvents and others use water only. For example, extraction using a mixture of water and alcohol in proportions ranging from 1:1 to 1:5 (v/v) will not affect the yield of

FIGURE 15
Production of cochineal extract and carmine



the extract. This entails placing the milled cochineal in a jacketed stainless steel vessel, adding the solvent mixture and stirring continuously at a constant 80 °C. Extraction can also be performed in hot water (e.g. 100 °C for 15 minutes), adding sodium carbonate as a pH regulator (pH 9) and stirring continuously.

The resulting solution is first passed through a screen to separate out the larger insect particles and a second time through a paper filter by centrifuge, or through a fine mesh screen. The extract is then concentrated in an evaporator. At this stage it contains 50–60 percent carminic acid and has become a *commercial* product. Various products can be obtained from this extract, such as carmine and carminic acid.

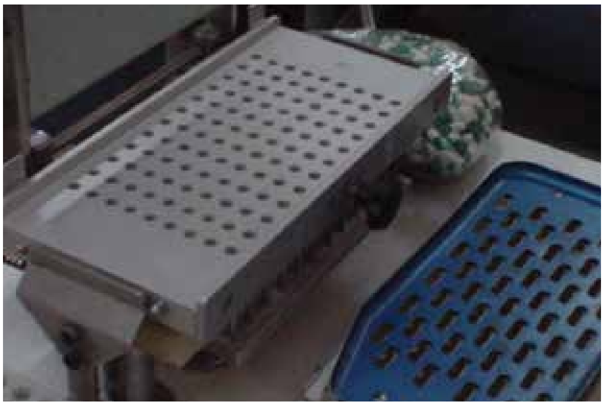
To make carmine from cochineal, the cochineal extract solution undergoes an operation called *lacaje*, consisting of precipitating the carmine with calcium and aluminium salts. This is a mixing and evaporation process. A vegetable gum is dissolved in water and potassium alum salt (double sulphate of potassium and aluminium) is mixed into the cochineal extract and stirred constantly. Evaporation is in two stages. In the first stage, the mixture is boiled in an evaporator to which calcium salts, such as calcium carbonate ($CaCO_3$), are added. Acidity is then adjusted to pH 4.5–4.8 by adding sodium acetate or citric acid. In the second stage, the solution is concentrated. Sodium chloride is added as the final reagent and the resulting product is decanted over a 12-hour period. When the product is completely cool, it is filtered out of solution and dried in a rotary filter, filter press or centrifuge. The resulting carmine pigment has an intense red colour. It is washed in de-ionized water to remove any impurities acquired during processing. Finally, the carmine is dried at low temperature (40 °C) to reduce moisture content and improve the quality of the final product. This is a lacquer of more than 60 percent carminic acid with moisture content of between 7 percent and 10 percent.

Vigueras and Portillo (2004) describe a simpler extraction method for the production of fibre dyes.

FOOD SUPPLEMENTS

A number of natural products – capsules and tablets of cladode powders, powders for mixing into drinks and others formulated with a mix of plant fibres – are used as traditional medicines (not 'food additives'). The formulations of these products are confidential to the manufacturers, and only brief reference may be made to the production processes involved. The products are based on the manufacture of cactus pear cladode flour/powder as described in Chapter 6 and shown in Figure 13.

PHOTO 38
Encapsulating apparatus



C. SÁENZ, CHILE (2005) (COURTESY OF FACULTY OF CHEMICAL AND PHARMACEUTICAL SCIENCES, UUNIVERSITY OF CHILE)

Preparation and processing

The practices for producing cladode flour tablets and capsules are similar to those of the pharmaceutical industry. For small-scale manufacture, manually operated or semi-automatic equipment can be used for encapsulating powder (Photo 38). To make tablets, a mixture is prepared and an agglutinant, such as carboxymethyl cellulose (CMC), is added. The ingredients are mixed thoroughly and the resulting powder is compressed in forming equipment to make the required shape and size for the tablet/capsule.

These supplements are sold to combat obesity or diabetes or to increase fibre consumption, but this can be controversial. The scientific basis of these medicines should be made clear, which requires further research to gain a better understanding of their action. Photo 39 shows a selection of *Opuntia*-based food supplements on the market.

COLORANTS FROM CACTUS PEAR FRUIT

Betalains are pigments found in red and purple cactus pear fruit that are widely used in the food industry. They are extracted mainly from beetroot (*Beta vulgaris* L.), hence the name 'betalains'. These pigments are well known and accepted. Cactus pear fruit offers an alternative source.

Preparation and processing

The fruit is processed in the same way as fruit for juices because colorants are extracted from concentrated juice. However, to make colorants the whole fruit is used, including the peel. As the

PHOTO 39
***Opuntia*-based food and dietary supplements**

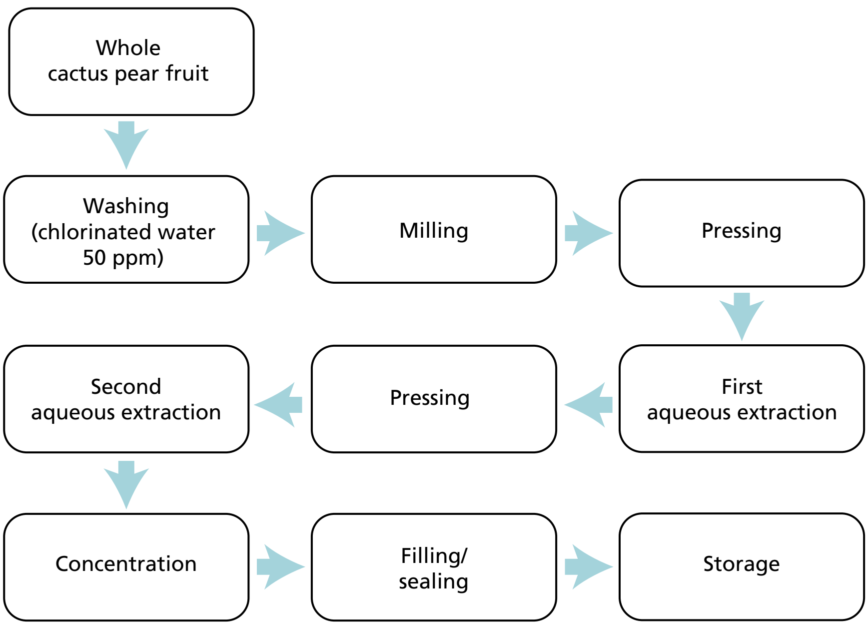
C. SÁENZ AND E. SEPÚLVEDA, CHILE (2005)

pigment content of fruit and peel varies widely, it is essential to choose raw materials with the *highest* pigment content. At present, there are no industries extracting colorants from cactus pear fruit or juice concentrates, and further research is required to determine which are the best plants, varieties and extraction processes. Figure 16 shows a flow chart for obtaining colorant from whole cactus pear fruits.

First the fruits are sorted by hand to remove any damaged material before transferring them to a stainless steel tank for washing by immersion in chlorinated water (50 ppm). As the fruits tumble into the tank, they are brushed to eliminate spines. After washing, the fruit is pulped and/or milled using equipment similar to that for making juices and jams, as described in Chapter 6. Finally, the pulp is pressed in an extractor to obtain the juice.

To complete extraction of the pigments, the residues that remain after pressing are placed in a tank and water is added in the proportion 1:1 by weight. The slurry of pulp and water is stirred for 30 minutes at 20–25 °C before being pressed a second time using similar methods and equipment to those used above. This is the *first* aqueous extraction. These operations are then repeated for the *second* aqueous extraction. Any remaining residues are mixed with residues from

FIGURE 16
Flow chart for making colorant from purple cactus pear fruits



the first extraction and a 75 percent water mix is added; the slurry is then stirred for 20 minutes. If residues still retain colour, a third extraction can be undertaken.

All extracts are combined in a tank and pumped to a vacuum concentrator at 40 °C to protect the pigment's stability. They are then evaporated until the extract reaches 60–65 °Brix, similar to the concentration of commercial beetroot colorant. The yield of colorant as a proportion of the whole fruit is 15 percent, and betanine content exceeds 120 mg $(100\ g)^{-1}$.

HYDROCOLLOIDS (MUCILAGE)

Mucilage or hydrocolloids are products with promising medical applications. They can be extracted from cladodes and the peel of cactus pear fruit. The methods currently used are complex and expensive and yields are low. Nevertheless, emerging industrial interest in using extracts for the treatment of gastric mucosa and other ailments augurs well. The extraction methods described below are taken from Sáenz *et al.* (unpublished data) and based on the use of cladodes – the part of the plant with the highest levels of mucilage. A powder obtained from this process may have potential as a thickener in food formulation.

Preparation and processing

Hydrocolloids can be extracted using 2–3 year old cladodes. Plant materials are washed in chlorinated water (50 ppm), brushed to eliminate spines, then chopped and milled prior to being steeped in a tank to which potable water is added at a cladode-to-water ratio of 1:7 (w/w) at 16–18 °C for a minimum of 16–20 hours (Figure 17).

The material is then passed through a gauze cloth or similar to separate out the larger pieces of cladode, before being transferred into a basket centrifuge, decanting centrifuge or similar to separate as much mucilage as possible from the impurities (i.e. cell walls). The supernatant liquid is concentrated under vacuum at 70 °C until at least one third of the initial volume remains, sufficient for the quantity of alcohol used in subsequent operations.

The concentrated mucilage is pumped into a tank to which isopropyl alcohol or ethanol

FIGURE 17
Flow chart for the extraction of mucilage from cactus pear cladodes

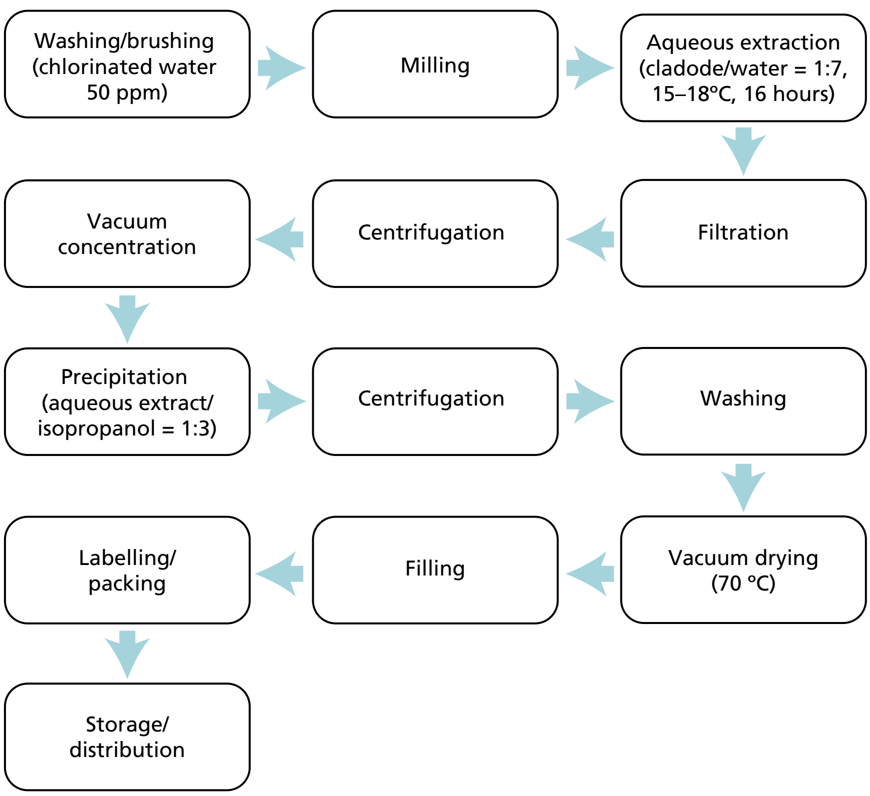


PHOTO 40
Mucilage extracted from cactus cladodes

C. SÁENZ, CHILE (2001)

PHOTO 41
Shampoo, creams and soaps made from cactus pear

C. SÁENZ AND E. SEPÚLVEDA, CHILE (2005)

is added in an extract-to-alcohol ratio of 1:3. The mixture is then transferred to a centrifuge to separate out precipitated mucilage, before being washed by boiling in isopropanol at 95 °C and then filtered to separate the mucilage from the alcohol.

The mucilage is dried at 70 °C in a vacuum dryer or a forced-air dryer until its moisture content has dropped to 5–6 percent. Photo 40 shows precipitated mucilage and the final powder.

COSMETIC PRODUCTS

The cosmetic industry is complex and highly competitive. Many different products are manufactured from cactus cladodes, including soaps, shampoos and various types of creams, lotions and face masks. Most are made in Mexico. The basic manufacturing operations and additives used are described below.

Manufacture of cream based on cactus cladodes

Opuntia cream is normally made from juice extracted from cladodes, as described in Chapter 6. The basis for manufacture has been described by Correa (personal communication).[1]

The oil phase, comprising 8 percent stearic acid, 2 percent white petroleum jelly and 2 percent mineral oil, is mixed in a double-bottomed vessel at 70 °C. The aqueous phase consists of 10 percent propylene glycol, 0.1 percent methyl paraben, 0.1 percent propyl paraben, 3.6 percent triethanol amine and 69.2 percent water. After the two phases are tempered, the aqueous phase is poured over the oil phase and vigorously stirred. Stirring continues until the resulting emulsion reaches a temperature of around 40 °C, when 5 percent cladode juice is added. The cream is packed as described above.

Manufacture of shampoo from cactus cladodes

Correa (personal communication)[1] showed that a transparent shampoo could be made from cactus cladodes by placing them in a container with a solution of 14 percent Texapon N70, 2 percent Comperlan KD, 0.1 percent methyl paraben and around 50 percent water, then heating the mixture to 50 °C until all components have completely dissolved. The mixture should be stirred gently while heating to prevent the formation of foam, before being cooled slowly. The pH should be measured at this point and, where necessary, sodium hydroxide, citric acid or lactic acid should be added to obtain pH 5–6. Next, 5 percent cladode juice is added and the viscosity is adjusted by incorporating 25 percent sodium chloride solution. Finally, perfume and colorant are added, as required, before topping up with water to complete the 100 percent mix. The product is then ready for packing.

Manufacture of cactus cladode soap

Glycerine soap can be made from cactus pear according to methods suggested by Correa (personal communication). The oil phase is based on a mix of fatty acids from tallow (27 percent), coconut oil (7 percent) and castor oil (5 percent), mixed and melted together in a vessel at 70 °C. The separate aqueous phase is prepared from a mixture of 15 percent sugar, 9 percent glycerine,

[1] Olosmira Correa, pharmaceutical chemist, Pharmaceutical Technology Laboratory, Faculty of Chemical and Pharmaceutical Sciences, University of Chile.

10 percent cladode juice, 0.25 percent EDTA and 10.75 percent water. The two phases are then mixed and heated in a reflux condenser together with an alcoholic solution of sodium hydroxide (6 percent with 10 percent ethanol) in a reflux condenser. The resulting soap mass should be slightly alkaline (0.1 percent). Perfume and colorant are added while maintaining a temperature of around 65 °C. The soap mass is poured into moulds and left to cool. The individual soap tablets can then be removed; wrapped in paper or plastic and packed into small cartons.

OTHER PROMISING PRODUCTS

Apart from traditional uses for cactus cladodes (e.g. foods or food additives), there is potential for a number of other novel uses. For example, in the construction industry they can be used as adhesives, for corrosion prevention and as an additive for paints and adobe. In agriculture, they can be used for soil improvement.

In Chile and Mexico, they have been used as an adhesive for manufacturing calcium hydroxide and for purifying water. Many commercial water purifiers are soluble polymers that trap dirt particles and form bodies heavier than water. Cactus mucilage probably works in much the same way (Bobby Crabb, personal communication).

López (2000) conducted a study in Cuba to compare the clarification capacity of cactus mucilage with that of conventional agents, such as aluminium sulphate ($Al_2[SO_4]_3$). The author found that the mucilage of *O. ficus-indica* and *O. stricta* var. Dillenii clarified water in a similar way to aluminium sulphate. Best dosages were around 0.8 ml l^{-1} in water of medium or high turbidity. Parameters used in the comparison included turbidity (NTU) and the Willcombs index, which reflects the quality of the coagulation–flocculation process. The mucilage was found to reduce the chemical oxygen demand (COD) of the water and to remove heavy metals (e.g. Fe, Al and Mn) and faecal coliform bacteria. After treatment with mucilage the water had no unpleasant odour.

In Peru, Ramsey (1999) studied the use of cladode mucilage as a stabilizer for adobe construction blocks and compared them with the lime traditionally used. Results were not as successful as anticipated, probably because of the low dosage used (10 percent). The method used to prepare cactus mucilage as a stabilizer consisted of washing and soaking the cladodes in water (1:1 w/w) for 18 days at 15–20 °C and 82–92 percent RH, or for 7–14 days at 20–25 °C and 77–88 percent RH. Cárdenas, Higuera-Ciapara and Goycoolea (1997) undertook similar work and, after testing the use of cladode juice in lime pastes, found that the juice *weakened* the texture of the lime paste. Finally, Torres-Acosta, Martínez and Celis (2004) confirmed that the addition of cactus mucilage to cement mixes *did* enhance the durability of the cement products. Such mixed results point to the need for further R&D to determine and cost the viability of cladode mucilage for use in construction.

Mexico has a long history of using cactus mucilage in combination with lime. The adhesive properties of the lime are enhanced and water repellence is improved. Traditionally, the mucilage has been used as plaster on adobe or brick walls, as well as a water barrier in stucco. Cárdenas, Higuera-Ciapara and Goycoolea (1997) reported that, in Mexico, cactus cladode juice was traditionally added to lime as an organic adhesive to restore and protect historical buildings, a practice that can be traced back to antiquity.

In a study, these authors tested cactus juice (extracted by boiling cladodes) added to different proportions of lime [$Ca(OH)_2$] (0.65, 1.0 and 1.95 percent). The resistance of the dried pastes was evaluated using a penetration–rupture test on a texturometer. It was found that, as the cladode juice level increased, there was a drastic reduction in maximum stress and in the rate of deformation when compared with a control trial (without cladode juice). Moreover, the lime control provided a more uniform mechanical structure. In the sample with the lowest level of cladode juice (0.65 percent), the mucilage had little effect on the network, resulting in a more discontinuous phase and a weaker calcium hydroxide network. When the proportion of cladode juice was increased, the mechanical properties also increased owing to the formation of a homogeneous network. In this case, the cactus pear mucilage penetrated the calcium hydroxide without modifying the structure, when compared with the control.

In a study by Hernández and Serrano (2003) on the addition of lyophilized cladode juice to mortars traditionally used in local construction, adding 0.5 g of lyophilized mucilage was found to improve the mixture's characteristics, with better compression resistance than the control mixtures to which no mucilage had been added. The mixture of plaster, silicate sand and lyophilized cladode mucilage showed compression strength of 151.8 kg cm^{-2} in 28 days, compared with 125.6 kg cm^{-2} for the control.

Gardiner, Felker and Carr (1999) reported the first experiments on the use of cactus pear extracts for improving water infiltration in soils. After comparing polyacryl amides (PAM) with an undiluted and a diluted extract of cactus pear cladode, the authors found that use of this extract matched the infiltration rates found using PAM. However, many questions remain concerning this research, including the durability of the effect and how the extracts work in the soil. Again, follow-up R&D is recommended.

More recently, in Morocco, Hammouch *et al.* (2004) reported on the successful utilization of an aqueous extract of cactus cladode that prevents steel corrosion. Torres-Acosta *et al.* (2005) found similar results with the addition of cladode mucilage to concrete mixtures poured around steel reinforcing rods. Torres-Acosta, Martínez and Celis (2004) also analysed the addition of cactus cladode to reinforced concrete, this time mixed with *Aloe vera*. Again, similar anti-corrosion properties were found once the concrete had set around the steel reinforcing rods.

An additional property of cactus pear is to repel insects. This is a traditional use for which no published information exists describing its scope, utilization and/or *modus operandi*. Reportedly an R&D product was tested successfully on Roatan Island in Honduras and subsequently patented and manufactured in Texas. It is available for sale on the Internet.

PACKAGING

Packaging methods, materials and systems used for many of these products are similar to those used to pack food products. Colorants derived from cochineal are packaged in different types of packs: liquids in plastic or glass jars, and powders generally in glass jars. Bulk packaging of powders is in plastic bags that are then stacked inside cardboard boxes. Ideally sealed packs should be stored in a cool, dry place protected from sunlight. Under these conditions, they can be preserved for many months without loss of quality.

Capsules, tablets and other food supplements made from cladode powder should be packed according to the safety and hygiene standards recommended by the domestic pharmaceutical industry. Usually this means packaging in glass or plastic jars according to capacity. Again, these will need to be stored in a cool, dry place.

Packaging for colorant extracts obtained from *Opuntia* fruit depends on whether they will be sold retail or wholesale. Wholesale markets generally prefer larger and/or bulk sales options, such as packaging in opaque plastic buckets. Retail markets require smaller quantities in the final package, such as amber-coloured glass jars to help protect the contents from sunlight, with screw caps for ease of use. Goods on shelves should be protected from direct sunlight. Vacuum packaging or packaging in a nitrogen atmosphere is also recommended because this protects the pigment from any loss of colouring power and/or stability.

Dried mucilage can be packaged straight from the dryer (having already been sorted by particle size) or it can be milled to a uniform size. Much depends upon market requirements and the extent of agglomeration and presentation required. Again, the mucilage particles are best packaged in plastic or glass jars, sealed and stored at ambient temperature in a cool, dry place.

As the market for cosmetic products is usually more valuable, special care is needed with packaging and presentation. Cosmetics present an image of beauty and care to the customer, and this should be reflected in the packaging of cosmetic products, whether for the skin, hair or body. Packaging for cosmetic products is usually more expensive than for foods, insecticides and similar products sold on domestic markets.

QUALITY

Given that many of the *non-food* products described earlier are used as inputs, ingredients or supplements in *food* industries, care is required to ensure full compliance with food industry safety requirements. In some cases, such as where products are used as medicines, regulations may be stricter than those applying to food products. In other cases they may not be as stringent. Manufacturers are required to ensure that the strictest possible level of safety assurance is maintained prior to products entering the food chain.

The quality of cochineal-based products is governed by different regulatory bodies in each country, such as ITINTEC in Peru and the FDA in the United States. All mainstream producers maintain high quality standards for manufacture and use.

For carmine, the colour depends on the proportion of aluminium and calcium in the final product. In formulations without calcium the colour is violet and varies from pink to scarlet as the amount of calcium increases. Colour also varies from red at pH <4 to blueish-red at pH 10. Colour must be stable when exposed to sunlight, temperature and oxygen. Carmine is soluble in alkalis and insoluble in acids. The concentration of carminic acid in carmine varies from 40 percent to 65 percent, although 50 percent concentration is the one most commonly found in commercial applications. According to the FDA (2000), carmine must meet the following criteria: minimum 50 percent carminic acid, lead <10 ppm and arsenic <1 ppm.

Cochineal extract is a concentrated solution obtained after removing the alcohol from the aqueous–alcoholic extraction. It has good stability in sunlight and resistance to oxidation. Colour varies from orange to red, depending on pH. According to FDA specifications (2000), cochineal extract must have the following characteristics: pH 5–5.5, carminic acid minimum 1.8 percent, total solids 5.7–6.3 percent, proteins maximum 2.2 percent, lead <10 ppm and arsenic <1 ppm.

In most countries, food supplement quality and marketing authorization are regulated by the ministry of health. Food for human consumption must have safety assurances that comply with national laws. Depending on the country, national testing requirements may include a series of safety tests and reports that must be undertaken before authorization for sale or use is granted.

Although colorants from cactus pear fruit have not entered into commercial use, success will be judged on the basis of pigment content and safety. This makes colorants similar to juice concentrates, in that they are defined in degrees Brix, representing the pigment's level of concentration.

At present there are no quality standards for mucilage extracted from cactus cladodes. However, the grade of purity is currently reflected in the ash content, the type and quantity of minerals, antioxidant capacity, adhesiveness and colour. End use will also dictate other important requirements. When quality standards are established, they are likely to be based on a combination of end use and purity.

MARKETING

The marketing approach for different cactus products is determined by the demands of the industrial sectors concerned (e.g. foods, food additives, construction materials or cosmetics). Many of the requirements and/or considerations that apply to food products apply equally to non-food products.

Market research is an essential part of selling and helps to determine the approach for the products concerned and to identify the customers to be targeted. Market research is particularly important for new products and/or new companies entering a particular market. Studies should be undertaken often enough to determine any changes taking place, as most markets continue to evolve. Shepherd (2003) provides the required elements for such studies.

A study by Sáenz, Garrido, and Carvallo (2004b) on recent cochineal and colorant markets highlighted the variability of demand over the previous 15 years, and the risks involved for those who failed to undertake preliminary research into market conditions. Success and sustainability is more certain for those prepared to invest in timely market surveys.

ECONOMIC ASPECTS

The economic aspects of a particular undertaking will vary according to the products manufactured, efficiency of manufacture, distance of the plant from raw materials and markets and, importantly, available markets and competition from companies selling similar products.

Combining the manufacture of different products within the same industrial facility makes economies of scale possible, saving costs. There are advantages in combining food and non-food processes within the same plant, bearing in mind the need to provide and maintain safety assurances for *all* materials that will eventually be consumed in foods. Poor management poses a risk, for instance where chemical processes using hazardous solvents and other toxic materials are allowed to come into contact with equipment, processes and/or products used for food production.

Parallel production facilities may be practical where wastes such as peel, mature cladodes and other materials derived from the production of flours or thickeners are kept entirely separate from products such as colorants made from cactus pear fruits. This offers practical opportunities for managing the processing plant in a modular manner, using the same equipment for different processes at different times. This has advantages in terms of efficiency and versatility and helps to reduce investment costs.

Levels of investment in infrastructure, equipment and inputs will also vary from one industry to another (e.g. foods, non-foods, chemicals or construction). As a general rule, the more demanding a product is to manufacture, the higher the investment costs; for example, chemicals may require larger-scale manufacturing with greater throughput than food. Much the same may apply to the technical and managerial staff required for manufacturing: the more demanding the industry, the more expensive the staff.

Markets always determine commercial viability, which is based on the choice of products to be manufactured, the success of those already sold on the market, and the difference in appeal (and subjective appeal) between the new product and products already available. Market surveys help to put issues of this kind into context and provide comparative costs.

There are a number of economic aspects common to any productive activity, including: distance from supplies of inputs to the processing plant and from the plant to consumer markets; the type and cost of transport; and overheads, such as the cost of land where the plant will be located and the cost of processing equipment. Other overheads include power, water and telecommunications. Labour is usually the biggest cost in industrial production, particularly where specialists and specialist skills are required. Are they available in the area where the plant will be located? Can the required staff be recruited?

Siting an industrial facility in a rural area with plentiful raw materials has advantages in terms of lower overheads, lower investment in land, and lower costs for workers. At the same time, government incentives are sometimes available for employing local people. Drawbacks may include markets that are a long way from the plant and skilled technicians and managers reluctant to locate to isolated places. Choices have to be made.

Chapter 8
Production of bioenergy and fertilizers from cactus cladodes

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GENERAL CONSIDERATIONS

Permanent constraints on water resources in arid region ecosystems are reflected in impoverished vegetation and scarce organic residues. This results in poor soil protection and soil degradation. Such degradation affects a large number of agro-production variables, including loss of organic material, which leads to gradual loss of natural soil fertility.

Conservation of the organic materials in cultivated soil remains a challenge for growers, particularly in intensive production systems. Estimated annual losses of organic material in such systems can be as high as 0.75–1.25 tonnes ha^{-1} $year^{-1}$. To offset such losses, organic material may need to be added at a rate 2–6 tonnes ha^{-1} $year^{-1}$ to replenish soils. Application rates vary depending on whether fresh or stabilized organic materials are available.

The periodic incorporation of organic residues into soils is a good husbandry practice that boosts the physical condition of the soil. It increases productivity and in the long term contributes to the recuperation of marginal soils. However, conditioning soils with fresh organic residues is expensive and challenging, not least because of the large volumes of material that need to be handled. In addition, it may take a long time for these materials to stabilize and become effective. The difference between applying raw fresh residues, such as harvest waste and animal manure, and bio-processed organic materials, is reflected in the short-term response during the crop establishment period.

The treatment of biodegradable organic solid residues as a means of decontaminating and/or recycling materials is based mainly on the use of micro-organisms and enzymes to convert the organic residue substrate into value-added products in the presence or absence of oxygen. According to Varnero (2001), there are two major groups of bioprocesses:

- Aerobic processes, where the biodegradable organic residues are degraded through biochemical oxidation and produce carbon dioxide and water, calorific energy and stabilized organic material. Aerobic processes include composting and vermiculture (earthworm/organic materials culture).
- Anaerobic or methanogenic fermentation processes, where the original biodegradable material is transformed by biochemical reduction and produces a combustible gaseous mixture called biogas. The principal components of biogas are methane and carbon dioxide. A stabilized organic material called ‘biofertilizer’ results.

A number of environmental factors determine the micro-organisms responsible for the metabolic activities of both processes, and these ultimately influence final yields. Stabilized materials obtained from these bioprocesses have the properties of soil conditioners and/or soil improvers that enhance natural soil fertility. The nutrients in the organic materials are made available to growing plants faster than fresh or untreated residues (Varnero, 2001).

The type of biodigester used in conventional installations is governed by the frequency of raw material loading: a continuous biodigester (daily or weekly) or a batch biodigester (no loading during the fermentation process). The choice of digester is based mainly on the availability of raw materials to feed the digester and water supplies. Limited water resources in arid regions usually reduce the availability of biodegradable raw materials. The batch biodigester is more useful in such situations, as it enables materials with a high concentration of total solids of around 50 percent to be accumulated and processed.

One way to overcome the drawback of limited organic residues in arid areas is to develop energy crops that are suited to the region's edaphic and climatic conditions. Plants with a crassulacean acid metabolism (CAM), such as *O. ficus-indica* L. Mill, are recommended as an alternative energy source, given their high potential for biomass production (García de Cortázar and Nobel, 1992; García de Cortázar and Varnero, 1999).

The biodegradation rate of organic residues is related to the microbial activity of the anaerobic system. Microbial activity depends on the characteristics of the raw materials, the pH of the medium, the level of total solids, the process temperature and other parameters that determine the digestion period for the production of biogas and biofertilizer.

HANDLING AND STORAGE

Studies have shown that one hectare of *Opuntia* over the age of five years is capable of producing as much as 100 tonnes of fresh cladodes each year in areas with little rainfall (150 mm or less). In some parts of Mexico, people living in semi-arid zones have a tradition of collecting cladodes from wild cactus plants.

Pruning cladodes is an important management practice to boost yield and/or raise the quality of the final produce (e.g. fruit and *nopalitos*), although this has not been done with *Opuntias* on a commercial scale. Opportunities exist for developing cultural practices to serve markets with better-quality produce, with the higher costs that this would entail.

Where waste material from pruning mature plants is not needed for new plantations or does not have the required characteristics, it can be used as feedstock for cattle or biodigesters, producing biogas and biofertilizer. It is also possible to plan cladode production specifically for biodigesters, separately from or in combination with livestock production. No special plant management is required; once cut and chopped, mature cladodes (around one year old) can be fed directly into the biodigester. Although cladodes are occasionally stored for short periods before use, this is detrimental because biodegradation will begin immediately, which will reduce the efficiency of the reactions in the biodigester. If raw materials cannot be used immediately because of the limited size of the biodigester, for example, they should be stored intact in the shade in a cool, dry area.

USE AS FUELWOOD

By definition, xerophytic plants are well adapted to thrive under arid conditions by rapidly accumulating large quantities of water during brief periods of humidity. The shape and structure of cladodes makes them highly efficient at preventing evaporation by transpiration, so conserving internal moisture. Tender cladodes are succulent and have little lignification. However, as they age they develop a lignified cuticle and numerous fibres, giving the structure an almost wood-like texture. In this state, cladodes can be used as fuelwood, as is traditional in a number of African countries (see Chapter 6).

OPUNTIA SPP. RESIDUES FOR BIOGAS PRODUCTION

Biogas experiments on cactus in the University of Chile's Faculty of Agronomic Science demonstrated that, when biodigested by themselves, cladodes are not good methanogenic material (Uribe, Varnero and Benavides 1992; Varnero, Uribe and López 1992; Varnero and López, 1996; Varnero and García de Cortázar, 1998). Mixing cactus pear cladodes with animal manure in the anaerobic digester did improve methanogenic fermentation but only when the pH of the mixture is kept neutral or slightly acidic (Uribe, Varnero and Benavides 1992; Varnero, Uribe and López 1992). This is because the energy and carbon in the cladodes favour the development of acidogenic bacteria and then generate the substrate required by methanobacteria, thereby accelerating the methanogenic process and reducing the time required.

The fermentation efficiency of manure/cactus mixtures with different proportions of cladodes and animal manure showed that it is crucial to maintain pH 6 or above in order to obtain biogas with methane content greater than 60 percent. The composition of biogas produced by fermentation is closely related to the pH of the raw materials biodigested. At pH levels of less than 5.5, biogas is predominantly carbon dioxide, reducing combustibility and energy content. Conversely, with neutral or basic pH, biogas is rich in methane. It is easier to obtain such a pH value by increasing the proportion of animal manure in the mixture and using cladodes older than one year. Particle size of the chopped material had no significant effect on the efficiency of the fermentation process (Varnero and López, 1996; Varnero and García de Cortázar, 1998).

The technology required to produce ethanol is more complex than that for producing biogas. Alcoholic fermentation, which in many ways resembles that required for biogas production, must be followed by distillation to obtain the fuel. In addition, *specific* yeasts are required to maximize ethanol production. These requirements have been described further by García de Cortázar and Varnero (1999).

USE OF RESIDUES FOR VERMICULTURE AND FERTILIZERS

Vermiculture is the cultivation of earthworms on biodegradable organic residues that have been semi-composted. The final product is called 'vermicompost' or 'worm castings', which can be incorporated into the soil in much the same way as compost or biofertilizer. In addition, animal protein can be obtained from the worms in the form of worm meal for use as an animal feed.

The best earthworm species for vermiculture is *Eisenia foetida* owing to its high reproduction rate, rapid body development and ability to produce up to 40 000 individual worms per cubic metre of material. Physiologically, *E. foetida* excels because of its capacity to survive and adapt to different conditions.

Vermiculture requires higher investment than composting because suitable infrastructure is needed for the worms to develop, and greater control is required over the humidity of the worm beds. Beds must be started with organic material that has previously been degraded to avoid temperatures higher than the 55 °C typical of aerobic bioprocesses. This means that the biofertilizer described above can also be used in the worm bed because biodigestion processes eliminate the substances responsible for high-temperature fermentation.

EFFECT OF BIOFERTILIZER ON THE ROOT DEVELOPMENT OF CLADODES

Studies at the Antumapu Experimental Station, belonging to the University of Chile's Faculty of Agronomic Science, evaluated the potential of biofertilizers obtained from fermenting a mixture of chopped cladodes and fresh cattle manure. The aim was to improve the physical, chemical and biological properties of soil. Findings suggested that the addition of biofertilizers increased the efficiency and sustainability of agricultural systems in arid regions. The results of two experiments are presented here: one undertaken in pots and the other in an open field.

Experiments were conducted on cladodes in black plastic bags containing biofertilizer made from a mix of cladodes and manure, with Santiago series soils:

- T1 – Control without biofertilizer.
- T2 – Volumetric mixture 25 percent biofertilizer and 75 percent soil.
- T3 – Volumetric mixture 50 percent biofertilizer and 50 percent soil.
- T4 – Volumetric mixture 75 percent biofertilizer and 25 percent soil.

All treatments were in black polyethylene bags (19 cm in diameter and 50 cm in height). Results indicated that biofertilizers accelerated cladode root development and sprouting. Biofertilizer treatments produced sprouting 30–60 days earlier than the control. Sprouting occurred at the end of the summer and the beginning of autumn. This gives the plant a greater surface area for photosynthesis to accumulate reserves for the winter months (Table 23 and Figure 18).

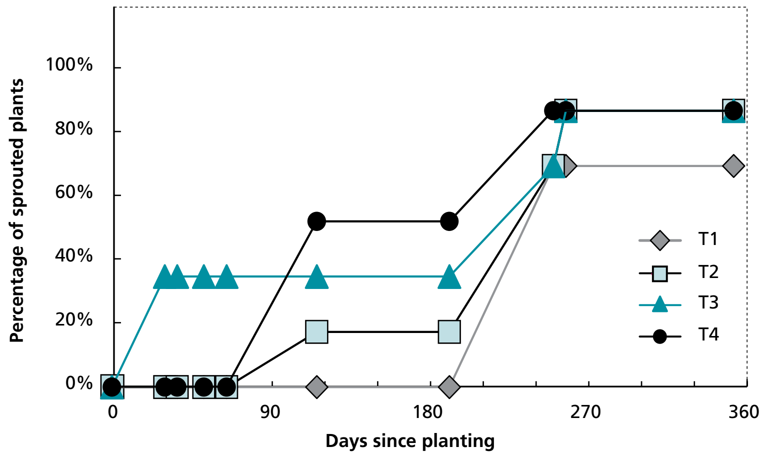
Figure 18 shows the evolution over time of the percentage of sprouted plants using the four soil-conditioning treatments. These were planted in black polyethylene bags containing 14 litres of conditioned soil, set three metres apart, for the treatments shown in Table 23.

As Figure 19 shows, there were no significant differences in the total biomass or root biomass produced. Root biomass per plant was a constant fraction of total biomass. The allocation of resources between the aerial parts of the plant and the roots is similar to that of C3 and C4 plants, where priority is given to the allocation of carbohydrates to the aerial part, providing a ratio of aerial biomass to root biomass of about 6:1 after one year (García de Cortázar and Nobel, 1992).

TABLE 23
Sprouting – average days for the appearance of the first sprout in cactus pear plants

Treatment	Days after planting	Standard deviation
T1	262 a	3.3
T2	140 a	51.1
T3	189 a	105.4
T4	194 a	68.2

FIGURE 18
Evolution in time of the percentage of sprouted plants using four soil conditioning treatments



In field experiments in plots 6 m × 3 m, the soil was conditioned with different volumetric doses of cactus pear biofertilizer and manure: 0.25 percent and 75 percent, plus one soil treatment using fresh cattle manure in a volumetric proportion of 50 percent, in order to evaluate the effects on root growth and cladode sprouting. In cactus pear plantations the usual sequence for the appearance of the main plant parts is as follows: first roots, second cladodes and third fruits. Root growth can be evaluated indirectly using the date of sprouting of the aerial parts, which proves that roots exist without the need to dig the plants up, disturbing the soil (and the plant).

Figure 20 shows the capacity of biofertilizer to accelerate sprouting. Treatments containing biofertilizer gave higher percentages of sprouting in the shortest time, and considerably more than the control without biofertilizer. Although fresh manure had a similar effect to biofertilizer, biofertilizer was favoured for its ease of handling, greater stability and ability to produce biogas.

EFFECT OF BIOFERTILIZER ON THE PRODUCTION OF *OPUNTIA* SPP. BIOMASS

A second advantage of biofertilizers is their capacity to provide nutrients in the soil. In a field experi-

FIGURE 19
Effect of soil conditioning treatments on the production of total and root dry weight
(note the standard deviation is shown on each bar)

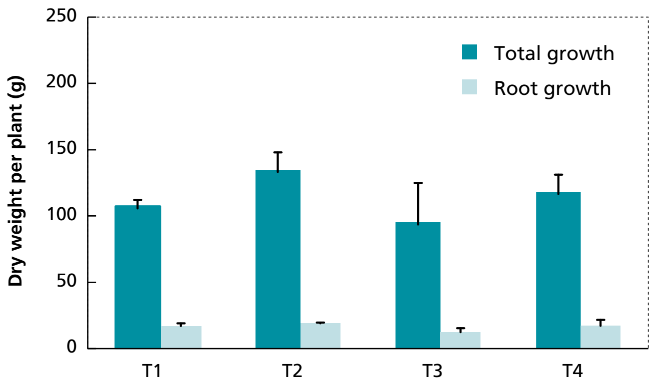
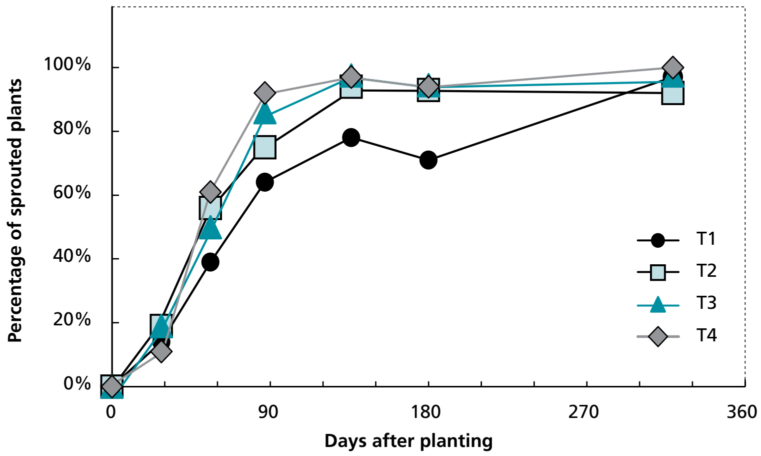


FIGURE 20
Evolution over time of the percentage of sprouted plants using four soil conditioning treatments



ment in a Santiago series soil, different dosages of biofertilizer obtained by fermenting a mixture of cladode residues and animal manure were applied eight months after planting in two furrows 20 cm deep with plants 30 cm apart, as shown in Table 24 (García de Cortázar, Varnero and Espinoza, 2001). The chemical composition of the biofertilizer is shown in Table 25. Treatments were: T0 – control without biofertilizer; T1 – 15 tonnes/hectare of biofertilizer; T2 – 30 tonnes/hectare of biofertilizer; T3 – 45 tonnes/hectare of biofertilizer; and T4 – 60 tonnes/hectare of biofertilizer. Experimental plots of 2 m × 3 m were used and 36 cactus pear cladodes were planted in each plot.

Nitrogen absorption was proportional to the quantity of biofertilizer applied and there was a linear relationship between the production of dry matter and the nitrogen absorbed (Figure 21). However, the nutrients were not immediately available and it was necessary to incorporate the biofertilizer early when demand for mineral elements was at its peak (1–2 months). This is essential, especially when biofertilizers with higher organic matter and lower nutrient content were compared with other biofertilizers used in such experiments (Pérez, 1989; Herrera, 1990; Contreras, 1993; García, 1994). The C/N ratio of the biofertilizer was high when compared with

TABLE 24
Analysis of the fertility of the arable layer of soil used in the experiment*

Analysis	Value
Total nitrogen (g kg^{-1})	1.26
Total phosphorus (g kg^{-1})	2.35
Total potassium (g $kg^{-1)}$	8.21
pH	7.90
Electrical conductivity (dS m^{-1})	1.05
Organic material (g kg^{-1})	21.50
Available nitrogen (mg kg^{-1})	70
Available phosphorus (mg kg^{-1})	24
Available potassium (mg kg^{-1})	179
Calcium carbonate (%)	6

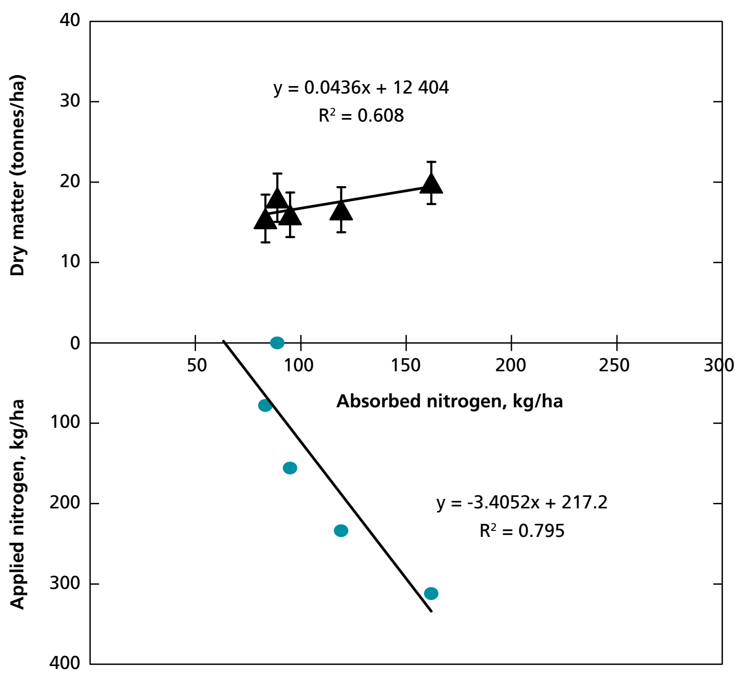
*Data taken from a composite sample of all surfaces in the field.

TABLE 25
Chemical analysis of the biofertilizer used in the experiment

Analysis	Value
Total nitrogen (g kg^{-1})	5.20
Total phosphorus (g kg^{-1})	3.90
Total potassium (g kg^{-1})	3.60
pH	8
Organic material (g kg^{-1})	561
Available nitrogen (mg kg^{-1})	119
Available phosphorus (mg kg^{-1})	1 070
Available potassium (mg kg^{-1})	604
Volatile solids (g kg^{-1})	638
C/N ratio	63

Source: García de Cortázar, Varnero and Espinoza, 2001.

FIGURE 21
Relationship between dry matter produced and nitrogen absorbed (upper panel and triangles) and between nitrogen absorbed and nitrogen applied in the biofertilizer (lower panel and circles)



Source: García de Cortázar, Varnero and Espinoza, 2001.

the C/N ratio of 30:1 established earlier for the mix of materials with the highest probability of fixing nitrogen (Mustin, 1987; Varnero, 1991). The main effect expected during the first few weeks after incorporating the biofertilizer into the soil is nitrogen fixation.

The efficiency of fertilizer recovery is linked to the relationship between nitrogen applied and nitrogen absorbed. Alternatively, this is the value of the inverse of the slope of the line of best fit: in this case the value is 0.29 and means that the crop recovered 29 percent of the biofertilizer applied.

However, taking into consideration only the three highest doses applied, the efficiency of nitrogen recovery would be 43 percent (focusing on the three highest doses reduces interference caused by the soil's high initial nitrogen availability).

In low-density and high-density plantations, a linear response was obtained between the quantity applied and the dry matter produced per unit of surface area, as shown in Figure 21.

EFFECT OF BIOFERTILIZER ON SOME PHYSICAL PROPERTIES OF SOIL

In experiments carried out over a three-year period at the University of Chile's Faculty of Agronomic Science, biofertilizers did not produce any *significant* changes in the physical properties of the soil. However, compared with the control treatment, there was more water available in the soil, increased infiltration velocity and an apparent reduction in soil density. While these changes are positive for the plant's functioning, they are not of sufficient magnitude to explain the changes in yield, which stemmed more from nutrient availability. Significant differences in the physical properties of soil as a result of incorporating biofertilizers will probably be seen over the longer term (5–10 years) and in soils lacking in organic matter.

ECONOMIC ASPECTS

The initial cost of biogas production in rural households is around US$50 per biodigester (Bui Xuan An, Preston and Dolberg 1997; Rutamu, 1999). This cost is recovered within 9–18 months through savings in fuel costs. In rural areas where the main fuel is currently wood, the use of biogas also reduces ecosystem damage (less deforestation and contamination) and leads to time savings of up to five hours a day per household. This time can be used for other productive tasks (Rutamu, 1999). The biofertilizer residues obtained from digestion processes contain nutrients that make it a valuable fertilizer, which reduces expenditure on fertilizer. According to Varnero (1991), one tonne of biofertilizer is equivalent to 40 kg of urea, 50 kg of potassium nitrate or 94 kg of triple superphosphate. International fertilizer prices vary from US$150 to US$250/tonne (FADINAP, 2005). Assuming an average price of US$0.20/kg of fertilizer, each tonne of biofertilizer would save US$38 on the cost of fertilizer.

Chapter 9
Case studies on agro-industrial utilization of *Opuntia* species in several countries

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Opuntia has been part of the human diet for at least 9 000 years and can be found growing from the hottest deserts to the snow-capped mountains, giving an indication of the plant's adaptability (Nobel, 1998). However, *Opuntia* is eaten mainly fresh and, in most countries, processing remains limited. Developing small-scale agro-industries or, at least, learning how to consume different parts of the plant, is a huge challenge for the people of countries where the plant grows wild or can be cultivated. Agro-industries are typically described as an engine for growth. Investments of this kind offer benefits to growers and others, many of whom live in places with limited resources and may face poverty, hunger and malnutrition.

This chapter describes the production and industrial processing of *Opuntia* species in different countries around the world. It has been prepared with the collaboration of a number of *Opuntia* experts, some of whom belong to CACTUSNET–FAO. It provides a brief analysis of each country's status and prospects for industrial processing of cactus pear fruit and cladodes. Although this chapter does not cover forage, in many countries, including Argentina, Brazil, Mexico and the United States, a significant acreage of *Opuntia* is used to feed livestock.

Inglese (2000) estimates that 100 000 hectares (ha) of cactus pear are cultivated worldwide. In addition, extensive but unknown areas of wild plants are regularly exploited for food, feed and materials.

ARGENTINA

According to Ochoa (1997a), cactus pear is grown mainly in the northeast of the country where it is traditionally cultivated in small plantations. Over the past ten years, improved cultivation techniques and practices have been introduced, with an estimated 2 000 ha of plantation crops now grown (Inglese, 2000; Ochoa, 2003). In addition, an estimated 200 000 ha of wild cactus pear plants are exploited (Ochoa and Uhart, 2004).

In Argentina only the fruit is eaten, mainly fresh. There is no culinary tradition of processing and eating cladodes. The most common fruit is yellow and spineless. Demand for the fruit is highest in the province and capital city of Buenos Aires, many of whose inhabitants come from the country's interior. Many are familiar with the cactus pear fruit and represent potential markets for both fresh and processed products (Ochoa, 1995). Domestic consumers prefer the yellow and spineless varieties called *criollas,* which make up 80 percent of available biotypes. However, red and orange fruits may also offer potential for export (Ochoa, personal communication).[1]

Small-scale processing of *Opuntia* fruit has been introduced as there are few processed products sold on local markets. A syrup known as *arrope* is produced from concentrated juice with no added sugar (Ochoa, 1997b). The syrup is eaten with cheese to make a delicious dessert. Jams and jellies are also produced on a small scale. Various foods based on cactus pear fruit are prepared in the home (Ochoa, personal communication).[1]

According to Ochoa, *arrope* is prepared as follows: the ends of the fruit are removed and the fruit is milled without peeling, and then sieved. Sieves with holes of different sizes are used in sequence: first 10 mm, then 4 mm and finally a fine mesh screen. The juice is concentrated by boiling to produce different types of *arrope.* Yields vary from 20 percent to 25 percent of the original volume of cactus pear fruit juice. The final product

[1] Judith Ochoa, Institute for Semi-arid Agriculture Development, Faculty of Agronomy and Agro-industries, Universidad Nacional de Santiago del Estero, Republic of Argentina. Coordinator for Latin America, CACTUSNET–FAO (2005).

is relatively dark in colour and has the appearance and consistency of honey.

The joint FAO/Government of Argentina project on fruit trees in arid zones was undertaken in partnership with the National University of Santiago del Estero. Over a two-year period it promoted cactus pear foods and prepared and distributed technical brochures describing agronomic practices, harvesting and diseases affecting the cactus pear plant. It would be useful to continue such work, particularly to promote household and small-scale industrial processing for their nutritional, health and market benefits. The project led to studies on the development of cladodes of *O. cochenillifera* planted on the university's experimental farm, for adding to the local diet (Ochoa *et al*., 2004).

The cochineal insect was exploited during Argentina's colonial period, although no contemporary use has been reported. The colorant was used to dye wool, textiles and ponchos. Recent efforts have been made to reactivate these practices as a means of developing a more integrated approach to *Opuntia* exploitation (Ochoa, personal communication).[1]

In rural Argentina, chopped cladodes are sometimes used to clarify dam water or rainwater collected for drinking. Mucilage is also sometimes used as an adhesive to mix with lime for whitewashing the walls of adobe houses (Ochoa, 1997b).

CHILE

ODEPA–CIREN (2003) estimates that Chile has 1 100 ha of commercial cactus pear (*O. ficus-indica*) for fruit production. Bustamante (personal communication)[2] reported that around 395 ha of cactus pear are used for cochineal production in northern Chile. Crops are owned and exploited by five companies, each with 30 ha and small numbers of outgrowers. The industry provides work for an estimated two people per hectare which, when compared with seasonal fruit production, has advantages of permanency and security.

Cactus fruit plantations are located mainly in the Til-Til, Pudahuel, Lampa and Noviciado regions in central Chile and near the capital city, Santiago, where they produce fruit for eating fresh (Saenz, 1998). These are commercial plantations; there are no large areas of wild plants in Chile.

In the past, cactus pear fruit was occasionally exported to the United States but Mexico has subsequently come to dominate this market. However, recently there has been some interest in redeveloping export markets.

In Chile, cactus pear is mainly eaten as fresh fruit, although it is also used in desserts or made into juices. Ecological restaurants provide a small market for freshly prepared juice. A small-scale industrial producer in the Til-Til Region has recently begun to produce cactus pear fruit jams commercially and to sell them to markets in Santiago.

A medium-scale company with its own plantations in a microclimate zone north of Santiago has planted a small area of *O. ficus-indica*. The company produces frozen exotic fruit pulps of excellent quality and plans to carry out trials with a view to adding cactus pear fruit pulp to its product range for dilution and for making drinks, ice creams and desserts.

Chile has a food supplements laboratory under the control of the Ministry of Health. The laboratory is developing a gastric protector based on cladode extracts. Some growers prepare cactus products, such as vinegar and juices, for household consumption.

Although cactus pear as a food is little known in Chile, this has done nothing to deter growing interest from a number of small-scale producers and collaborative crop diversity researchers in exploring new products and markets. The University of Chile provides training in small-scale production and processing. A course was held in the VII Region to the south of Santiago, as part of a project supported by the Ministry of Agriculture and the Foundation for Agricultural Innovation (FIA). FIA promotes small-scale production of cactus pear plants in dry coastal zones. The course covered both theory and practice and taught participants basic forms of processing and different ways of preparing and eating fruits and tender cladodes (Photo 42).

In 2002, a survey was undertaken in the municipality of Til-Til, where more than 60 percent of Chile's output of the crop is grown, to ascertain the interest of small-scale producers in boosting industrial productivity. The survey was conducted jointly by the University of Chile and Til-Til municipal council on the basis of the questionnaire shown below. Findings served as guidelines for use elsewhere in the country.

The first part of the survey focused on technical issues (to assess the municipality's real production situation), growers, practices and knowledge of

[2] José Antonio Bustamante, Foodsafe, Chile (2005).

PHOTO 42
Participants at a workshop for the preparation of products from *Opuntia* fruits and cladodes

CRATE FOUNDATION, CHILE (2005)

the plant. The second part focused on the views of local producers and their interest in innovation and training (in support of industrial development).

SURVEY OF SMALL-SCALE CACTUS PEAR PRODUCERS

Survey results revealed that few producers had experience of processing cactus pear fruit or cladodes. However, everyone (100 percent) was interested in participating in training courses to learn more. Producers were also keen to form associations in support of industrial development in order to diversify production and exploit new markets. The request from Til-Til municipal council following the survey led to training for small-scale producers in the municipality on the first steps required for small-scale industrial development.

Despite the fact that Chile has no culinary tradition of processing and eating cladodes, findings from a joint study conducted by the Centre for Food Research and Development (CIAD) of Hermosillo (Sonora, Mexico) and University of Chile's Faculty of Agronomic Science, showed that Chilean consumers were willing to sample cactus pear products.

Rows of *Opuntia* plants have traditionally been used as living fences to separate fields and to hold livestock, and cladodes have regularly been used to clarify water in poorer rural areas. Such has been the shift towards modernization in Chile that both practices are declining in preference for more technically advanced materials and systems. Cladodes are occasionally used as adhesives added to lime for the maintenance of adobe houses.

Small-scale producers have shown enthusiasm for proposed initiatives for boosting agro-industrial production and processing of cactus pear crops. This would require receptive individuals and good collaboration between centres of information and rural communities. It also suggests that viable small-scale industries could be developed with minimal investment, and that this would add value to local crops, help raise incomes and boost employment in rural communities.

Collaboration is required between Chile's Ministry of Agriculture and municipalities in regions where cactus pear is already grown commercially or where the plant could be successfully introduced. Representatives of the institutions concerned share responsibility for proactive planning, investment and actions that will result in the transfer of knowledge and technology already available in the country. Small-scale industrial ventures can then be established wherever cactus pear can be grown. The future looks promising.

ERITREA

Eritrea is a country in northeast Africa. It has a total area of 12 430 000 ha and an estimated population of 3.5 million people, 80 percent of whom depend on subsistence agriculture. The country is poor economically and people regularly face hunger and malnutrition. The appropriate exploitation of natural resources such as cactus pear may help alleviate some of the nutritional and food security issues facing local people.

Beles is the local name for the cactus pear plant and fruit. It grows wild and is used as a living fence, for erosion control and for feeding ruminant livestock. A study by the Ministry of Agriculture in 1999 estimated that 4 794 tonnes of fresh fruit was collected during the summer months of 1999 in the areas of Arberebu and Segeniti. One-quarter of this was eaten at home. Although local people have a tradition of eating fruit, they have no tradition or knowledge of using

Survey of small-scale cactus pear producers

Technical data		
Name *(optional)*:		
Variety:		
Age of plantation:		
Number of hectares:		*In production:
		*Under development:
Production/hectare:		
Production System:		
Type of irrigation:	*Availability of water:	
Fertilization:		
Pruning operations:		
Thinning operations:		
Harvesting systems:		
Marketing systems:		

1. Is this the only activity carried out?

2. Do you have other crops?

3. Do you have experience in making products based on cladodes and/or fruit?

4. If you had the tools, would you be interested in making products from cactus pear (artisanally), such as jams, dried sheets (snacks), pickled cladodes, or other?

5. Are you open to becoming a member of an association of small-scale cactus pear producers in Til-Til?

6. Just as other parts of the country are known for certain products, do you see Til-Til as a cactus pear region that could be attractive to tourists?

7. Would you participate in training courses to improve production and learn about product processing and other matters?

8. What would be your main reason for *not* participating in this project?

Notes

Date

PHOTO 43
Typical marketing of cactus pear fruit in Eritrea


M. MURILLO, ERITREA (2003)

nopalitos as a vegetable; people do not know how to prepare them for eating. The fruit is eaten fresh and sold throughout the country, alongside roads and in all communities (Photo 43). According to Murillo-Soto (2003), the capital city, Asmara, is the country's biggest market.

Cactus pear fruits are sold in markets alongside other fresh fruits, such as bananas, guava, oranges, papaya, lemons and mangoes. Cactus pear fruit production is limited and the quality of harvesting, transport and presentation in markets is usually poor (this applies to *all* fresh fruits). Most fruits are harvested from wild plants. There is no tradition of processing fruit into other products, although Murillo-Soto (personal communication)[3] reported the small-scale manufacture of cactus pear fruit jam (one producer).

Findings from the joint FAO/Government of Eritrea project FAO/TCP/ERI/2802 highlighted opportunities for the sale of fresh *nopalitos* in the market and/or small-scale processing of fruit and cladodes for home consumption or income generation. The country has no experience of breeding and harvesting cochineal insects or extracting colorants. The project recommended exploiting opportunities for boosting consumption of *nopalitos* and for processing fruit and cladodes (Murillo-Soto, 2003).

UNITED STATES OF AMERICA

The United States National Agricultural Statistics Service (NASS) has no published information on the extent of cactus pear production in the country. By comparison with other crops, planted areas are insignificant. Specific contacts with national specialists[4] suggest that around 200 ha are dedicated to cactus fruit production, more than half of which is in California (Basile, 2001).

Felker (personal communication)[4] estimates that 120 ha of red cactus pear are owned by one company in the Salinas Valley, California, and used to produce acidified frozen juice. However, fresh fruit in this area is high quality and production focuses on fresh fruits rather than juices. Production of a range of products based on a red cactus pear variety introduced from Sicily has recently begun. The company has now switched its focus to the production of frozen cactus pear purée made from cactus pear pulp, sugar and malic and citric acids to 22–24 °Brix, which must be kept frozen. The company established a processing plant where purée is processed and pasteurized according to strict quality standards (Bunch, 1997). The purée is distributed by specialized agents who offer it in different types of packaging for use in desserts, salad dressings, jellies and sauces.

Large areas of land in the southern United States are available for cactus pear cultivation. There are also thousands of hectares of wild cactus pear plants in Texas, which create problems for cattle producers.[5]

In the United States, cactus pear products are eaten mainly by the Mexican community. Felker[11] reported that D'Arrigo Bros. Co. sells fresh *nopalitos* in local markets, and has started to produce a mature cladode powder for use as an ingredient in food mixes and/or for industrial applications. The United States imports fresh and minimally processed cladodes and processed cladodes, in brine and pickled, from Mexico. A number of local producers in the United States import chopped and individual quick frozen (IQF) *nopalitos* (in slices or cubes) from Mexico (Felker).[4]

A wide variety of cactus pear-based foods are manufactured. Many companies advertise various ways of eating and enjoying cactus pear fruit and cladodes on the Internet, where they offer such products as jams and candies, medicines

[3] Margarita Murillo, Universidad Autónoma Agraria Antonio Narro, Buenavista, Saltillo, Cohauila, Mexico, 2005.

[4] Peter Felker, D'Arrigo Bros. Co., Salinas, California, 2005.

[5] Robin O. Roark, Director, Texas Agriculture Statistics, National Agricultural Statistics Service (NASS) of the United States Department of Agriculture (USDA), 2005.

PHOTO 44
Some products available in markets in the United States

J. BREMNER (DESERTUSA), D'ARRIGO BROS, (CALIFORNIA) (2005)

and food supplements (Photo 44). According to Felker, these companies are mainly artisanal and small-scale.

ETHIOPIA

According to Vigueras (2004) and Haile, Belay and Zimmermann (2002), cactus pear is well known in Ethiopia, where around 355 000 ha grow, including a cultivated area of 30 000 ha. Varieties with and without spines are grown, although there is a slow trend towards spineless varieties. Despite people's familiarity with the plant, current use is limited to eating the fruit. Cladodes are not eaten but typically used for cattle feed. Old and woody cladodes are used as fuel (Brutsch, 1997).

Following its introduction in the mid-nineteenth century, cactus pear became one of the more popular plants in northern Ethiopia, particularly in the Tigray region. For more than 50 years, the cactus pear fruit has been considered an important forage crop and a major source of income and food for peasant growers in the period from June to August. Cactus pear is an important part of the cultural heritage and a food resource for people in the Tigray region (Tegegne *et al.*, 2004).

The same authors point to the cactus pear's important ecological role in the region in combating desertification, for soil remediation, as a refuge and a food source for wild fauna, as well as providing fruit and cladodes for people, forage for cattle and biomass for energy. There is potential to develop the full range of products in Ethiopia (carmine from cochineal insects, juices, jams, medicinal products and cosmetics) and there is much to be gained from sharing the expertise and knowledge of Latin American producers.

This approach underpinned the joint FAO/Government of Ethiopia project on cactus pear production and utilization implemented in 2003–2005. The national counterpart for project TCP/ETH/2901 and TCP/ETH/2903 was the University of Mekelle (Tegegne *et al.*, 2004). Describing the outcome of the project, Vigueras (2003) commended the many workshops held in different parts in the country with the aim of promoting opportunities, adapting the cactus pear plant, processing fruit and cladodes to make them attractive to people and generally encouraging the uptake of these foods in the traditional Ethiopian diet.

Basic elements of cladode and fruit processing were taught through preparatory cooking and processing demonstrations. Much of this training was undertaken by local non-governmental organizations (NGOs). A pilot area was established in the Tigray region. At workshops, people from focus communities in Adigrat, Erob, Mehomi and Mekelle were encouraged to participate. Schools and women's groups were involved. The strategy included incorporating cladodes into the typical meals of the people and their communities. This was well accepted by participants, who showed interest in fruits and cladodes as a novel and alternative food. There was some resistance to the idea of people eating crops associated with livestock feed. The trainers' needed to use all their skills to encourage people to think differently and, importantly, to prepare the cladodes in a much more attractive way for human consumption.

Vigueras (personal communication)[6] confirmed that there was no industrial production and/or processing of cactus pear in Ethiopia. This is no longer the case, and project investment has encouraged local NGOs to promote small-scale enterprise development based on cactus pear. Fresh cactus pear fruit has always been eaten locally, and people have recently started eating fresh *nopalitos* as a vegetable. Although further opportunities exist for the production of cosmetics and cochineal

[6] Ana Lilia Vigueras, Departamento de Botánica y Zoología, Universidad de Guadalajara, Mexico, 2005.

PHOTO 45
Cactus pear sales in Mekelle, Ethiopia

A. L. VIGUERAS (2003)

extracts, success hinges on the extent to which cladodes are adopted into the local diet.

Photos 45 and 46 show sales of cactus pear fruits in the streets of Mekelle and the workshop commissioned by the Tigray NGO 'Mums for Mums'.

ITALY

Italy is the world's second largest producer of cactus pear fruit after Mexico. According to Basile (2001), there are an estimated 3 000 ha of *intensive* plantations in the country with annual production of around 70 000 tonnes. Most are found in Sicily (90 percent) and commercial areas in the island have continued to expand in recent years. However, *traditional* production has declined and was estimated at 20 000 ha in 1998 (20 percent less than in 1989) when 25 000 ha of croplands were exploited.

PHOTO 46
Workshop participants tasting food samples containing cactus pear in Mekelle, Ethiopia

A. L. VIGUERAS (2003)

Intensive plantations are found in three parts of Sicily: the San Cono Mountains, to the southwest of Mount Etna in Catania and the Belice (*Bèlici*) river valley. San Cono is popularly known as the city of the cactus pear *(Cittá del fico d'India)* and on the Internet there is promotional tourist information for *fico d'India* in the region. This describes the range of products derived from this species of cactus pear and holds an annual festival to celebrate the crop.

Cactus pear fruit are typically eaten fresh in Sicily and other parts of southern Italy and in the main towns. Different coloured fruits are produced, including *Gialla* (yellow), *Rossa* (red) and *Bianca* (white). Yellow make up 80 percent of the total harvest, red 15 percent and white 5 percent. Different characteristics also affect processing. For example, yellow fruit are generally higher quality than red or white fruit. Red fruit have a higher sugar content and better flavour. Estimated per capita consumption is 2.5 kg in Sicily and 1 kg elsewhere in the country (Basile, 2001).

There is limited processing of the fruit in Italy but *nopalitos* are not eaten. According to Basile (2001), Italy produces jams, ice creams and liquors from *mostarda* (a spicy mix of fruit in syrup – see Photo 47). However, there is generally little demand for these products, which are found mainly in Sicily. Production is typically within the family or by the growers, and is consumed in the home. Much of the commercial production is small-scale and artisanal. Basile (2001) reported that online sales of these products were increasing and that electronic commerce could become an important means of boosting sales, obviating the need for large-scale distribution chains. No official information describing sector development has been reported and the industry is likely to remain provincial and small-scale.

MOROCCO

Opuntias are widely distributed across rural Morocco, with the exception of the Sahara Desert and the northern coastal mountains. Small commercial plantations can be found around most villages and the plant is used for living fences to protect crops or gardens mainly from stray livestock. In the Moulay Idriss region close to Meknes, at altitudes of 500–800 metres, there are *Opuntia* plantations for fruit production. Around 72 percent of plantations are found in the Sidi Ifni and El Kalaá regions, with average fruit yields of 14.3 tonnes ha^{-1} $year^{-1}$ (Maataoui, 2002). The fruit is highly valued in summer and provides a reliable

PHOTO 47
Liquor based on cactus pear on the Italian market

FIASCONARO, ITALY (2005)

source of income for peasant families. Even though *Opuntia* has been cultivated in the country for many decades, the fruit is considered of secondary importance and associated with traditional peasant communities. As a result, little has been done to promote and industrialize production (Walali Loudyi, 1998).

An estimated 45 000 ha of *Opuntias* are grown (Hilali, personal communication),[7] mostly in El Kelaa des Sraghna in central Morocco, close to Marrakech, and in Tiznit in southern Morocco. The most important species are *O. dillenii*, *O. vulgaris*, *O. compressa* and *O. ficus-indica*. The latter is the most widespread species. Both spined and spineless varieties are grown, with early- and late-maturing varieties that extend the season during which they can be marketed (Abedrrahman, personal communication).[8]

Locally sold fruit is available from July through to the end of September (see Photo 48). In addition to being eaten fresh, the fruit are also used as livestock feed/forage. There are few reports of other forms of consumption. Hammouch (personal communication)[9] reports that, in the south of the country, the fruits are sometimes dried and, although no other forms of processing are undertaken, there is interest in exploring opportunities for new products. An NGO recently formed by women in Tiznit province has begun to produce jams, seed oil and other products from the plant.

As Hammouch also reported that cactus pear flowers were valuable for honey production, it would make sense to develop apiculture as a subsidiary industry to cactus pear fruit production. This is already happening in the Tiznit region, where apiculture relies on cactus pear plants as forage for bees. In southern Morocco, tender cladodes have been ground and used as hair conditioners for many years. There is no information on the scale of cochineal production in Morocco, if any.

Growing interest in cactus pear production was highlighted at the Conference on Cactus Pear, held in Ben Guerir in 2004.[8] In addition, there is ongoing work at several Moroccan universities on the use of different parts of the plant. For example, the University of Settat has conducted studies to characterize the pigments of orange and red cactus pear fruits (Maataoui, 2002). There is also interest in studying uses for mucilage. Researchers at the Faculty of Science of Ibn Tofail University in Kénitra have studied the

PHOTO 48
Marketing cactus pear fruit in Morocco

E. CHESSA, MOROCCO (2004)

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7 Said Hilali, Faculté des Sciences et Techniques, Université Hassan Premier, Settat, Morocco, 2005.

8 Ait Hamou Abedrrahman, Chef du Service de la Production Agricole, DPA, El Kelaa des Sraghna, Morocco, 2005.

9 Hind Hammouch, Laboratoire d'électrochimie, de corrosion et de l'environnement, Faculté des Sciences, Université Ibn Tofail, Kenitra, Morocco, 2005.

use of aqueous extracts of cladode as iron corrosion inhibitors (Hammouch *et al.,* 2004).

Boujghagh and Chajia (2001) state that much remains to be done to promote the crop in Morocco. It is highly prized as livestock forage and the authors suspect that many cattle, both domesticated and wild, have survived the innumerable droughts to have afflicted Morocco thanks to this plant. In Morocco and other countries that have suffered (and continue to suffer) successive years of drought, the plant holds out the prospect of food and economic security to communities that may face growing climate change challenges, with less rainfall and less certainty for rainfed cultivation. Studies should begin by exploring existing genetic variability, leading to the selection of varieties for the different products that can be derived from the plant. This should be followed by small-scale processing suited to rural communities and markets for the products that are developed.

MEXICO

Mexico is the country with the largest number of small- and medium-size enterprises making products from cactus cladodes and cactus pear fruit. The plant's great diversity and Mexico's tradition of eating different parts of it have continued to encourage industrial utilization in the country. The country leads international development of the plant and its products.

Large areas of Mexico are covered by wild and/or cultivated cactus pear, distributed widely across different climatic zones. Areas where the cactus pear grows provide potential for the development of home-based, small-scale and/or microenterprises to produce, process and sell a range of different products for domestic consumption, as well as for export. Small-scale and home-based enterprises are particularly valuable for resource-poor people.

In Mexico, cactus pears grow in three types of area: in the wild, in family gardens and in commercial plantations. Wild lands are found mainly in the Sonora Desert in the states of Sonora, Baja California Sur, Baja California and northern Sinaloa. These areas continue into Arizona and parts of California in the United States. Other wild lands are found in the Chihuahua Desert in the states of Chihuahua, Coahuila, Nuevo León, Tamaulipas, Durango, Zacatecas, San Luis Potosí, Jalisco, Guanajuato, Querétaro and Hidalgo, continuing into New Mexico and Texas in the United States (Corrales and Flores, 2003). Although wild plants occupy hundreds of thousands of hectares, their utilization and consumption is limited.

Family cactus gardens are found in many parts of the country where wild plants grow naturally, including Zacatecas, San Luis Potosí, northern Guanajuato, Jalisco and Aguascalientes. Originally, cactus pear fruits for eating were gathered from wild plants, with family gardens cultivated alongside them. Although this dual system of exploitation continues to the present day, commercial plantations have expanded and replaced much of the once common wild harvesting. Family gardens produce fruit and *nopalitos* for household consumption and for small-scale trading in village and city markets. These crops are also used to prepare traditional foods, such as jams, *colonche*, *melcocha,* cactus pear fruit cheese and others. Clearly, *nopalitos* have become part of Mexico's traditional cuisine, and not only in rural communities. Small-scale agro-industries are found in most areas and produce a range of artisanal products, such as liquors, sauces, jams and other foods.

As a result of population growth, increased wealth and demands for more and higher quality, family gardens have gradually become incapable of meeting market demand for cactus pear fruit and fresh *nopalitos*. This has provided opportunities for the emergence of commercial plantations to replace family gardens, sometimes in the places where family production once dominated. For example, Milpa Alta is Mexico's leading *nopalito*-producing area. According to SAGARPA (2004), the annual production of *nopalitos* is 563 443 tonnes and per capita annual consumption is around 6 kg, making *nopalito* the country's sixth most commonly consumed vegetable. Mexico exports processed *nopalitos* in brine or pickled to Europe, Canada, the United States and the Pacific Basin countries. Sauces and jams made from *nopalitos* are produced commercially, with diversification into food supplements, capsules, tablets and powders and a range of cosmetic products.

Mexico is the world's biggest cactus pear fruit producer, with 72 500 ha of fruit farms producing a variety of coloured fruit: yellow, white, red and orange. Fruit is grown mainly in the states of México, Hidalgo, Puebla, Zacatecas, San Luis Potosí, Guanajuato, Jalisco and Aguascalientes and, to a lesser extent, Nuevo León and Tamaulipas.

Despite the great variety of products available from fruits and cladodes, the proportion of the crop that is processed remains low. Corrales and Flores (2003) emphasized profitability as the basis for industrialization. It may be that supplies of raw materials are insufficient for sustainable commercial production. Other factors, including harvesting and transport costs and distance from markets, also hinder commercial exploitation.

Opportunities for cochineal production continue to raise issues – for and against industrial development. Although future activities remain uncertain (location, scale, etc.), this has not deterred a number of companies from producing carmine from cochineal. Del Río-Dueñas (1995) suggested that cochineal red had regained the interest of artists and artisans, and that the future was bright.

PERU

According to Flores-Flores (2004) the area planted with cactus pear varied during the period 1982–2002 and planting intensity has been cyclical. Planting increased in the period 1994–2000 and decreased to 2 499 ha in 2001. The following year, planting rose again by 7.92 percent. The average yield of fruit during the period was 6.15 tonnes/ha. This is relatively low compared with other countries, mainly because of inadequate phytosanitary control and poor harvesting and post-harvest practices. In recent years, the largest production area was 2 974 ha in 2000, and the smallest was 2 050 ha in 1980.

A leading use for cactus plantations is for producing cochineal. Peru is the world's largest producer, with 90 percent of total production. The industry is dependent on the estimated 35 000 ha of wild plants growing in the mountains. More recently, intensive cultivation of cochineal has begun in coastal regions of the Department of Arequipa (Barbera, 1999). In 2004, Flores-Flores (2004) estimated that 26 250 ha of cactus pear fruit plants were used for cochineal production, 15 000 ha of which were in the Department of Ayacucho (56.8 percent of national output). This was followed by Huancavelica (26 percent) and Arequipa (10.18 percent). The same author confirmed that cochineal was produced from extensive areas of wild plants of very diverse morphotypes, separation distances and ages, as well as from the living fences used to protect the many small fields that make up traditional family land holdings.

The density of wild plants varies but averages around 1 770 plants/ha. From wild stands, collectors typically obtain 40 kg/ha/year of dried cochineal from natural infestation. With improved management techniques, including artificial infestation, sanitary pruning and other measures, these same plants could produce up to 200 kg/ha of dried cochineal (Flores-Flores, 2004).

Cochineal insects are collected in the mountains by many thousands of women and children, and this accounts for more than 90 percent of annual export volumes. Around 27 companies export cochineal, carmine and lakes.

Cactus pear in the mountains is typically a multipurpose crop: for harvesting, cochineal and fruit. Flores-Flores (2004) is of the view that this multipurpose approach is a mistake as it is impossible to manage the crop well enough to produce the highest standards and yields of either cochineal or fruit required by markets. The focus should be placed on producing fruit to meet market standards. A commercial value-chain approach was designed in which the main participants would be growers, technical advisors, commercial operators and consumers, with market access through self-service stores.

The strategy for boosting fruit quality was to focus on management, harvesting techniques, storage and transport, as well as on the investment required for fruit collection centres and the need to maintain the interest of growers/fruit collectors and to improve field operations. Key supermarket chains were invited to participate, in view of their demand for high-quality fruit. Fruit harvesting was modified to ensure that the fruit was handled carefully with minimum damage and delivered to fruit collecting centres. Here the fruit was sorted by size and colour, cleaned and the spines removed, before being waxed, labelled and packed for transport by road to markets in Lima.

Since 1999, there have been considerable efforts to boost domestic fresh fruit production. Following the initial trial period with small growers and technical agents, numerous small-scale marketing enterprises were established and have formed networks that continue to operate autonomously and collectively to the present day.

Despite successful fresh fruit development and the continuing success of the largely traditional cochineal harvesting industry, no substantial agro-industries have been established based on fruit.

SOUTH AFRICA

Swart and Swart (2003) estimate that South Africa has 1 500 ha of commercial cactus pear plantations with an annual output of around 15 000 tonnes. Zimmerman (personal communication)[10] reports that, in 2005, the area cultivated for cactus pear fruit production was approximately 2 000 ha and, for forage production, approximately 525 000 ha. In 1988, this was 814 000 ha. During the summer

[10] Helmuth Zimmermann, CACTUSNET–FAO, 2005.

of 2003/2004, 848 tonnes of cactus pear fruit were sold in South Africa's 16 main markets. While there are still significant informal markets for fruit, the quantities traded are difficult to estimate.

Sales of cactus pear fruit from wild plantations (i.e. land covered with invasive cactus pear plants that have not been cultivated), such as *O. ficus-indica* (with spines), are around 30 000 tonnes. Fruits are sold at the roadside and in the shanty towns, mainly around Port Elizabeth, Grahamstown, Uitenhage, Fort Beaufort in the Eastern Cape and Polukwane (formerly Pietersburg). South Africa's exports an estimated 10–20 tonnes/year of cactus pear fruit to Europe.

Until 1930, almost one million hectares in the country were covered with cactus pear, chiefly in the Eastern Cape and Limpopo provinces. At that time, these plants were considered an environmental issue. These were poor areas and local inhabitants typically depended on cactus pear and wild animals for food. Although people also consumed cladodes, in the end they abandoned the land because they could not survive on cactus pear. Industrialization encouraged people to move to the towns in search of work and they took with them their tradition of eating cactus pear. Their descendants continue to enjoy cactus pear and generally object to paying high prices. Zimmerman reports that, prior to the 1930s, people also made soap and other products from cactus pear fruit but that these skills have become largely lost in modern society. That said, the tradition of making food, jams, candies and syrups at home continues, and many of these goods are sold in the streets during festivals or in local markets. Small groups of cactus pear farmers have started to consume *nopalitos*. Small-scale artisanal production has begun and *nopalitos* can be bought in packages in local markets.

South Africa's popular spicy condiment, *atjar*, is made from green mangoes. The possibility of replacing green mangoes with cheaper cladodes has been explored, adding flavours and aromas to mask the differences. Some successes have been reported, particularly in reducing costs, as cactus is considerably cheaper than green mangoes.

Potgieter (personal communication)[11] reports that there are microenterprises in rural areas (e.g. the Karoo) producing jams, syrups and dried peels for sale in health food stores and alongside main roads. A number of small-scale artisanal producers have become established. For example, one producer in Limpopo province began making jams from fruit and packaging cladodes for eating and selling them in local markets. This used around three tonnes of fruit per year.

Syrups are typically made from fruit harvested from invasive plants because they are more abundant and cheaper. Syrups are prepared by boiling the juice and pulp to the desired consistency and can be prepared with or without sugar. They are dark brown in colour. On a larger scale, peel from cactus pear fruit can be dehydrated and exported for the manufacture of medicinal products.

In South Africa, processing of cactus pear products is at a far lower level than for other agricultural materials. However, there is considerable interest in adding value to waste streams from cactus fruit production, using the lower grade fruit, peel and other materials that are rejected by mainstream markets. *Opuntias* are considered to have useful potential for agro-industry.

TUNISIA

Since the early 1900s, various strategies have been adopted to reduce erosion and desertification in northern Africa (Nefzaoui and Ben Salem, 2001). Many different species, including *O. ficus-indica* f. *inermis*, have been planted, some of which provide livestock feed in times of drought. According to Selmi, Khalfaoui and Chouki (2002), there are between 400 000 ha and 500 000 ha of cactus pear plants in Tunisia. In the Zelfene region of Kasserine province, there are an estimated 16 000 ha of commercial plantations for fruit production.

The principal use of *Opuntia* in Tunisia today is forage for livestock. Although small quantities of fresh fruits are eaten, there is no fruit processing and no use is made of cladodes. However, there is interest in learning more about the species and the products that can be manufactured from them. There is also interest in boosting the productivity of cactus-growing areas to provide higher quality fruit. Additional commercial areas could be planted.

With the support of the Secretary of State for Scientific and Technological Research, a workshop was held in the Zelfene region for small-scale producers, private entrepreneurs and other interested people. The workshop aimed to raise awareness of the potential for cactus pear production by using modern production/processing technologies. The workshop focused on agronomic practices (fertilizer application, irrigation, pruning, *scozzolat-*

[11] Johan Potgieter, Limpopo Department of Agriculture, Agricultural Research Services, Polokwane, South Africa, 2005.

ura, etc.), post-harvest techniques, good storage requirements and marketing opportunities.

OTHER COUNTRIES

Cactus pear grows successfully in many other countries of the world. There is growing awareness of the plant's potential to provide food for people, feed for livestock and employment from the manufacture of cactus products. *Opuntias* grow mainly in arid areas where it would be difficult to grow alternative crops. In addition to the countries already mentioned, large areas of cactus pear can be found in Brazil, Cuba, Egypt, India, Israel, Spain, Turkey and Venezuela. Basile (2001) also describes production in Algeria, Colombia, Greece and Jordan. In Brazil, the cactus pear is an important source of cattle forage.

Israel has plantations of cactus pear and manufacturers near Jerusalem produce juices from red fruit varieties. Juice containing a mix of cactus pear fruit and apple has also been produced, with a minimum fruit content of 15 percent. Research centres and universities, including Ben Gurion University, have been commissioned to explore the processing of different parts of the plant (Nerd and Mizrahi, 1999). One of the few studies on the usefulness of flower extracts contributed to improvements in the treatment of benign hyperplasia of the prostate. Results are promising according to Jonas *et al.* (1998). The University of Jerusalem has conducted studies on the use of mucilage as a stabilizer for food emulsions (Garti, 1999).

In Turkey, cactus pear has been classified as an underutilized crop, which grows wild in many parts of the country (Karababa, Coskuner and Asay, 2004). The same authors confirmed that there are currently no commercial plantations or product-defined varieties. Plants are typically found in isolated groups or around private homes. Most plants are spiny and produce orange-yellow fruit, eaten locally as fresh fruit. Traditionally, they are sold in the streets, with traders peeling them for buyers to eat straight away. To date, there is no information on research initiatives for either breeding or marketing. However, groups of researchers at the University of Mersin are exploring the potential of cactus pear.

Mousa (personal communication)[12] states that, in Egypt, the area cultivated with cactus pear for fruit production has increased since 1994 when there were 650 ha and production was 10 233 tonnes. By 2002, this had grown to 2 548 ha and 29 442 tonnes. Most plantations are old and are found in the Nile Valley. There are currently no cactus pear production industries in Egypt, although technical interest exists in some universities (Zagazig, Cairo and Suez Canal), where applied research is under way. Labib (personal communication)[13] reported that there has been no real change in recent years with regard to exploiting the crop. Back in 1996, Labib had established 'Cactus Land', the first commercial plantation with a homogeneous cactus pear cultivar (cv. *Ofer*) similar to the Italian *Gialla*. Once harvested, cactus pear fruit are sent in bulk to the market and sold peeled on the street through large numbers of vendors.

Singh (2003) reports that, in India, a number of cactus pear species grow wild in arid and semi-arid regions. Small quantities of cactus pear fruit are eaten in season, the plant is used as a living fence and is grown as an ornamental plant in urban gardens. However, a few years ago various new clones were introduced as the result of a collaborative project between India and the United States. The aim was to introduce cactus pear into central India to exploit its potential as a living fence, food for resource-poor people and feed for livestock in adverse environments. According to the same author, project results have been promising and the new clones provide a basis for establishing low-input commercial industries in arid/marginal lands.

While there are small plantations of cactus pear in the southern Spanish province of Murcia, consumption of the fruit in Spain is minimal. In the Canary Islands, cactus pear provides the basis for the production of cochineal on commercial-scale. In recent years, researchers at the Polytechnic University of Cartagena and University of Murcia have studied the characteristics of red cactus pear pigments based on *O. ficus-indica*, *O. stricta* and *O. undulata* taken from cropping areas in the Murcia region (Fernandez-Lopez *et al.*, 2002).

In Venezuela, utilization of *Opuntia* fruit is restricted to the consumption of fresh fruit because of difficulties with post-harvest management. However, research is ongoing at Simon Rodriguez University in Carabobo province, mainly into using *O. boldinghii* pigments as natural colorants (Viloria-Matos *et al.*, 2002).

[12] Tamer El-Sayed Mousa, Agriculture Faculty, Suez Canal University, Ismailia, Egypt, 2005.

[13] Sameh Labib, Faculty of Medicine, Cairo University, Egypt, 2005.

A number of countries have shown interest in the cactus pear plant, hoping to exploit its considerable potential by investing effort and raising interest in this relatively under-exploited and under-appreciated crop. The plant has an extensive habitat and will grow where other food crops would fail. It also has the potential to help mitigate hunger in resource-poor parts of the world. When managed well, cactus helps to stabilize soils and prevents erosion in arid areas. Agro-industrial ventures based on cactus could provide employment and income. Collaboration among countries, such as through the CACTUSNET–FAO/ICARDA network – sharing knowledge, vegetative materials, technology and expertise – would benefit many people throughout the world. Further information is available at: www.cactusnet.org.

Chapter 10

Development of value chains and networks based on *Opuntia* spp. production

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The results obtained from two FAO technical cooperation projects (TCP), conducted jointly by FAO and host governments and completed in 2002 and 2004 respectively, illustrate some recent activities to develop and utilize *Opuntia* spp. A number of alternatives were proposed for adding value to cactus cultivation.

TCP/ERI/8923 AND TCP/ERI/2802: TECHNOLOGY TRANSFER OF CACTUS PEAR (*OPUNTIA* SPP.) PRODUCTION AND UTILIZATION

The aim of the first phase of the project (TCP/ERI/8923) was to strengthen and develop the Government of Eritrea's capacity for the domestication, improvement and total utilization of cactus pear plants by providing new technologies and technical assistance, training and planting materials. The second phase of the project (TCP/ERI/2802) was intended primarily to complete earlier activities, carry out a technical review and make recommendations to strengthen production, utilization and control of *Opuntia* spp.

The project confirmed that cactus pear is the fruit with the highest consumption rate in Eritrea during the summer months. For instance, an estimated 8 tonnes per day are consumed in the city of Asmara, excluding consumption by farming families in the surrounding areas. Consumption is limited to the mountain plateaus. In some Eritrean cities there is *no* consumption at all.

Most fruits are obtained from wild plants and, to a lesser extent, from plants cultivated in family gardens or grown as a living fence. The phytogenetic resource base is strictly limited. Only two varieties with little difference between them were found in the market. However, the project identified a spineless variety in a remote region, which was evaluated for further reproduction in the near future.

The fruit has specific economic significance in terms of market volume and demand for labour, which has immediate value for boosting employment (to harvest and sell it on the streets). Harvesting is carried out mainly by children and marketing is the responsibility of women and children – a group of workers with no impact on the formal economic sector.

Moreover, information on the potential benefits of cactus pear is scarce, and rural communities are still keenly aware of the plant's invasiveness. Cladodes are used for animal feed (for goats, sheep, camels and donkeys) although they are not normally used on a regular basis. However, irregular use can lead to abuse and/or over-utilization that could eventually result in soil degradation (Fuentes, 2002 and 2004).

The project provided intensive technology transfer support and training for researchers, technicians, students and farmers. More than 540 people received up-to-date technical knowledge through seminars, workshops, short training courses and participation in conferences, round tables and/or fieldwork.

The project recommended including the cactus pear crop in the national food security strategy. Project recommendations also included: promoting cactus pear as a natural resource and a potential new food crop; agro-industrial exploitation of fruit and cladodes; and exploring the possibility of exporting fresh fruit and other products. This entails the development of value chains, including the production of food for humans and feed for livestock, as well as processing to make foods, cosmetics and nutraceuticals (see Chapters 6 and 7).

TCP/ETH/2901 AND TCP/ETH/3002 – CACTUS PEAR (*OPUNTIA FICUS-INDICA*) PRODUCTION AND UTILIZATION IN TIGRAY

The objective of the project was to strengthen and develop the national authorities' capacity for domesticating cactus pear, improving its productivity and encouraging its use as a food source. The aim was to enhance food security through technology selection, technical assistance and training, introducing new plant materials as the basis for food trials and for the exploitation of cochineal as a natural colorant.

Opuntia spp. is a familiar plant in many parts of Ethiopia, especially in the Tigray Region in the north of the country, where it is traditionally used by the local people. After it was introduced into the country around 1850, it spread quickly because of favourable edaphic and climatic conditions and the absence of natural pests and diseases. However, unsuitable harvesting methods have helped to spread the species, particularly in marginal soils, on mountain slopes and in uncultivated areas. Farmers use it as a living fence, to combat erosion or to protect family gardens, and harvest the fruit for home consumption and the cladodes as feed for livestock. The country is estimated to have more than 300 000 hectares of wild cactus pear plants and 30 000 hectares of cultivated plants. The resource is underutilized and people remain largely unaware of its potential.

Cactus pear fruit becomes the main source of income and food for many people in Tigray during the period from June to September. The fruit is sold on the roadside and in villages in cactus pear regions. The main beneficiaries of these informal markets are children, who do most of the harvesting, and women, who are responsible for selling. Although the fruit is eaten fresh in large quantities, there are significant losses resulting from the inaccessibility of plant stands, poor harvesting practices and little or no understanding of good post-harvest handling practices.

A key project activity was to provide technical training to technicians, students and farmers. More than 550 people received training on a range of topics through seminars, practical classes, fieldwork, conferences and workshops, or by sharing the information produced. Many of the trainees were quick to transfer knowledge to others in their home communities (Photo 49).

Project recommendations included the need to design an appropriate strategy for developing and maximizing the use of cactus pear in the community. This should be followed by the development of agro-industrial value chains to link the crop in the field to customers in the market, on every scale. A further recommendation encouraged: production and consumption of the fruit and young cladodes as vegetables, jams, juices and sauces; improved techniques for boosting its use as forage; and the production of soaps and cosmetics. All this could improve food security, generate employment and increase the income of local people. In addition, the introduction of cochineal could lead to the development of a natural colorant industry. How-

PHOTO 49
Training women's groups in the preparation of meals based on *Opuntia* cladodes, Mekelle, Ethiopia

A. L. VIGUERAS

ever, this would be contingent upon prior risk analysis concerning the introduction of pests, as well as genetic materials for testing productivity and eventual reproduction.

GUIDELINES FOR THE AGRO-INDUSTRIAL UTILIZATION OF *OPUNTIA* SPP.

One of the biggest challenges facing developing countries is how to generate sufficient income and produce enough food in rural areas. Horticulture serves an important function in rural communities by increasing incomes, improving food security and reducing malnutrition based on the high nutritional and commercial value of horticultural products. Unfortunately, many constraints remain, including:

- limited technical knowledge of production methods;
- limited extension services:
- low prices, poor product preservation and inadequate marketing systems;
- poor transport systems and logistics;
- limited access to credit;
- limited access to land;
- highly variable climatic conditions, including irrigation/water supply.

POTENTIAL FOR THE DEVELOPMENT OF *OPUNTIA* SPP. CULTIVATION

The various species of the genus *Opuntia* originated in Mexico and Central America. In these regions and elsewhere *Opuntia* has become an important part of people's lives because of its abundance and multiple uses. In Eritrea and Ethiopia, for example, consumption of the fruit is generally low and comes mostly from wild plants. During the rainy season, the fruit is sold in urban areas and is eaten regularly, thereby increasing and stabilizing food supplies. Fruit is sold through informal street trading channels. Widespread consumption demonstrates the plant's social acceptability in the cities and among farmers and other rural dwellers.

However, perceptions concerning the plant's value vary and conflicts of interest may arise. In some places, it is considered an invasive plant, despite its multiple benefits and uses. In other places, particularly in the highlands and at the limit of normal propagation, the cactus pear is appreciated as a source of fresh fruit and livestock forage. Productivity comes from an understanding of crop management in the field, which is dependent on location, plant density and cover. Failure to follow such basic rules means that the plant will continue to be grown under less than favourable environmental conditions, leading to further land/cover degradation, lower productivity of land/crops and the associated risks to dispersed people and livestock as they move in search of forage. Risks of this kind are more severe in times of drought. To understand and manage this process, and to be able to consider cactus pear as both a valuable natural resource *and* a versatile agricultural product, it is essential to show people how to control, manage and exploit it – *innovation is required.*

General considerations

Many cactus pear cultivars do not have spines but rather hairs, which are really small spines. However, spines/hairs are useful when the plants are grown as a living fence. The ecological consequences of uncontrolled spread of these spiny types are a concern, considering the rate of spread when they are introduced, for example, as was done in Australia. There, biological methods were eventually used to control the plant. Spiny cactus pear management is a serious issue and requires constant supervision to determine size, and to evaluate and define suitable methods for integrated control and/or use of the plant.

Both introduced cultivars and wild cactus plants can be used for cultivating and producing fruits. Introduced cultivars typically produce fruits that are more palatable and/or more acceptable to people, but wild cactus pear may provide the basis for the development of *formal* cropping, beginning with the selection of native lines with commercial potential, combined with the use of improved introduced varieties.

Marketing objective

Commercial, technological and/or social programmes similar to those developed in Mexico may be of interest to other countries, for example, using spiny cactus varieties to control land/soil erosion. Similarly, cultivars of spineless varieties can be introduced to provide higher yields, higher quality and easier processing. Crop areas are expanding in Algeria, Chile, Korea, Morocco, South Africa and Tunisia in the light of market opportunities. According to Mondragón-Jacobo and Pérez-González (2001), crop areas have also increased in developed countries, such as Israel, Italy and the United States.

A key to developing sustainable chains and networks for value-added cactus pear production is to identify the requirements of the end-user or consumer. Production systems of this kind enable small-scale farmers to participate; they promote the role of the producer, boost access to resources and integrate the producer into the post-production value chain. More value is retained and this typically includes greater access to credit, improved technologies and other key inputs, ultimately boosting productivity. Networks encourage cooperation between buyers and sellers, enabling them to discuss points of common interest and to gain some understanding, and ownership, of the value chain as a whole.

Developments of this kind can be seen from FAO technical cooperation projects to support cactus pear production in Ethiopia and Eritrea, with an understanding of the fundamental role of industrial planning leading to better utilization, cultivation and processing/industrial production of cactus pear. However, a number of areas continue to require attention:

- irregular supplies of raw materials, which are mainly climate-dependent;
- seasonality of markets;
- poor quality fruit;
- heavy crop losses resulting from poor post-harvest practices;
- high perishability.

As a result of such constraints, most of the fruit produced in developing countries is consumed locally. Few low-quality production systems are able to meet export quality standards. Use of *Opuntias* as forage is limited and farmers generally ignore its potential as an animal feed supplement and/or source of moisture, even though both feed and water are critical for livestock during the dry season. The use of cladodes as human food and the industrial exploitation of the whole plant remain to be developed in most countries. However, the potential clearly exists, as agro-industrial exploitation in Mexico has demonstrated in recent years. Producers in other countries could do the same.

General agricultural development issues

Arid zones are found all over the world. They are typical of many developing countries and feature in 24 of what have come to be called the least developed countries (LDC), in which one-third of the world's population lives. While in times past, when there were fewer people, people and their ecosystems were bound by a shared sense of resilience and sustainability, this is no longer the case, and marginal lands are increasingly subject to damaging and irreversible exploitation, including land/soil degradation.

There is also the challenge of making sometimes vast tracts of marginal land productive, in spite of the natural limitations of biological productivity and the difficulty of establishing viable communities. Regardless of which approach is adopted to resource use, it will lead to improved living conditions for millions of people as a result of a stable economy based on markets for high-quality products, providing employment opportunities that may help to curb migration. By choosing the appropriate crops and production systems, even marginal land can become productive to some degree.

In many developing countries, agricultural production is severely restricted by scant, highly variable rainfall and a lack of modern agricultural inputs, such as improved varieties, fertilizers, agricultural machinery and pesticides. Further constraints include traditional land tenure systems, insufficient technical skills, lack of infrastructure, insufficient support services, poor access to markets, inadequate social facilities and limited integration between markets and services. Agro-industries continue to use antiquated, low-productivity technology, poorly skilled workers and inadequate management systems.

Drought is common in some parts of the world, preventing local people from growing crops or feeding their livestock on natural cover. In developing countries, wild forage and crop by-products are usually the main source of energy, protein, minerals and vitamins for livestock. However, they are generally insufficient in quantity to meet local or national requirements, forcing people to overstock land beyond its carrying capacity. In addition, adverse climatic conditions may provide only forage of low nutritional value. Using *Opuntia* spp. as feed may help to overcome some of these shortcomings, although much will depend on circumstances.

Low productivity in countries like Eritrea and Ethiopia has led food processing industries to develop slowly, and these countries continue to depend on imports of even the most basic foods. Although many could be produced locally, insufficient low-cost raw materials for processing jeopardizes the industrial sector. Much could be done to promote small-scale agro-industries and self-sufficiency, to preserve, store and/or prepare products for domestic and foreign markets, and to provide for out-of-season consumption.

Considering the cactus plant's natural distribution and the extensive areas it covers, the importance of informal markets and the plant's intrinsic

PHOTO 50
***Nopalito* harvest in Mexico**

A. RODRÍGUEZ-FELIX

value as human food, it is surprising that the crop has not received more agro-technical attention in food-deficit countries. Cactus pear has proven to be an agronomic and market success in vast semi-arid areas of Brazil, Mexico, Morocco, South Africa and Tunisia (Nefzaoui and Ben Salem, 2001). Cactus production could potentially be included in all agricultural development programmes (Photo 50).

Cactus pear is a perennial crop requiring minimal care compared with other popular fruits like oranges and bananas. The plant tolerates poor soils, is adapted to rainfall of 400–600 mm/year, is typically found growing on mountain plateaus and its soil nutrient needs can be easily supplemented by low-cost organic fertilizers such as livestock manure or wood ash. In more productive environments, it is possible to introduce improved multipurpose varieties and growing systems to obtain fruit, forage and tender cladodes for consumption as a vegetable (Mondragon-Jacobo and Perez-Gonzalez, 2001). The more specialized forage systems can produce up to 100 tonnes of edible produce a year. Improved harvesting and post-harvest techniques for fruit and cladodes will boost output. Much depends on the planning and investment provided, and much of this has to come from external sources: local people in poor communities are usually unable to provide the required resources. This is the role of the public sector, working in partnership with the donor community, people-friendly NGOs and, importantly for long-term sustainability, the private sector.

The introduction and dissemination of crops/cultivars in suitable areas could meet domestic and foreign demand for high-quality fruits. Depending on the areas planted and quantities of fruit produced, small-scale agro-industries could be established to make use of fruit that is not sold fresh (because it is lower quality, damaged, surplus, etc.), as well as waste materials. Cactus pear rarely competes for land with other fruits. More important crops, such as mango, banana and orange, are generally grown on irrigated land. Although guava prospers on non-irrigated land, it has different environmental demands.

Cactus pear can be grown on mountain plateaus with average annual rainfall of 500 mm or less, where the agroclimatic environment suits plant growth. Planting should be on semi-arid land, i.e. secondary land where there is limited potential for tree crops. This helps to avoid competition and makes more effective use of marginal lands to exploit the potential of cactus pear. Room is required for crop expansion, and the site should have relatively easy access for road vehicles to transport the fruit from the field to packing centres or markets. Spiny cactus pear can also be grown as a living fence around other crops or livestock, providing both protection and a source of income.

The perennial nature of cactus pear and the time required to obtain a marketable crop make it is essential to establish working agreements between the different sectors of the value chain in order to keep people interested and informed and to continue promoting commercial opportunities. The main focus of networking is to:

- build the technical capacity of national experts through training;
- make use of the abundant information available in other countries;
- make use of modern technologies that can be adapted to local conditions;
- encourage small-scale entrepreneurs to become involved in industrial development;
- establish self-sustaining enterprises that will provide a stable supply of foods, regular employment and a reliable income.

Technical assistance

In response to requests from several FAO member countries concerning the conservation and/or productive use of arid areas, FAO has provided technical assistance and support for the development and use of cactus pear as a source of livelihoods for local communities. The FAO International Technical Cooperation Network on Cactus (CACTUSNET) was formed in 1993 with the objective of promoting the potential economic, ecological and nutritional benefits of producing this crop. It was recognized that cactus pear:

- served an important role in subsistence agriculture in **arid regions**, with the production of fruit, forage, vegetables and natural colorants;
- provided the basis for establishing **sustainable agricultural systems** with the potential to increase the productivity and economic viability of small- and medium-scale farms, which would derive direct benefits from producing and selling high quality fruit and cladodes;
- required **limited inputs** (low energy, little water and reasonable soils) to obtain satisfactory yields, giving it high agronomic significance in arid lands;
- helped to **prevent soil degradation and desertification**;
- provided large quantities of raw materials for processing by agro-industries, including wastes recycled for use as fuel and/or as a source of biogas or ethanol.

FAO has supported national and global initiatives in Angola, Argentina, Chile, Italy, Mexico, Peru, South Africa and Tunisia in the form of technical meetings, congresses, symposia and workshops. Through its technical cooperation programme, FAO has helped to improve cactus pear cultivation in Argentina, Eritrea, Ethiopia, Iran and Namibia. Cuba and Pakistan have shown interest in similar developments.

The utilization of cactus pear calls for a commitment by interested countries and the development of strategies and programmes in what may be conflicting historical and sociocultural contexts, with varying impacts from the introduction and/or improved cultivation of cactus pear. Substantial investment funds may also be required.

PARAMETERS AND SCOPE OF THE APPROACH

The experience of many countries has shown the importance of developing the cactus pear industry as part of an approach centred on value-added chains and networks. A value-added network can be defined as a set of steady relationships among the often wide array of producers, organizations, institutions, companies and traders involved. This approach ultimately focuses on consumer preferences and trends, as well as market behaviour and requirements, to underpin the productivity of the value-added chain.

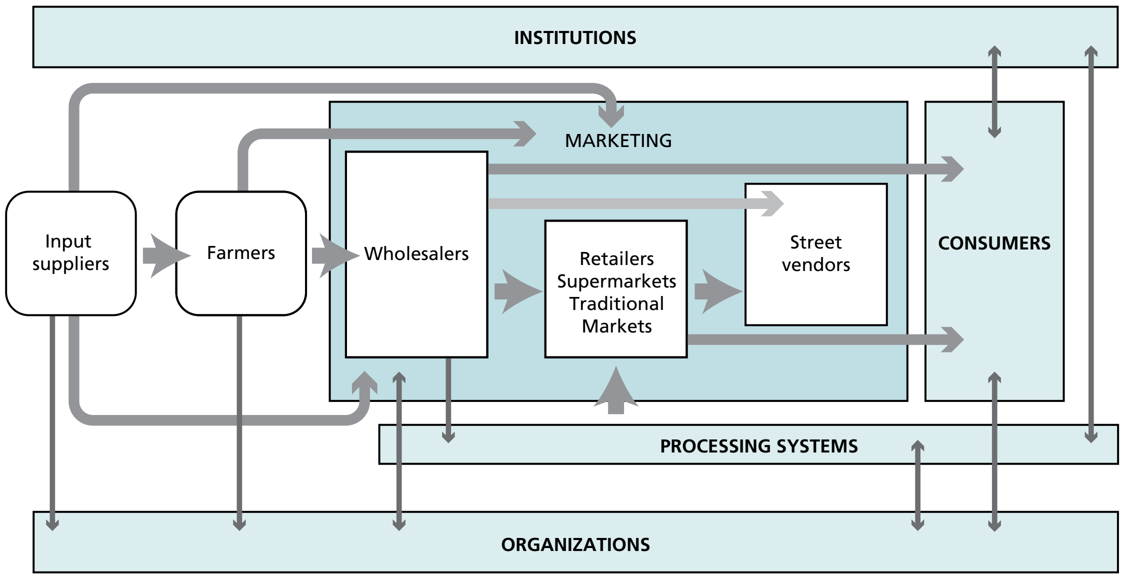
Value-added networks are based on creating value and sharing the benefits equitably among all the participants involved. This provides for rapid and efficient product differentiation in response to changes in consumer demand (see Figure 22). The networks consider the commercial potential of the different products in domestic and export markets. Examples of such products were described earlier.

Investment in *Opuntia*-related industries is dependent on regular supplies of raw materials, on the seasonality of production and, most importantly, on the perishability of fruit after harvest. Processing industries should be planned on the basis of quick turnaround: field to factory/packing centre to market. Such systems are available and the required technology and equipment can be procured. Modern cactus pear industries have been established in many countries and the same techniques could provide the basis for industrial development in other countries that may be *exploring* or *planning* crop production.

Small-scale enterprises should be promoted in parallel with developing market opportunities. This helps to ensure a smooth economic transition from subsistence to commercial activities in value-added networks based on cactus pear. Development of the private sector is closely linked to the country's economic progress and its institutional framework. Successful agricultural production stimulates economic growth in rural communities, and small-scale enterprises are an important element in the transformation of society. As a rule, they enrich people and help to alleviate poverty. Increasing wealth brings additional resources, boosts employment and raises incomes.

The sale of cactus pear fruit directly augments the total *value* of the cactus pear crop within the community. This leads to development of the local microeconomy, with family/home-based processing and trading for the supply and distribution of cactus pear products. Cactus pear agro-production/processing is typically less affected by climate variability than are crops more susceptible to periods of drought, and employment and income are more secure.

FIGURE 22
Marketing chain for cactus pear fruit based on institutions and organizations



Source: Adapted from Parada and Flores (2004).

Opuntia spp. plants are also less dependent on external inputs, including the funds typically required to pay for seed, fertilizer, soil preparation, planting and other costs associated with annual crops. Cactus pear is a perennial crop so, even though annual inputs are required (for example fertilizer), timing may not be crucial.

Satellite imagery can be used to pinpoint the best places for initiating cactus pear cultivation and to locate the infrastructure required for production, transport and processing. Maps can be generated, together with weather charts and data from field trials, to support decisions on where to begin and where to expand into new lands as production increases. Applied R&D, in cooperation with farmers, processors and/or traders, is an ongoing requirement. This is typically a government responsibility and helps in dealing with such issues as diseases, soil nutrients and the exploitation of new cultivars.

The most appropriate approach for domestic industries can be identified by means of national workshops, demonstrations, radio broadcasts, R&D trials, international conferences and marketing efforts. This will tend to favour the development of small-scale farms and processing units. This approach will open up opportunities for the use of existing but underutilized phytogenetic resources. It will help diversify agricultural production/processing based on small-scale enterprises and cactus pear use. It will also contribute to rural–urban understanding/linkages that may boost food self-sufficiency. Production models of this kind lead to the development of a knowledge base that includes technologies, practices, management tools and commercial networks for products that ultimately enhance domestic and international markets.

A proposed line of action is based on observations, activities, results and recommendations of the FAO technical cooperation projects. Cactus pear is a perennial crop that could be included in the exploitation of *naturalized* plant resources in the wild. This may include introducing new cultivars, techniques, management practices and institutional capacity within the value chain. In brief, this will include:

- cultivation;
- harvesting;
- post-harvest handling;
- processing;
- packaging
- integrated and diversified agro-industrial utilization;
- marketing.

The key to the introduction of new varieties and techniques will be training for farmers and others interested in exploiting the crop's potential. This may require the establishment of national teams, including networks of rural and urban leaders. In such a context, there are major opportunities for enhancing food security by incorporating cactus pear into local diets. Processing the fruit and vegetative parts of the plant will make value-added products more readily available to people. It will also provide the basis for the manufacture of nutraceuticals, functional foods and cosmetics, and this will help boost farmers' incomes and local services. The production of animal feed from cactus pear will help not only to raise the income of livestock producers but also to alleviate the sometimes chronic feed deficit suffered by livestock in arid and semi-arid areas.

As a perennial species, cactus pear is less subject to the vagaries of sporadic rainfall, and forms an important link in the value chain with more valuable products such as meat, wool and leather. A further benefit is that livestock manure and cactus pear by-products can be mixed and used for biogas production. First though, it is essential to increase people's technological independence, and this comes from training. National teams can be formed to deal with: technology adaptation and transfer; information collection; and providing farmers and others with technical assistance for cropping, processing and adding value. Such trained teams can provide leadership and encourage and motivate people within the industry to adopt recommended technologies and models of agro-industrial development.

EXAMPLE OF A PROGRAMME FOR THE AGRO-INDUSTRIAL DEVELOPMENT OF *OPUNTIA* SPP.

The overall objective of the programme is to develop the production, management and diversified use of cactus pear on a sustainable basis. This will include: the production, processing and marketing of cactus pear resources; increased consumption of products; diversification of commercial activities; improved domestic markets; export prospects; employment and income generation; and improved household food security. The specific objectives of the programme are:

- **Technical resources**: to increase national technical capabilities (technicians, institutions, practices, etc.), including the formation of a national team to promote the development of value-added networks.
- **Technical information**: to develop a national repository of applied knowledge and technical capacity to address the multi-disciplinary requirements of value-added networks.
- **Technical capacity**: to train producers, processors and other stakeholders in all aspects of the value chain to ensure that high-quality agro-industrial products are delivered to national and international markets.
- **Value-added networks**: to increase the sustainability of production and utilization systems and provide technical resources and market information to help establish value-added networks for cactus pear (with the aim of 'formalizing' the crop to provide income, employment and food security).

The direct beneficiaries will be community members, particularly women and children, who will be encouraged to participate in the value chain in different ways and at different stages of development. Beneficiaries will include people currently harvesting wild plants and newcomers involved in processing, livestock farmers in search of feed and entrepreneurs. Entrepreneurs are essential because they will invest and bear the risks associated with production, processing, marketing and utilization. The indirect beneficiaries will be the families and communities related to the direct beneficiaries. Finally, the environment, the horticultural sector and the national economy can also expect to benefit, although it will be challenging to quantify to what extent.

There are a number of strategic key components for the development of value-added networks for cactus pear cultivation:

- Cactus pear farmers must be integrated and organized in order to help resolve political and technical problems arising from agro-industrial development, providing guidance and advice for the integration of small-scale producers, processors and traders that will benefit rural communities. Success will be built on access to improved varieties and the introduction of integrated systems of production, processing and control within the industry. Cost-effectiveness will be essential.
- Critical inputs must be available for the production and commercial utilization of cactus pear. These will probably be *supervised* by the public sector (ministry of agriculture or equivalent) but provided on the basis of mixed public–private services. Essential tools, services and inputs must be supplied

in a timely and equitable manner. Support should include protection against distortions in production and markets (at least in the initial stages of establishment).

- Competent personnel is essential. Trained staff are required for all stages of development and for all aspects of cactus pear value-added networks. This will include entrepreneurs willing to invest in agro-industrial production and processes and in the required plant.
- A coherent institutional framework that includes public mechanisms to strengthen cactus pear production, processing and marketing is required. Legal and administrative frameworks are also needed to encourage the establishment of value-added networks and the development of agro-industries.
- Support for an open and well-defined policy for technological development based on human capital should be encouraged. This will cover all critical components, including the participation of experts and external knowledge sources, as well as increased national capacity for the applied research needed to support cactus pear. The transfer and development of new technologies should take into account local cultural norms and any social, economic and marketing issues that may arise.
- High-quality plant materials will be required. These will be cultivars that add value to existing cactus pear production networks, from production through to the consumer. This may include: larger cladodes and/or fruit of a better colour; the use of improved cultural and/or post-harvest practices; and plant disease management and control – all based on the planning required for adding value.
- It will be essential to evaluate cultivation practices. An evaluation of production from wild and cultivated plants based on statistical analyses will help determine the impact of different agricultural practices and of improved varieties on quality, characteristics, yield and other technical and economic variables.
- Introduced varieties must be tested jointly with farmers and organizations at selected trial sites, with careful evaluation of the varieties in terms of yield, functionality, multiple use and quality (see Photo 51).
- Workshops should be held in the field and in rural communities to help demonstrate new varieties, alternative growing systems and recommended cultivation, harvesting, processing and utilization techniques, including animal feeding.

PHOTO 51
Coloured cactus pear fruits

FUNDACIÓN CRATE, CHILE (2005)

- The unit costs of plantations, crop maintenance, harvesting, storage, transport, processing and marketing need to be evaluated to identify opportunities for integrating value-added networks for cactus pear production into the country's general economy.
- Technical trials should be undertaken to determine optimal conditions for storing cactus products: methods of storage and preparation of packaging materials, management and transport. This should include comparisons of locally available packaging materials.
- Marketing surveys should be conducted in urban and rural areas to ascertain demand for fruit and other products from wild and/or cultivated plants.
- The promotion, design, establishment and development of pilot-scale commercial packaging centres are required. This is where the quality of cladodes and fruit will be determined and where materials will be handled, sorted, washed, disinfected and classified by size and colour before being marketed. Simple operations of this kind can be organized in strategic locations near cactus growing communities and integrated into the local agricultural calendar.
- It is recommended to design, develop and establish pilot-scale processing plants and mobile processing units that will help to add value to fresh and processed products. This will better prepare them for markets and the likely competition from similar goods from elsewhere. Transparency, with demonstrations and training in support of market quality, should be made an integral part of the pro-

gramme for the development of value-added cactus pear networks. This will ensure that economic benefits reach the host community.
- A national team of technicians will be required. These technicians will be selected and trained to organize workshops, provide technical assistance and attend conferences, international congresses and symposia, and will be capable of preparing demonstrations for the media on all aspects of cactus pear promotion and use.
- The role of the market in the success of cactus pear value-added networks should be recognized from the outset. It will be a key component of success, especially for international markets. The structure of the domestic cactus pear marketing chain will have to be strengthened according to institutional and organizational demands, many of which will not be immediately apparent. A measure of organizational flexibility will be essential.

Basically a project for the development of productive cactus pear value chains consists of the following four components and activities:

1. Development of technological and managerial capacity.
2. Studies of basic information.
3. Technology transfer for the development of cactus pear networks.
4. Promotion of value-added networks for cactus pear.

1. Development of technological and managerial capacity

- Development of technologies and the capacity to manage them.
- Establishing a national coordinating committee.
- In-service training for the technical management team.
- Designing a programme of applied research, technology transfer, training, extension and commercial development.
- Building the technological, managerial and commercial capacity of farmers, cooperative structures and small-scale enterprises and identifying the support services, minimum infrastructure and promotion required to encourage entrepreneurs to participate in the development of value-added networks for cactus pear.

2. Studies of basic information

- Monitoring of advances in cactus pear technologies, including market penetration, mapping to identify priority growing areas, control and management options, and ecological aspects.
- Studies of cost–benefit and economic resources in order to identify the management and integrated utilization activities suitable for, and in line with the needs of, the different regions.
- Identification, characterization and evaluation of technologies and practices, tools, equipment and resources that are currently in use or have potential for improving the management and integrated use of cactus pear.

3. Technology transfer for the development of cactus pear networks

- Applied technological R&D on key topics for integrated management and utilization of cactus pear.
- Technology transfer to promote and optimize family gardens for the production of fruits, vegetables and forage from cactus pear.
- Technology transfer for the semi-commercial production of forage and for animal production.
- Technology transfer for the viable production of cochineal, including demonstration plots.
- Technology transfer for non-food products and agro-industrial production – to include medicinal substances, nutraceuticals, cosmetics, chemicals and artisan crafts.
- Technology transfer for the production of bioenergy from cactus pear.

4. Promotion of value-added networks for cactus pear

- Evaluation of national markets and institutional frameworks, the potential capacity and establishment of marketing plans, with policy support for the industrial development of cactus pear networks.
- Enhanced training to boost people's self-confidence, including awareness-raising, information management, outreach and training, credit services, support for cooperatives and vocational training, extension and information-sharing activities, including demonstrations and farmer field days.
- Support the development of commercial and viable cactus pear networks, including links with the business sector, improvements in marketing systems and more information on

markets, support for microfinance institutions, implementation of policies, logistical plans, support services and commercial and retail structures.
- Promotion of small ruminants under mixed-feed systems.
- Promotion of viable small-scale agro-industries for processing cactus pear fruit and cladodes.
- Promotion of viable small-scale agro-industries for various non-food products from cactus pear, including pigments from cochineal, cosmetics, medicines, nutraceuticals, bioenergy and crafts.
- Development of management support systems, including adequate laboratory resources for monitoring the quality of cactus pear products.

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Agro-industrial utilization of cactus pear

Cactus pear (*Opuntia* spp.) makes a valuable contribution to the food security and nutrition of people throughout the world wherever water is scarce. The plant is highly versatile and, in addition to feeding people, it is widely used for livestock feed, burned as fuel and used to protect the environment in which it is grown. *Opuntia* spp. provides the basis for viable rural communities.

There are more than 300 species of the *Opuntia* genus, which originated in Mesoamerica and subsequently spread throughout the world, adapting to different agro-ecological zones and to the demands of people, to preferences for traditional foods and culinary tastes, and to the constraints imposed by different agricultural practices.

The versatility of *Opuntia* spp. makes it particularly useful to small-scale producers and provides the basis for exploiting the species in applications ranging from home-grown produce prepared in the home, to small-scale and large-scale production/processing value chains. Agro-industrial manufacturing enables cactus products to be packaged and shipped over long distances, stored safely and sold in supermarkets wherever there is a demand for these foods. For smallholders, production of the resilient cactus species provides opportunities for wealth creation and improved living conditions for rural communities.

This publication confirms the importance of cactus production and explores the opportunities for boosting productivity throughout the value chain from farm to consumer. The ten chapters cover the biological, technical, socio-economic and industrial potential of this relatively well-known, but sometimes little appreciated crop.

This easy-to-follow guide is based on research and development work by institutions, mainly in Latin America, and the practicalities of artisanal and commercial agro-industries linking producers with consumers. It describes harvesting through to post-harvest handling, storage and delivery to the processing plant, as well as the equipment and technologies required for different scales of production. It also highlights the extraordinary resilience and value of *Opuntia* spp. and the contribution it can make to agro-economies and agro-environments wherever it can be grown.

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