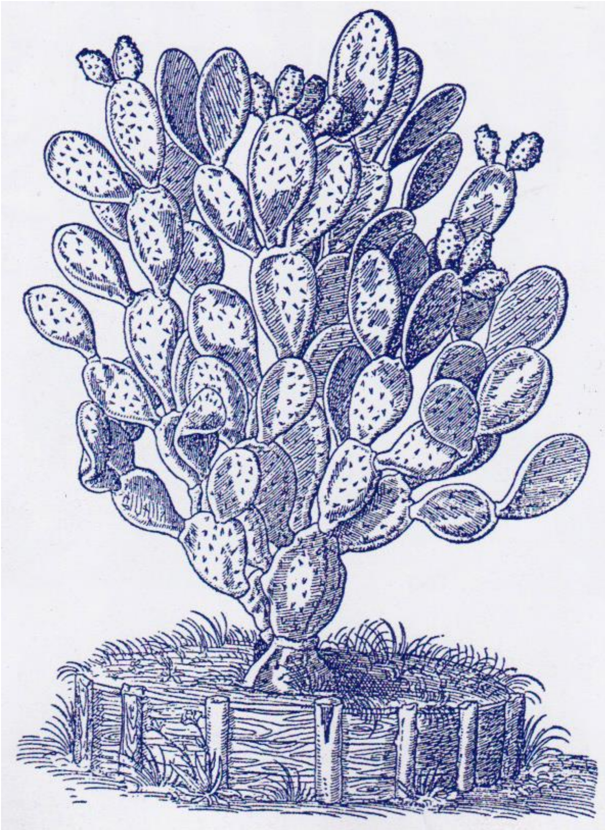


PRODUCTION PROTOCOL OF PRICKLY PEAR

CIHEAM Bari - Mediterranean Agronomic Institute of Bari
Via Ceglie, 9 - 70010 Valenzano (Bari) - Italy
Web: www.iamb.it Phone: +39 080 4606 111

Contents

PREFACE

This protocol is prepared by the local and international experts of the project JOSME "*Enhancement of Jordanian SMEs inclusiveness, competitivity and sustainable innovation*" implemented by CIHEAM Bari in Jordan and funded by the Italian Cooperation. This information is provided for the guidance of the food chain SMEs as producers (individual and/or gathered in associations and cooperatives) and any others that deal with this fruit.

The overall expected outcome for this protocol is to produce a quality and safety product enhancing the added value in the domestic and international markets.

Common name	Scientific name	Family name	Variety
Prickly Pear	*Opuntia ficus-indica* (L.) Mill.	*Cactaceae*	*Local*

1. INTRODUCTION

1.1 ORIGIN, CLASSIFICATION, GENETIC RESOURCES

The cactus pear (*Opuntia ficus-indica* L. (Mill.), Cactaceae, is a species originating on the plateau of central Mexico. Together with maize, gourd, agave and some legumes, for centuries it has constituted the alimentary base of the local populations (Turkon, 2004).
In the course of the 16th century, it was brought to Europe by the Spanish conquistadores.
At first the cactus pear was grown in the gardens of the nobles and subsequently in cultivation, naturalizing itself quickly and becoming, in the whole Mediterranean basin, an essential element of the natural and agrarian landscape. Widespread in both hemispheres and on all the continents, it is a constant presence in the livestock and human diets of the aboriginal populations of North Africa, the Middle East and southern Europe, in particular Sicily (figure 1), Greece and southern Spain.
Opuntias are cultivated, according to the more reliable estimates, on a total area of about one hundred thousand hectares for fruit production and more than a million hectares of land devoted to pasture or to the production of forage destined to bovine and ovicaprine fodder in Mexico, South America (in Brazil more than 300 thousand hectares of Opuntia are cultivated for forage production), USA (Texas in particular), North Africa and Western Asia (the so-called WANA Region), the Horn of Africa and South Africa. In Ethiopia, the cactus pear ("Beles") is cultivated in Tigray and it can grow even at 3,000 m a.s.l. where cactus fruits are gathered from wild stands that feed local people for 2-3 months.

Figure 1: Cactus pear plantation in Sicily

In each of these regions of the globe, derivative products are worked up from the processing of both the fruit and of the cladodes, and they are destined for human consumption or for non-alimentary uses (Barbera et al., 1995). The Opuntias have a strategically important role in the diet and therefore in subsistence agriculture of the semi-arid regions where their cultivation is widespread. Only recently, from the 19th century inItaly and the 20th century in the rest of the world, have they been cultivated on a large scale for commercial purposes. These are two very different cultivation and cultural models but of equal importance.

For fruit production, the Opuntia ficus-indica is cultivated, in specialized plantations, in Mexico - in the northern central region (Zacatecas, Saltillo, Durango, Saint Luis Potosí, Aguascalientes and Guanajuato) and in the southern central region (Puebla, Mexico, Tlaxcala and Hidalgo) - on more than 70,000 hectares. In Chile it is found in the Metropolitana region on a little more than a thousand hectares; in Argentine there are specialized plantations in the regions of Santiago del Estero, Tucuman and Catamarca, covering a little less than a thousand hectares; in Israel, in the area of the Negev approximately 250 hectares of specialized plantations, in South Africa another thousand hectares of cactus pear in the Western Cape, the Northern Province and the region of the Ciskei. In the United States Opuntia ficus-indica is cultivated in California, in the Salinas plain on more than 300 hectares of specialized cultivation. Data are lacking on its diffusion in the North African countries, where it is estimated that not less than 50,000 hectares are under specialized cultivation (25,000 in Tunisia alone.

In Italy it is cultivated on a little more than 3,000 hectares distributed in the areas of Santa Margherita Belice (AG) and San Cono (CT), as well as on the south-western slopes of **Mount Etna (Biancavilla, Belpasso and Paternò) where it has received the acknowledgment of Protected Designation of Origin (PDO).**

Considering an average production of 10 tonnes per hectare on a world-wide scale, it can be estimated an annual production of a million tons derives from specialized plantations, while that from spontaneous plants and non-intensive cropping, common in many of the regions of subsistence agriculture where the species is present, must be enormously greater (Pimienta Barrios, 1990; Barbera e Inglese, 1993; Nobel, 1988 and 2002).

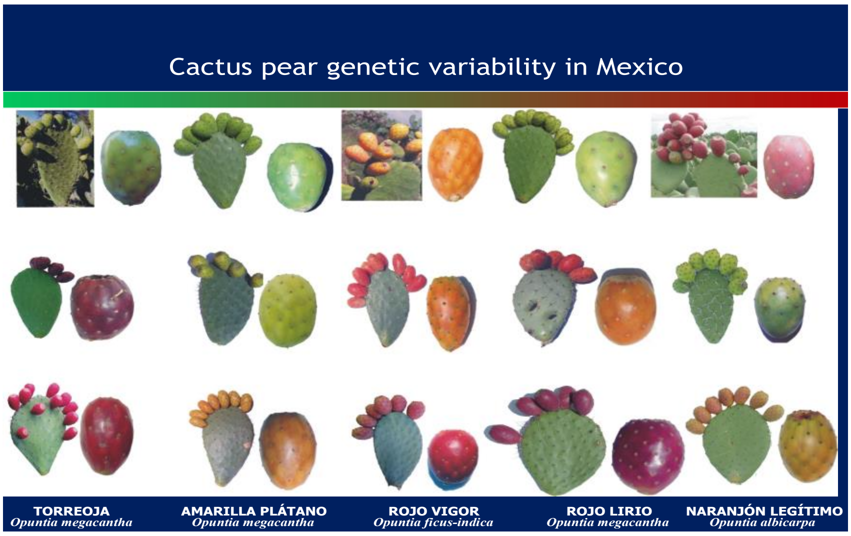


Figure 2: Genetic variability of Opuntia sp. pl. in Mexico

1.2 OPTIM SITE SELECTION

Opuntias colonize environments characterized by:

• mild winters (mean annual temperature > 10°C);

• an extended dry season which coincides with short days;

• summer precipitation.

These are the conditions of the environments where the species is native, while in the Mediterranean basin and in North Africa the dry season coincides with long days, high temperatures and fruit growth. This means that the plant has to copy with environmental conditions that are not similar to those of its native areas.
Prickly pear plants can tolerate very high temperatures without any negative consequences. Hower, 'tolerate' does not means that the plant like those conditions. Indeed, Crassulacean acid metabolism (CAM)[1] plants metabolism allows the plant to achieve maximum photosynthetic productivity with temperatures of 25°C and nighttime temperatures of 15°C; temperatures above 30°C led to reductions of up to 70% in photosynthetic activity. Temperatures below 0°C, even for 4 hours, cause irreversible damage to cladode tissue and fruit. The species does not perform efficiently in very hot areas and reduces its ability to produce fruit in areas where winter temperatures stay higher than 20°C. In these regions the plant is grown profitably for production fodder. In some areas it can become a weed, especially where seed germination can occur soon after the fruit has fallen into the ground.
However, interest has recently increased to Opuntia to combat desertifcation, especially with the low cost of production and high economic return. Opuntia plants are likely to play an essential role in sustainable agricultural systems of many arid and semi-arid regions.

[1] is a method of carbon fixation evolved by some plants in dry circumstances; that allows a plant to photosynthesize during the day, but only exchange gases at night.

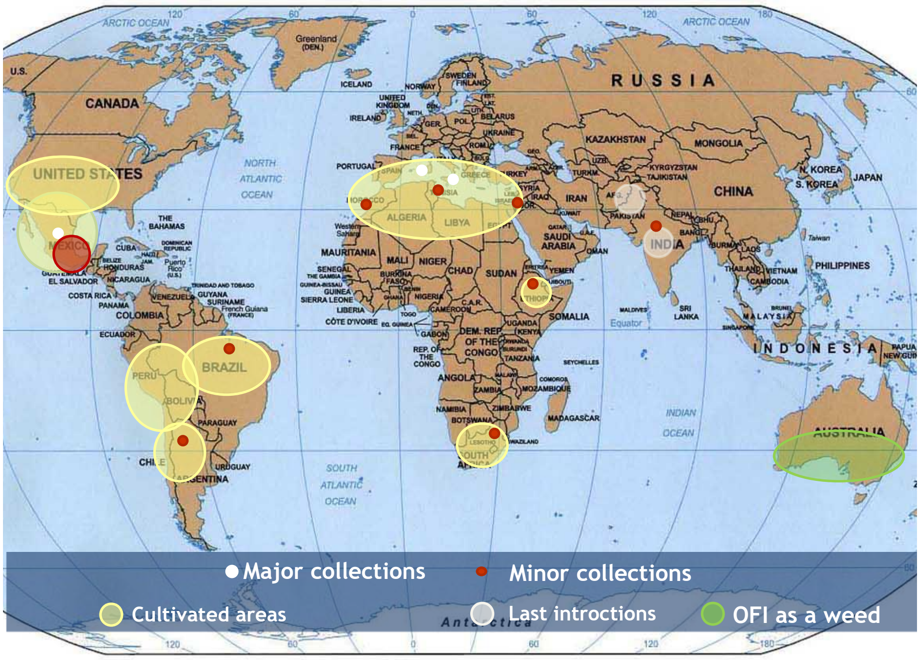


Figure 3: Opuntia ficus-indica distribution worldwide

1.3 RESPONSE TO TEMPERATURE

In its native highlands of Mexico, O. ficus-indica is grown in semi-arid areas, where annual rainfall is concentrated in summer during the period of fruit development. In the Mediterranean basin, the Middle East, North and East Africa, the dry season coincides with a long, hot summer, where vegetative and reproductive growth occurs. In the area of greatest biodiversity, the central plateau of Mexico (altitude 1800 to 2200 m above sea level) the annual precipitation is less than 500 mm, the average annual temperatures vary from 16°C to 18°C and the maximum daily temperatures long term for the hottest month does not exceed 35°C. The optimal nocturnal CO2 uptake range for O. ficus-indica is 25-15°C Day/night. Higher or lower day/night temperature ranges lead to a sharp decrease in carbon assimilation, resulting in poor plant growth and production and ultimately low crop value. High temperatures (>30°C) during the period of fruit development affect fruit shape if they occur during the early bud development stages of fruit growth and shorten the third stage of fruit growth, when most edible flesh growth occurs, leading to advanced and early ripening, with small fruit, low firmness and low sugar content. High temperatures during fruit development increase fruit susceptibility to low temperatures (<8°C) during post-harvest storage, thereby reducing post-harvest fruit storage and shelf life. On the other hand, daily temperatures below 15°C delay fruit ripening time and result in thicker fruit peel and lower soluble solids content and peel color. High temperatures are, in fact, one of the major constraints for high quality fruit production in areas with hot and dry summers. In fact, the optimum daily temperature for CO2 uptake decreases from 17°C in wet weather to 14°C after seven weeks of drought.

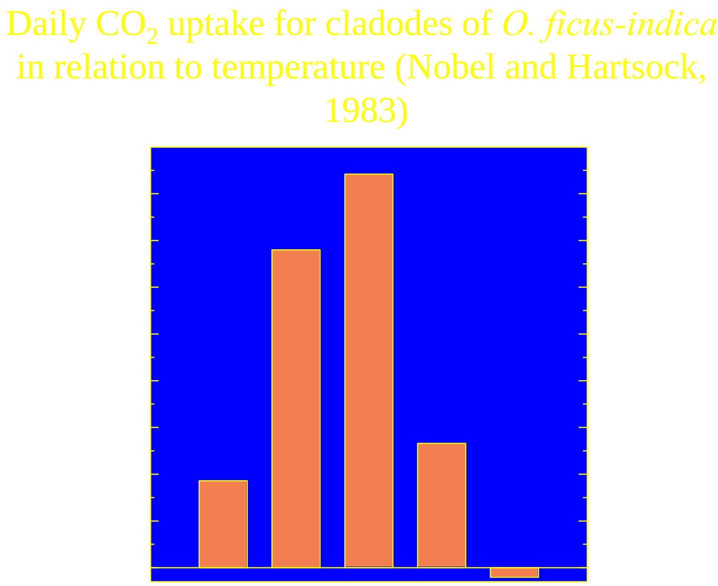


Figure 4: Opuntia ficus-indica response to light and temperature

1.4 SOIL

O. ficus-indica (OFI) can be grown in a wide range of soil types. It frequently adapts even to soils that are limited by continuous hard rock in the first 25 cm, or that are underlain by materials with a calcium carbonate content greater than 40% or that contain less than 10% by weight of soil. end. Sandy to sandy-loam textured soils is ideal for growing OFI, although it can grow well on heavier soils as well. OFI is very sensitive to lack of oxygen in the soil, but in very sandy soils, low water holding capacity and excessive nutrient leaching can occur. The plant prefers a neutral to slightly alkaline soil pH. The soil should be plowed to a depth of 60-80 cm, to ensure good drainage, alternatively the soil should only be cut with a chisel to improve drainage and avoid alteration of the soil profile. In sandy soils and weed-free soils, pre-planting operations might be limited to single holes in the rows.

Figure 5: Pre plant soil preparation for cactus pear orchards

Functional characteristics		Classes			
		S1 *Most suitable*	**S2** *Suitable*	**S3** *Less suitable*	**N** *Not suitable*
Minimum temperature	°C	> 3	> 3	> --3; < 3	< -5
Medium temperature	°C	18-23	15-18	10-15	< 10
Annual rainfall	mm	> 400	> 400	200-400	< 100
Texture		sandy to mixed		clay—silt	clay-silt
Skeleton		indifferent	indifferent	indifferent	abundant
Depth		indifferent	indifferent	indifferent	indifferent
Carbonates		indifferent	indifferent	indifferent	indifferent
Reaction	pH_{KCl}	5-8	5-8	5-8	< 5; > 8
Organic matter	%	< 0.5	< 0.5	> 0.5	> 0.5
Ca available		elevated	elevated	mean	insufficient
K available		elevated	elevated	mean	insufficient
EC_e [a]	$dS\ m^{-1}$	< 2	2-4	4-7	> 7
Subsuperficial groundwater		absent	absent	absent	present

[a] EC_e = electrical conductivity of the saturate extract of the soil

Table 1: Functional characteristics and classes of soil capacity for *O. ficus-indica* cultivation.

1.5 CACTUS IN JORDAN

In Jordan spiny cactus plantations were started 60 years ago as hedges around homes and orchards. The spineless cactus was later introduced and planted extensively under a sole cropping system in the semi-arid areas in the middle of Jordan (Nasr, Y. 2015). Khadari cactus which is also referred as Baladi is the common variety used by cactus farmers in Jordan other imported cultivars especially those are good candidates for export market are evaluated in research stations of Karameh and Mushqar by National Agricultural Research Center.

Figure 6: A commercial orchards in Dhiban, Madaba, Jordan (JoSME 2022).

The commercial area Planted to cactus is approximately 300 ha (JDOS 2020) and it increase from year to year, the crops is concentrated in Malih area in Madaba with an estimated production of 3000 tons, where farmers grow cactus for fruit production in rows using supplementary irrigation. Cactus is also planted under mixed plantation systems, intercropped with other fruit trees, such as fig and olive and as hedges around farms (Nasr, 2015). In Jordan cactus farmers needs to be trained and educated about the best post-harvest practices to add value to the cactus crop, which include sorting grading packaging and the possibilities for processing.

Figure 7: Cactus in mixed (olive and guava) plantations in Madaba (JoSME 2022).

Jordanian cactus farmers also need to be trained in adoption of appropriate cultural techniques to postpone flowering to extend the marketing period to September or October or to produce a second harvest, with fruits ripening between December and March and on the use of cactus cladodes as feed for animals especially in arid and semi-arid marginal areas where it is very hard to find forage for animals mainly sheep and goats. (Shaba Dhiban cooperative for agricultural development, personal communication 2022). The cactus pear offers an alternative as an animal fodder in communities living from livestock production where the availability of forage plants is minimal. Several studies have demonstrated that cactus (Opuntia ficus-indica f. inermis) cladodes (Vasta et al., 2008) have a good nutritional value, when used as supplements in small ruminant diets like sheep and goats which are the main livestock animals in the cactus area in Jordan.

Figure 8: Google arial photoaged picture of Cactus pear fields in Malih and ground picture of a cactus pear field in the same area (JoSME, 26-9-2022).

2. AGRICULTURAL PRACTICES

Little knowledge and sound experience on cactus pear cultivation and agricultural practices is known by commercial Jordanian cactus framers, since most of them consider cactus pear just need some little or no care and still gives high productivity especially in their arid areas (Shaba Dhiban agricultural cooperative and JoSME 2022). Even though some research on good agricultural practices of cactus was done by the Jordanian Agricultural research in the past two decades, internationally and by the end of the last century much more information has become available on orchard management and other cultivation aspects of cactus pear (Felker and Inglese 2003) which can be used to improve and expand the production of this resilient multipurpose crop to support small and medium framers in the arid and semi-arid marginal areas of Jordan.

Generally, increasing the crop value of cactus fruits (quantity and quality) are very much dependent on the adoption environmentally friendly good agricultural practices like irrigation, fertilization, pruning, thinning, pests and diseases control by the farmers that will mainly increase the crop quality and hygiene.

Cactus fruits are mainly marketed by farmers directly or through traders as fresh fruits in central markets using a polystyrene box of 7 to 9 kg locally. Even though the opportunities for export is very high there is no exporting of cactus fresh fruits outside Jordan.

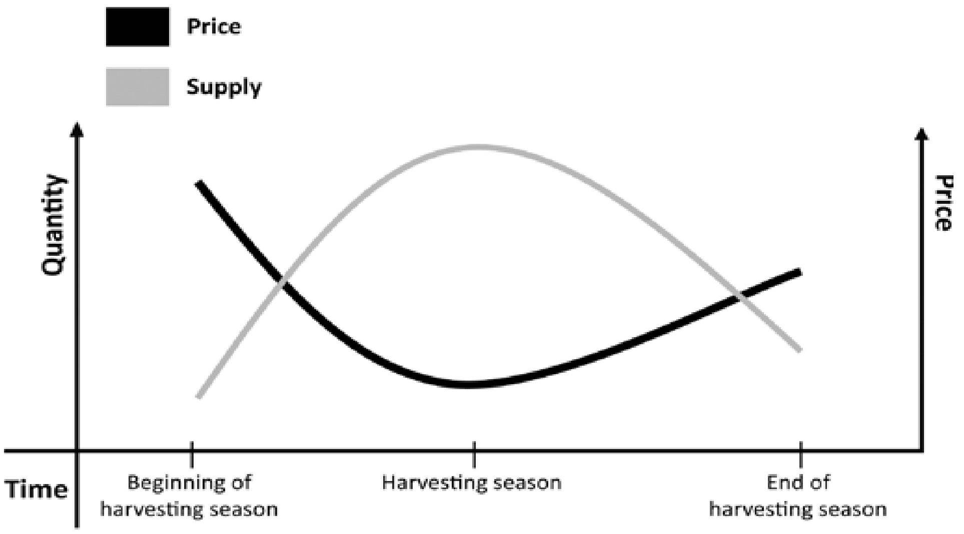


Figure 9: Simple description of marketing model of cactus in Jordan.

There is an opportunity for using cactus waste and cladode as animal feed which can give farmers new marketing.

Figure 10: Prof. Paolo Inglese from University of Palermo, Italy giving a training in the class and in the field for Jordanian Cactus pear farmers in Malih area near Madaba (JoSME 2022).

2.1 SOIL PREPARATION AND CLADODE MANAGEMENT BEFORE PLANTING

Soil preparation before planting is a critical factor for successful cactus pear: Recommendations include:

1. Remove perennial weeds before they become established as they compete strongly with the OFI plant, especially during the early stages of plant growth when it is weakly competitive.
2. Use a single-hole pant in weed-free sandy soils.
3. Check the drainage capacity of the soil.
4. Soil testing is recommended to measure soil salinity and texture.
5. Avoid soils with excess water or excess clay.

2.2 PROPAGATION AND PLANTING MATERIAL

The orchard is established using cuttings.

Recommendations include:

1. Careful selection of planting material, based on the age of the cut, cladode area left above ground (number and size of joined cladodes used as planting material), planting depth and planting time.
2. Dry the cladodes in partial shade to dry the cutting wound before planting the cladodes.
3. Disinfestation before planting, using Bordeaux paste or oxichloride.

Single or multiple cladode cuttings are used commercially for establishing orchards.
The area and dry mass of the planting cladode have a significant influence on the success of rooting and budding in the field.
The cuttings are composed of:

1. Simple one-year or two-year-old cladodes;
2. several cladodes consisting of a basal 2-year-old cladode placed under the ground and bearing two 1-year-old cladodes,

The use of simple cladodes has the advantage of reducing transport costs and facilitating handling during the planting process.
Multiple cladodes allow faster development and earlier fruiting than single cladodes after planting.
Another option is to plant more cladodes in each position, up to 3-4 single cladodes, to increase growth during the early stages of planting and create a favorable microenvironment for plant growth. However, this strategy involves a large amount of planting material, which increases field variability and also increases plant competition for light and soil resources

(water and minerals), ultimately resulting in reduced growth of simple cladodes and of the whole tree.
Mature cladodes from the middle part of the plant should be used for propagation.

2.2.1 RECOMMENDATIONS INCLUDE:

1. Use cladode with uniform appearance, visually free from defects, insects and diseases should be selected as plant material.

2. Use cladode with an area of 500 cm^2 or a dry mass of 70-100 g which allows good plant growth.

3. Cladode washed individually in the insecticide mixture with a soft brush to destroy all possible insects.

4. Take cuttings in late spring for planting soon after the rains. This will result in rapid and intense root development. Planting in late summer slows root system and canopy development and increases the risk of cladode rot, due to low winter temperatures and reduced daylight. Cladodes planted during the dry season are able to develop initial roots after planting, thereby reducing disease incidence during the wet season.

5. Plant the cladodes in an upright (vertical) position with the cut end down in the soil and at least 1/3 until half of the cutting is planted in an upright position below the soil surface.

6. Consider a hole depth of 50 cm; optionally fill the hole with cow manure or fresh soil by hand with 30 g of nitrogen.

7. Give one or two light irrigations (10 L/plant), soon after planting to promote root development, but do not over-irrigate young plants.

2.3 ARRANGEMENT AND SPACING OF PLANTS

Depends on field shape and size, environmental conditions, cultivar growth, orchard use, planting systems:

- Hedge systems with plants placed closely in the row (1.5m - 2.5m) and rows spaced 4-5m apart. This system is common in contour lines in hilly areas

Figure 11: Plant establishment with a single cladode with "ears" (left) or two cladodes (bottom right) and three cladodes (top right) a few weeks after planting.

Figure 12: Plant establishment procedures

- Squares or rectangles are arranged with plants trained on a globe, and well separated from each other are the most common planting systems ranging from 290 plants ha-1 (plants spaced 5 x 7 m); 333 plants ha-1 (plant spaced 5 x 6 m); 416 plants ha-1 (plants spaced 4 x 6 m).

Close spacing increases the number of fertile cladodes on a hectare basis, in the early stages of orchard life and results in continuous canopies which require high pruning are usually left on the ground in the aisle and eventually chopped mechanically.

Figure 13: Plantations of Cactus pear in Tunisia (left) and Sicily (right).

Most reproductive buds are located on one-year-old cladodes, so adequate production of these cladodes each year is required. Lower planting distance requires high pruning intensity and frequency. The reduced density facilitates cultural practices (fruit thinning, cockatoblastis spraying and harvesting) and contributes to improved fruit quality.

2.3.1 RECOMMENDATIONS FOR PRUNING MANAGEMENT

1. Leave no more than two daughter cladodes on a parent cladode.
2. In productive plants, 80% to 90% of one-year-old cladodes should produce fruit one year after formation.
3. two-year-old cladodes can be fruitful, but their contribution to plant fertility is limited.
4. Most plants reduce their production potential 20-25 years after planting. The rejuvenation of these plants can be considered as an alternative. This can be done by reducing the cladodes to 5-6-year-old cladodes. The pruned plants could produce two years after pruning depending on its intensity.

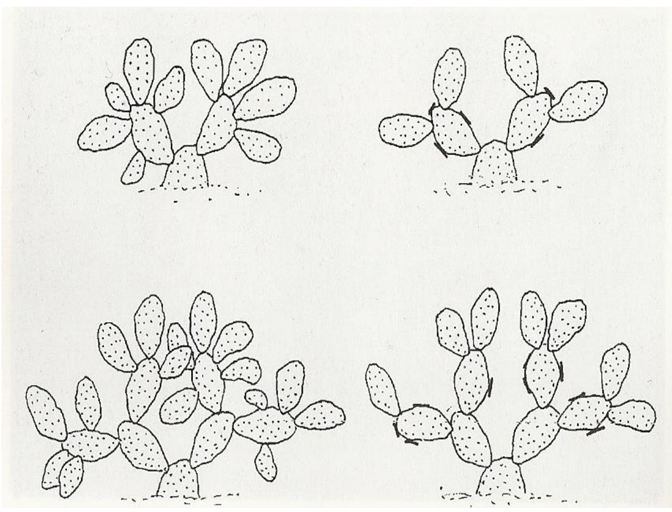


Figure 14: Size of newly developing cladodes, leaving no more than two parent cladodes

2.4 SOIL FERTILITY MANAGEMENT AND FERTILIZATION.

Fertilizer applications should be based on the results of soil analysis, which indicate the levels of plant nutrients in the soil, otherwise farmers can use the following fertilization scheme. Cactus farmers in Jordan usually use the same fertilization practices in their fields as they use in olive plantation mainly animal manure is applied, chemical fertilization is rarely used since it is expensive. However, only limited studies are available on planting time and nutrient management response of cactus pear for semi-arid regions, the response of cactus pear to supplementation of nutrients and other management practices is highly dependent on soil type and its fertility status. (Kumar, S. 2021).

Nutrient	*Year 1*	*Year 2*	*Year 3*	*> Year 4*
N	50	50	70	80
P	10	10	20	30
K	20	20	30	50
Mg	10	10	20	40

Table 2: General fertilizer recommendations for cactus pear fruit production where no soil analysis results are available (plant nutrient amounts in kg per ha per year), ICARDA, 2017.

Studies in South Africa also indicates the optimum soil nutrient levels for cactus pear fruit production for rainfed cultivation is as indicated in Table 2.

Element	*Optimal soil level (mg kg−1)*
Phosphorus (P)	20-30
Potassium (K)	80-100
Calcium (Ca)	> 400
Magnesium (Mg)	100-150

Table 3: Optimum soil nutrient levels for cactus pear fruit production (Potgieter, 2001 from ICARDA; Crop ecology cultivation and uses of cactus pear, 2017).

2.4.1 SOIL MANAGEMENT

1. Cultivation of the soil should be kept to a minimum in order to avoid damage to the superficial root system of the pear cactus and to preserve the structure of the soil;
2. Weeds can be mowed and left as mulch in the ground cover. This method reduces weed growth and retains soil moisture.
3. Chemical control can be achieved with paraquat and glyphosate (20 g l-1); care should be taken to avoid drift, as cladodes are extremely sensitive to herbicides.

2.5 IRRIGATION AND FERTILIZATION

1. Opuntia ficus-indica is a well-known drought resistant crop, but still requires irrigation to achieve optimum fruit size. This is especially true in areas without summer rains and where the annual rainfall is less than 300 mm, and when fruits ripen during the summer season or when no rain is available. Just 10mm of rainfall is enough to wet the soil in the root zone of the cactus pear, allowing the plant to use small amounts of rainfall effectively.
2. The water use efficiency (WUE)[2] of OFI is quite high, ranging from 3.0 to 4.0 mg DM g-1 H20, compared to about 1.3 for wheat and 1.4 for barley 0.5.
3. The total water requirement for OFI cultivation is met by 500-600 mm yr-1.
4. Lack of water before flowering reduces flower bud induction and fruit size.
5. Irrigation can be supplementary and it is necessary to obtain an accessible fruit size (> 120 g) if no rain (or less than 30 to 50 mm) occurs during the period of fruit development.
6. The economic value of the harvest (fruit size) can be greatly reduced before the plant shows an apparent symptom of water stress.
7. Irrigation alone cannot compensate for reduced size when there is a high number (>9) of fruits per cladode.
8. Irrigation cannot counteract the effect of very high temperatures as they affect the carbon exchange rate more than transpiration and always lead to reduced fruit growth and advanced maturity, even under irrigation.

2.5.1 IRRIGATION RECOMMENDATIONS

Irrigation is required:

- At the time of planting as an aid to promote root growth.
- During the early stages of fruit development (2-3 irrigations after flowering to 4-5 weeks after fruit set).
- Moderate watering in the last stages of fruit development.

Drip irrigation (two rowing lines) or localized micro-sprinklers properly managed, which cover a relatively large soil area with small volumes, respond to the characteristics of the Opuntia shallow root system.

[2] the ratio of water used in a plant to water lost by a plant through transpiration

2.6 FRUIT THINNING AND SPRING FLUSH REMOVAL (SCOZZOLATURA)

Thinning of the fruit is necessary to obtain a uniform and maximum size (greater than 120 g). Flower buds emerge in spring. Photoperiod and/or low winter temperatures may be the environmental cue for such bud initiation. Additionally, nutrients can also affect bud initiation, as exposing plants to nitrogen fertilization (using ammonium nitrate) can increase the number of buds per plant.

Most owers occur on terminal 1-year-old cladodes, and new cladodes usually develop on 2-year-old or even older cladodes.

Vegetative and reproductive buds appear contemporaneously in spring or early summer, when the spring shoot is suppressed to induce regeneration. Flowers usually develop from areoles arranged along the crown of the cladode, but the production of flowers from areoles on the flat surface exposed to the sun is common.

A cladode can produce 35 to 40 flowers; during abundant flowering under conditions of high potential evapotranspiration, each may lose ≤ 3 g of water per day-1, or 15% of its weight at the time of anthesis. The number of flowers for fertile cladode becomes more and more stable every year; it depends on the age of cladodes and is highest in one-year-old cladodes.

Fruit size varies among trees and depends on factors such as plant architecture and crop yield per plant and per cladode.

2.6.1 RECCOMENDATIONS FOR FRUIT THINNING

1. Regardless of the initial number of flowers on the cladodes There can be no more than 6-7 fruits left on each of the one-year-old fertile cladodes, because a greater harvest load leads to a sharp reduction in fruit size, even if the plants are irrigated.
2. All flowers born on the flat surface should be removed.
3. Thinning is done manually and can take place as soon as the spherical fruit buds are distinguished from the elongated vegetative buds but no later than 3 weeks after anthesis, otherwise no effect will be recorded at harvest.
4. In a dry environment without irrigation or rain during fruit growth, it is advisable to reduce the number of fruits to increase the fruit size. The reduction in the number of fruits can be obtained by reducing the number of fruits on each fertile cladode (<6 fruits) or by reducing the number of fertile cladodes (-30%).

2.7 SCOZZOLATURA

"Scozzolatura" involves removing all flowers and new developing cladodes to induce a second bloom which usually occurs a month later than the first. This practice allows the production of off-season crops, in September-October.

2.7.1 RECOMMANDATIONS FOR" SCOZZOLATURA"

1. Flowers must be completely removed.
2. At least 80% of newly developing cladodes must be removed.
3. Spring bloom removal of flowers and cladodes should take place no later than after sintering. The best periods are from the beginning of flowering (5% of flowers in bloom) to full flowering (50% of flowers in bloom).
4. The earlier the spring flush is removed, the earlier the flush will be.
5. Do not withdraw if daily temperatures are above 25°C. Otherwise, the plant will not produce flowers, only cladodes.

2.8 PESTS AND DISEASES AND THEIR CONTROL

There is no much information about pests and diseases of cactus and its effect in Jordan.
Two to three years ago an outbreak of newly introduced insect of cactus the cottony cochineal (Dactylopius opuntiae) occurs in northern parts of Jordan, no commercial cactus plantation presents in that area but farmers complain about this new pest and Ministry of Agriculture launch insecticide spraying campaign to contain and control this insect, most importantly is to prevent the spread of this insect to other areas where cactus present. Other insects like Mediterranean fruit fly that directly attacks fruit can be destructive reducing crop quantity and quality.

2.8.1 USED PESTICIDES

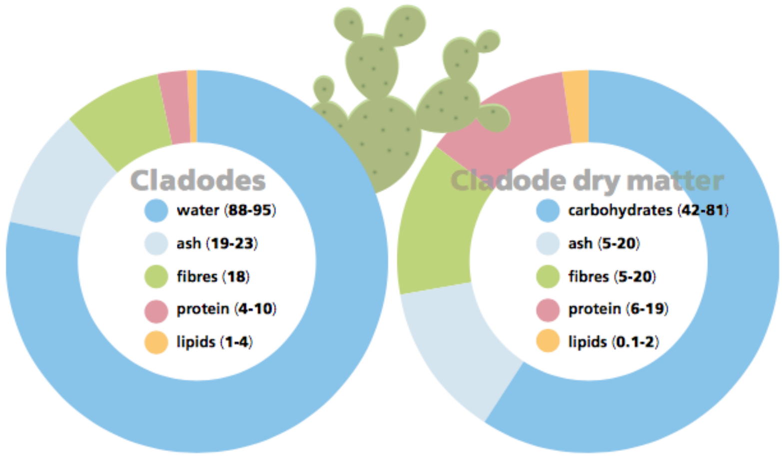
Farmers in main cactus production area in Madaba do not use any pesticides at all but Ministry of Agriculture use some insecticides to control outbreak of cottony cochineal in the north like Imidacloprid mainly.

3. FRUIT HARVEST AND QUALITY MANTAINANCE

3.1 HARVEST RECOMMENDATIONS

• Fruit harvest should take place when the outer color changes from green to yellow or red; at this stage, the color of the pulp is already formed and the soluble solids content is close to maximum, but the firmness is still sufficient to allow post-harvest handling and storage.
• The fruits should be harvested early in the morning in order to avoid excessive fruit temperature and reduce the discomfort of glochids moving away from the epicarp and to avoid harvesting.
• Ripening is generally progressive and therefore the harvest takes place in 2-3 stages and can be quite differentiated. The ripening rate is a function of the thermal conditions which, if characterized by high temperatures, induce very rapid and early ripening. If, on the contrary, it is below the necessary 18-25°C, ripening will be delayed and substantial changes in the

shape and characteristics of the fruit will be induced (lower pulp yield, less sugar and less color in the fruit). epicarp).



3.2 FRUIT QUALITY PARAMETERS

The marketable fruit must have:

- fruit weight not less than 120 grams,
- Soluble Solids content not less than 13°Brix[3] measured with refractometer
- Fruit firmness not less than 8 kg cm-2 measured with a penetrometer (8 mm tip).
- Percentage of fruit flesh not less than 55%;
- Fruit acidity ranging from 0.03 to 0.12%, expressed as malic acid).
- The nutritional value is equal to 15 kJ kg- of fresh digestible fraction.

3.2.1 SCIENTIFIC BACKGROUND

Fruit growth follows a double sigmoid pattern in terms of fresh weight; there is a pronounced gain in dry weight for the bark at stage I (0-40 days after fruit set, for the seeds at stage II and for the kernel at stage III of the fruit development period. Growth fruits and daughter cladodes involves a substantial translocation of stored carbohydrates from the basal cladodes.In fact, when more than six fruits develop on a one-year-old fruiting cladode, a significant importation of assimilates among the cladodes of different ages occurs, particularly in stage III of fruit growth.Young developing claodes apparently compete with the fruit - as indicated by their higher absolute growth rate.However, they become a source of carbohydrates at an early stage of their development, a period which coincides with the development of flowers or the earliest stage of fruit development Fruits become the main force of attraction at stage III.

[3] A measure (in degrees) of the amount of dissolved solids in a liquid via its specific gravity; used especially to measure dissolved sugar in fruit

Tab.1 Qualitative parameters for *Opuntia ficus-indica* fruit					
parameter	range	parameter	range	parameter	range
Soluble Sugars (Brix %)	12 - 16	Biotiolo (mg/100 g)	4.17-8.82	Ca (mg/100 g)	12,4-12.8
pH	5.4 - 6.5	Taurin (mg/100 g)	8-11.7	K (mg/100 g)	90-199
Acidity (% di citric acid)	0.06- 0.15	Vitamina E (µg/ 100 g)	111-115	Na (mg/100 g)	0,6-1,09
Fruit fw (g)	100-250	Carotenoids (µg/100 g)	1.45-3.47	Mg (mg/100 g)	16,8-18,8
Percent flesh (%)	55-65	Seed vs flesh (n g-1)	3.0-4.5	glucose (%)	29
				fructose (%)	24
Seed count	150-300	Ascorbic acid (mg 100g-1)	20-40	sucrose (%)	0.2

Fonte: Inglese et al (2010, 2006, 2002); De Wit et al (2010); Salim et al (2009); Tesoriere et al (2005); Barbera et al., (1992)

Table 4: Quality parameters of *O. ficus-indica* fruit

Fatty acid	Countries						
	Morocco [a]	Turkey [b]	South Africa [a]	Tunisia [a,c,g]	Germany [d]	Chile [e]	Algeria [f]
Palmitic (C16 : 0)	11.9	10.6-12.8	13.7	12.2-12.7	23.1	16.2	13.1
Stearic (C18 : 0)	3.4	3.3-5.4	3.38	3.2-3.9	2.67	3.3	3.5
Oleic (C18 : 1w9)	21.3	13-23.5	15.7	16.4-22.3	24.1	19.9	16.3
Vaccenic (C18 : 1n-7)	–	5.1-6.3	–	4.8	–	–	5.3
Linoleic (C18 : 2w6)	60.8	49.3-62.1	64.38	53.5-60.6	32.3	57.7	61.8

[a] Gharby *et al.* (2015); [b] Mattháus and Özcan (2011); [c] Tlili *et al.* (2011); [d] Ramadan and Mörsel (2003a); [e] Sepúlveda and Sáenz (1988); [f] Chougui *et al.* (2013); [g] Ouerghemmi *et al.*, 2013.

Table 5: Fatty acid content (%) in cactus pear seed oil (*Opuntia ficus-indica*) from different countries

3.3 POST HARVEST MANAGEMENT

OFIs are highly perishable, susceptible to physical and mechanical stresses as well as microbiological alterations due to various pathogens.

As with other fruit species, post-harvest losses can vary considerably depending on production areas, cultural practices and post-harvest facilities available, but, due to their high succulence and the presence of glochids, the susceptibility of pears of cacti to mechanical damage, bruising and microbiological deterioration can be significantly higher than other species in terms of frequency and intensity. Pre-harvest conditions and degree of ripeness at harvest greatly affect post-harvest fruit quality.

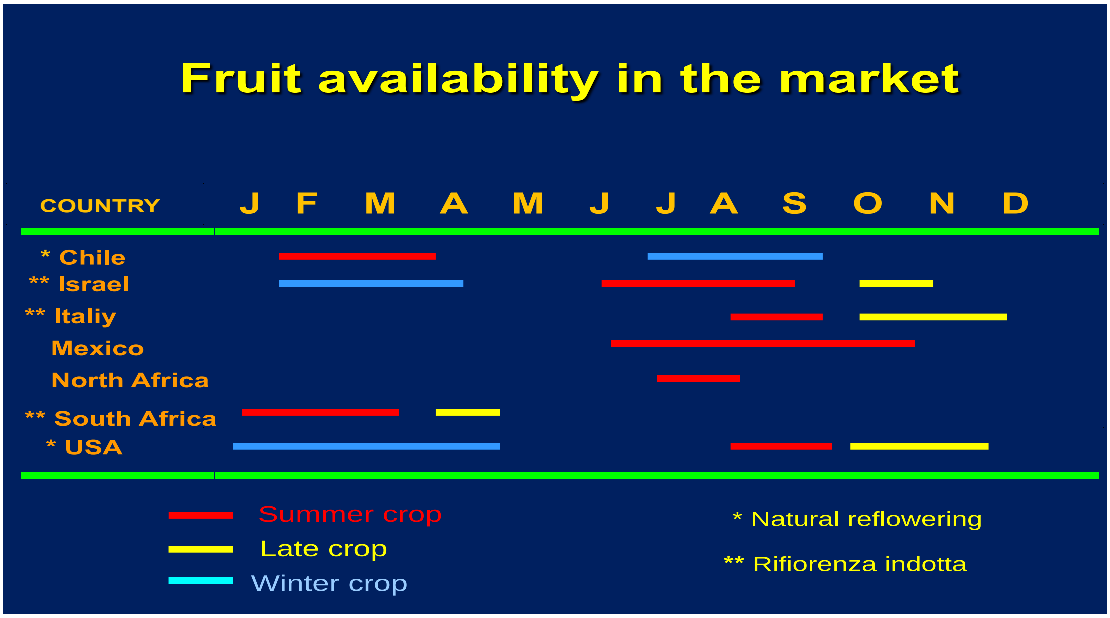


Figure 15: Harvest time of cactus pears worldwide

Great care should be taken during harvesting operations to reduce bruising and injury, which can greatly increase susceptibility to microbiological spoilage. The potential lifespan of OFI plants after harvest is strongly affected by fruit respiration; the higher its activity, the shorter the post-harvest life. Nevertheless, factors other than respiration, both biotic and abiotic, can clearly anticipate the end of postharvest life.

Figure 16: Fruit thinning in a fruiting claodode at fruit ripening time

3.3.1 ABIOTIC FACTORS

Glochids and spines cause frequent damage in the form of pitting. Fruit susceptibility increases with maturity and most damage is inflicted during harvesting, transport and handling in storage.

Figure 17: Tiny glochid pits (left) may increase in size during storage (right) for the high transpiration that occurs in the bitten area, especially when environmental humidity is low enough.

Figure 18: Parenchymatous tissue breakdown (left) occurs in over-ripe fruit where tissue underneath collapses giving rise to depressed areas on fruit surface. Wilting and shriveling (right) appear on fruit surface as a consequence of excessive water loss.

Superficial damage only changes the appearance of the fruit, while deeper wounds can greatly increase fruit susceptibility to wound pathogens, such as Penicillium spp., especially in fruit harvested under humid conditions. Weight loss and susceptibility to chill injury may increase significantly in severely affected fruit during storage. Ripe fruits are also susceptible to bruising, which usually involves the parenchymal cells below the cuticle and epidermis. The injured areas appear depressed due to the release of cytoplasmic material from the broken cells into the intercellular space, but the surface of the fruit shows no damage. Parenchymal tissue degradation is another physiological disorder consisting of suberification of the parenchymal tissue below the glochids and occurs in fruits at an advanced stage of maturity in the field as well as during storage. Water imbalance or marked fluctuations in soil moisture and temperature can cause fruit to split.

Figure 19: Water imbalance leading to high hydrostatic pressure can cause fruit to split both in the field (left) and during storage (right).

When the splitting is severe and visible, the fruit is left in the field or thrown into storage. Chill injury, which occurs when fruits are stored at temperatures below 10-12°C for long periods of time, is the most important physiological disorder of cactus pear. Visible symptoms of cold injury that affect the appearance of the fruit develop as a scalded area, black pits and sunken brown-black spots of the skin.

Figure 20: Cold injury in the form of brownish sunken spots of epidermal cells (left) or withered leathery and sunken blackish spots or spots, aggravated by severe weight loss (right).

3.3.2 MICROBIOLOGICAL SPOILAGE

The succulence of the tissues of cactus pears together with the relatively high pH of the juice, which in ripe fruit can be close to neutral, makes the fruit susceptible to a large number of pathogens, including fungi, bacteria and the yeasts. The practice of picking fruit in the morning when dew is present on the skin and air humidity is high, if on the one hand prevents the release of glochids which represents a serious risk for pickers, d on the other hand promotes micro-wounds and mechanical damage conducive to infections of wound pathogens. The incidence of rot caused by different species of Penicillium is markedly reduced by careful care taken to avoid any mechanical damage to the fruit.

Figure 21: Incidence of soft rot induced by wound pathogens such as Penicillium spp. (left) or infections caused by other microorganisms (right) can be significantly reduced by minimizing mechanical damage during harvesting and packing operations.

Figure 22: Dry rot caused by Alternaria spp. usually starts from the glochids (left) as necrotic black depressed pits that gradually coalesh and increase in size during storage (right).

Dry rot in the form of black necrotic spots develops as pitted areas which eventually overlap to form dark black leathery necrotic patches, sometimes sunken and extensive, usually affecting the first layers of skin cells. This alteration is probably caused by latent infections of Alternaria spp. from the glochids or the calyx scar, but also by conidia present on the surface of the fruit which trigger the infection of the injured sites during storage. Post-harvest losses can increase dramatically if Mediterranean fly (*Ceratitis capitata* Wideman) attacks are not adequately controlled. When ovipositon precedes harvest by a few days, fruits are apparently healthy, but eggs hatch within a few days and larvae may develop during storage or distribution. Even in cases where the larvae do not survive low temperature storage, injury to the ovipositon will increase pathogen infections.

Figure 23: Fruit damaged by medfly infestation in the field (left). When the Mediterranean fly bridge precedes a few days of harvest, the fruits are apparently healthy, but the larvae continue to grow even when the fruits are cold stored and eventually self-disintegrate (right).

The simplest packing line design consists of an inclined ramp onto which the fruit is dumped dry, followed by moving conveyor belts along which workers perform pre-selection. Fruit then passes through a series of brushes to remove glochids and increase skin luster and is then transported to a rotating sorting table where workers sort and grade before packing the fruit into units. retail or in plastic crates placed in plastic or cardboard trays.
The fruits are generally not washed or treated with disinfectants or fungicides and are intended for direct consumption and refrigeration is limited only to transport or brief periods between processing and shipping. Under these conditions, the development of physiological disorders or rotting is rare and impractical. However, the growing market demand for fresh produce and the need to extend the marketing period well beyond that of harvest require cold storage. However, exporting fruit to countries where the Mediterranean fruit fly is not present involves cold quarantine treatments.

Figure 24: Small and simple packing chain (left). Often in large packing lines, the processing lines used for citrus fruits are adapted to also process cactus pears (right).

To extend post-harvest shelf life by 1-2 months, fruits should be stored at 6-8°C and 95% relative humidity, while to achieve cold quarantine requirements, fruits should be kept at 0 to 2°C for 2 to 3 weeks despite high temperature. humidity can stimulate the growth of pathogens, a relative humidity of 90% to 95% is strongly recommended during storage to minimize weight loss, preserve visual appearance and decrease injury by cooling temperatures, which can be more severe when low temperatures are associated with dry conditions. Great care must be taken when unloading fruit into the processing line. Dry dumping, which is the most popular, can induce mechanical damage like bruises and micro-injuries in the skin which, in fruits destined for the fresh market, can heal easily, the fruits being generally preserved under the conditions of the part for a period of time before delivery. In contrast, in fruit kept cold for a long time, the lesions do not heal as easily and may be the entry point for rot-causing pathogens. To reduce the risk of rotting the edges and rails of the line should be padded, while canvas curtains should be fitted along the line to reduce the speed of the fruit or to break the chute when the fruit falls into a plane inferior.

Figure 25: Cactus dans packaging in Italy.

Maturity indices	Peel color change (breakage) from green to yellow or red, fruit firmness, flattening of floral cavity
Quality indices	Total soluble solids (minimum of 13%, maximum of 17%, depending on cultivar), pH (6.0–6.5), tritatable acidity (0.03–0.12%), firmness (10–12 kg cm^{-2}), percent flesh (50–60%), fruit size (minimum of 120 g, maximum of 240 g, depending on cultivar)
Optimum storage temperature	6 to 8°C with a storage potential of 2 to 6 weeks, depending on cultivar, ripeness stage, and pre-harvest environmental conditions
Optimum relative humidity	90 to 95%
Fruit respiration rates	Nonclimacteric, with low respiration rate (15–20 ml CO_2 kg^{-1} $hour^{-1}$ at 20°C)
Physiological disorders	Chilling injury, when exposed at temperatures below 5°C for more than 24 hours (pitting and dark brown spots on the peel surface)
Pathological disorders	Fruit decay may result from peel or stem-end damage occurring during harvest and storage, or after glochid removal; main agents are *Alternaria* spp., *Dothiorella ribis,* and *Penicillium* spp.
Postharvest heat treatment (hot water dips or curing)	Conditioning fruits at 37 to 38°C for 24 to 48 hours reduces chilling injury; prestorage dipping in water at 50 to 55 °C for 3 to 5 minutes reduces decay

Adapted from Kader (1999).

Table 6: Recommendations for maintaining postharvest fruit quality

REFERENCES

- Barbera, G., Carimi, F., Inglese P. 1991. The reflowering of prickly pear *Opuntia ficus-indica* (L.) Miller: influence of removal time and cladode load on yield and fruit ripening. Advances in Horticultural Science, 2: 77-80.
- Barbera G., Carimi, F., Inglese, P. and Panno, M. 1992. Physical, morphological and chemical changes during fruit development and ripening in three cultivars of prickly pear, Opuntia ficus-indica (L.) Miller. Journal of Horticultural Science, 67 (3): 307-312.
- Barbera, G., Carimi, F. and Inglese P. 1993. Effects of GA_3 and shading on return bloom of prickly pear (*Opuntia ficus-indica* (L.) Mill.). Journal of the South African Society of Horticultural Science, 3: 9-10.
- Gugliuzza, G., Inglese, P., Farina, V. 2002. Relationship between fruit thinning an irrigation on determining fruit quality of cactus pear (*Opuntia ficus-indica*) fruits. Acta Horticulturae, 581: 205-210.
- Inglese, P., Israel, A.I. and Nobel, P.S. 1994. Growth and CO_2 uptake for cladodes and fruit of the Crassulacean acid metabolism species *Opuntia ficus-indica* during fruit development. Physiologia Plantarum, 91: 708-714.
- Inglese, P., Barbera, G., La Mantia, T., Portolano, S. 1995. Crop production, growth and ultimate size of cactus pear following fruit thinning. HortScience, 30: 227-230.
- Inglese, P., Mondragon, C. Nefzaoui, A., Saenza, C. 2017. Crop ecology, cultivation and uses of cactus pear. FAO-Icarda, 217 pp. http://www.fao.org/3/a-i7012e.pdf
- Le Houerou, H.N. 2002. Cacti (*Opuntia* spp) as a fodder crop for marginal lands in the mediterranean basin. Acta Horticulturae, 581: 21-46.
- Nobel, P.S. 2006. Parenchyma-chlorenchyma water movement during drought for the hemiepiphytic cactus *Hylocereus undatus.* Annals of Botany, 97: 469-474.
- Nobel, P.S. and Hartsock, T.L., 1983. Relationships between photosynthetically active radiation, nocturnal acid accumulation, and CO_2 Uptake for a crassulacean acid metabolism plant, *Opuntia ficus-indica*. Plant Physiology, 71: 71-75.