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Fruit production and post-harvest management

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INTRODUCTION

A worldwide expansion of cactus pear cultivation was predicted by Nobel in 1988. Predictions were partially based on the particular environmental biology of the cactus pear plant, which makes it possible to develop sustainable agricultural production systems in areas with limited water and poor soils (Inglese *et al.*, 1995a). Furthermore, there was an increased interest in cactus pear fruit production due to a greater demand for exotic fruit on the world's major markets (Inglese *et al.*, 1995a). In addition, limited irrigation water for expansion of mainstream crop production in arid and semi-arid areas has forced agriculturalists to look at alternative crops with improved drought tolerance and water-use efficiency (WUE). The plant is cultivated in a wide range of environments, resulting in differences in orchard practices (depending on the country), fruit quality and crop productivity (Inglese *et al.*, 2009; Liguori and Inglese, 2015). Fortunately, since the 1990s, much more information has become available on orchard management and other cultivation aspects of cactus pear (Felker and Inglese, 2003).

Currently, cactus pear cultivation for fruit production takes place in at least 18 countries in semi-arid areas in both hemispheres on more than 100 000 ha (Inglese *et al.*, 2002a); this figure does not include naturalized plants, nor plants cultivated for home consumption, commonly found in many countries (Inglese *et al.*, 2002a). The country with the largest area under cultivation of cactus fruit is Mexico (51 112 ha) (Reyes Agüero *et al.*, 2013), while other countries, such as Italy, Chile, South Africa, Argentina and Israel, also commercially cultivate the fruit (Inglese *et al.*, 2002a).

The innaccurate perception that cactus pear does not need to be cultivated like other crops and that little or no care still gives high productivity persists today to some degree. Even the early cactus pear researchers – Griffiths (1909) and Turpin and Gill (1928) – ascribed this theory to the ease with which the plant grows in virtually any environment. Today we know that this is untrue: in order to be profitable, the plant requires appropriate care.

ORCHARD PLANNING AND ESTABLISHMENT

Thorough planning is crucial when establishing a commercial cactus pear fruit orchard and many important decisions must be made prior to planting. Many aspects require consideration:

- meso- and microclimate of the growing site;
- physical and chemical soil analysis;
- cultivar choice;
- soil preparation;
- ordering of plant material;
- planting of windbreaks;
- determination of planting distances and row orientation; and
- installation of an irrigation system.

Site selection

The worldwide distribution of cactus pear is indicative of its extensive adaptability to various climatic and soil factors (Brutsch, 1979). Cactus pear plants can tolerate very high temperatures with no negative consequences (Nobel *et al.*, 1986); on the other hand, planting sites where the minimum temperature drops to below -5° C should be avoided, as most fruit cultivars are killed at these temperatures (Inglese, 1995). Low-lying areas where frost occurs in late winter to early spring may cause flower bud abortion (Wessels, 1988b; Inglese, 1995; Nerd and Mizrahi, 1995a) with partial to total crop failure. The optimal temperature range for nocturnal CO_2 uptake is 25/15° C day/night for cactus pear, because higher day or lower night temperatures result in reduced carbon uptake, leading to poor plant growth and production (Nobel 1994; Nobel and Bobich, 2002). Temperature patterns during floral budburst (late winter to spring) and fruit development period (FDP) have a particularly significant effect on productivity and fruit quality. Most *Opuntia* species are poorly adapted to long periods of cool moist weather (Brutsch, 1979).

In most countries characterized by predominant summer rainfall, cactus pear is grown under rainfed conditions; however irrigation is necessary where the dry time of year coincides with the FDP or where annual rainfall is < 300 mm (Inglese, 1995). Cactus pear is successfully grown in winter rainfall areas when provision is made for irrigation in the hot dry summer months. The maximum rainfall limit is 1 000 mm per year (Le Houérou, 1992, 1996a), but high rainfall is less ideal as it results in poor pollination, increased presence of fungal diseases, fruit cracking and reduced fruit quality (Wessels, 1989).

Given the succulence of the plant and fruit, it is easily damaged by hail, and commercial fruit production should be avoided where hail is a regular occurrence (Wessels, 1988a; Brutsch, 1997a). Physical damage as a result of hail facilitates the entry of pathogenic fungi into the plant (Granata, 1995; Swart *et al.*, 2003), and causes cosmetic damage making the fruit unmarketable.

Snyman (2004, 2005) showed that at 2 years, *O. ficus-indica* roots comprise only 7% of the total plant biomass – indication of the large difference between below – and above-ground biomass in the early years of plant growth. As a result, strong winds accompanied by rain may cause plants to lodge, especially when plants are young and the root system is not yet fully developed to keep it upright.

It is important to carefully examine the microclimatic features when selecting the most appropriate planting site for orchard establishment. For example, a north-facing site is warmer than a south-facing one (Southern Hemisphere), resulting in earlier harvest and improved fruit quality.

While cactus pear can be grown in a wide range of soil types (Inglese *et al.*, 2002a), it is important to select the best soils available for high productivity (Wessels, 1988a). Soils with a sandy to sandy loam texture are ideal (Vazquez-Alvarado *et al.*, 2006), but cactus pear can grow equally well on heavier soils. Wessels (1988b) noted that soil drainage rather than soil type is the conditioning factor. Cactus pear is very sensitive to a lack of oxygen in the soil (Brutsch, 1979; Le Houérou, 1992, 1996a), but very sandy soils have poor water-holding capacity and are more prone to leaching of nutrients (Wessels, 1988a). The plant prefers a neutral to slightly alkaline soil pH (water) (Wessels, 1988b; Zegbe *et al.*, 2015). Soil selected for planting should be at least 300 mm deep (Wessels, 1988a), although deeper soils (600–700 mm) are preferred for commercial production (Inglese *et al.*, 2002a). Most *Opuntia* species do not tolerate even moderate levels of dissolved salts in the rooting zone. Since net CO_2 uptake is inhibited, it negatively affects the vegetative growth of cacti in soils high in sodium chloride or calcium carbonate (Nobel, 1994, 1995). Gersani *et al.* (1993) report a 40% reduction in plant growth with a concentration of 30 mol m^{-3} (1.76 g $litre^{-1}$ NaCl), and a 93% reduction with a concentration of 100 mol m^{-3} (5.85 g $litre^{-1}$ NaCl).

Soil preparation

Pre-plant soil preparation is essential for successful cactus pear production and cannot be adequately performed after orchard establishment. Land clearing and levelling may be required (Inglese, 1995); irrigation supply lines may be installed and plant rows marked out. In areas where game and domestic animals can damage young plants, fencing is required.

Adverse soil conditions, such as impenetrable layers, perennial weed infestation and shallow soil depth, need to be addressed before planting (Wessels, 1988b; Inglese *et al.*, 2002a). Deep soil cultivation (at least 500 mm) with a ripper/subsoiler on the plant row is needed to break up any hardpan layers, and to improve drainage, aeration and water-holding capacity. In heavier compacted soils, deep cultivation across the rows may also be beneficial: it helps the plant survive during low rainfall years when it can utilize soil water from deeper soil depths (Inglese, 1995; Potgieter, 2001). On very shallow soils, ridging is recommended (Singh, 2003). It is important to remove perennial weeds before establishment – either mechanically or chemically – as they compete strongly with the cactus pear plant, particularly during the early stages of plant growth (Wessels, 1988b).

Pre-plant fertilization

Soil amendments to correct soil nutrient imbalances and soil pH must be carried out prior to establishment. A soil pH (water) of 6.5-7.5 is considered optimum (Wessels, 1988a, b; Singh, 2003). Fertilizer applications should be based on the results of soil analysis, which indicate the levels of plant nutrients in the soil (**Table 1**).

TABLE 1

Suggested optimum soil nutrient levels for cactus pear fruit production for rainfed cultivation in summer rainfall areas of South Africa

Element	Optimal soil level (mg kg^{-1})
P	20-30
K	80-100
Ca	> 400
Mg[a]	100-150

[a]Mg levels should not be higher than Ca levels.

Source: Potgieter, 2001, 2007 (adapted).

Representative soil samples of the topsoil (0-300 mm) and subsoil (300-600 mm) need to be taken for chemical and physical analysis. The secondary effects of soil pH on the availability of other plant nutrients are probably more important than soil pH *per se*. For example, P becomes less available to plants at a low soil pH (Nobel, 1988). Lime and P are relatively immobile in soils and as a result these need to be thoroughly mixed with the soil prior to planting. In addition to decreasing vegetative growth and dry mass (Berry and Nobel, 1985), high soil salinity also decreases water content of the cladode, uptake of K and Ca, and root-shoot ratio (Nerd *et al.*, 1991c). The addition of gypsum helps to neutralize excess salts in the soil solution. Cactus pear reacts very well to organic manures which also improve the soil structure, nutrient content and water-holding capacity (Inglese, 1995; Singh, 2003). As a general guideline, 6-10 tonnes ha^{-1} of well-composted animal manure needs to be incorporated into the soil before planting.

Windbreaks

In windy areas, it may be beneficial to plant live windbreaks to minimize the negative effects of wind in cactus pear orchards. Heavy rainfall accompanied by strong wind can cause young plants to lodge and can even cause branches and cladodes to break off (Felker *et al.*, 2005). Pollination and plant protection sprays are all negatively affected by high winds; it is difficult to perform orchard practices (pruning, fruit thinning, harvesting) under windy conditions as the glochids tend to become airborne (Wessels, 1989). When developing cladodes and fruit are too close together on a cladode, fruits can be damaged by chafing during windy spells. Live windbreaks must be adapted to the area of planting and they should receive water and plant nutrition to ensure that they do not compete with the orchard. A popular tree for live windbreaks in orchards is the Australian beefwood (*Casuarina* spp.).

Cultivar choice

The number of cactus pear fruit cultivars available varies significantly between countries. Mexico and South Africa have numerous cultivars, while in most other producing countries the cultivar choice is rather limited (Inglese *et al.*, 2002a). The choice of a fresh fruit cultivar depends primarily on the climatic conditions of the planting site and on market demand. *Opuntia* species and cultivars differ greatly with regard to their potential fruit yield, quality characteristics and adaptability to environmental conditions. Not all cultivars are equally adapted to a particular area; indeed, most cultivars exhibit strong genotype–environment interaction (G × E) (Potgieter, 2007). Cultivars must be chosen wisely; changing cultivar after establishment entails very high costs, because plants are self-rooted and grafting or top-working is not economically viable.

In addition, cultivar characteristics must be carefully considered (**Table 2**) before a final decision is made: there may be specific cultivar preferences for supplying a particular market. For example, cultivars with a red, pink, orange or yellow pulp are preferred on most European and North American markets, whereas white and green pulp fruit are favoured by South African (Wessels, 1988) and Mexican consumers (Mondragón Jacobo and Perez Gonzalez, 1994, 1996). If growers are contemplating exporting fruit, the cultivar choice becomes even more important as characteristics such as appearance, post-harvest resistance to handling and shelf-life play a major role in successful exports. Producers should take into account that some cultivar characteristics can be influenced by the environment or by orchard management practices. For example, although fruit mass may be genetically controlled, it can be influenced by fruit thinning, irrigation, fertilization and pruning. Annual variation in fruit yield and quality is also evident in most commercial orchards.

TABLE 2 Main cactus pear fruit cultivar characteristics in producing countries of the world

Cultivar name	Country	Species	Spininess	Peel/pulp colour	Ripening season	Fruit mass	Pulp	TSS	Post–harvest handling
				50% peel colour break	N. Hemisphere	g	%	°Brix	
Algerian	SA	*O. ficus-indica*	none	red/dark pink	Jul./Aug.	162	59.4	13.9	moderate
Gymno Carpo	SA	*O. ficus-indica*	none	Yellow/Orange	Aug./Sept.	170	61.7	11.2	moderate
Meyers	SA	*O. ficus-indica*	none	red/dark pink	Jul./Aug.	176	60.7	13.6	good
Morado	SA	*O. ficus-indica*	none	Green/White	Jul./Aug.	146	60.0	14.4	poor
Nudosa	SA	Unknown	slight	Red/red	Aug./Sept.	236	60.8	11.2	good
Roedtan	SA	*O. ficus-indica*	none	Yellow/Orange	Aug./Sept.	171	60.7	14.2	moderate
Turpin	SA	*O. ficus-indica*	none	Yellow/Orange	Jul./Aug.	181	55.0	13.6	moderate
Zastron	SA	*O. ficus-indica*	none	Light green/ White	Jun./Jul.	137	57.2	13.5	good
Reyna	Mexico	*O. albicarpa*	spiny	Light green/ light green	Jul./Aug.	120	63.7	16.4	poor
Cristalina	Mexico	O. albicarpa	spiny	Light green/ light green	Aug./Sept.	207	60.2	12.7	good

(Continued)

Cultivar name	Country	Species	Spininess	Peel/pulp colour	Ripening season	Fruit mass	Pulp	TSS	Post-harvest handling
				50% peel colour break	N. Hemisphere	g	%	°Brix	
Villanueva	Mexico	*O. albicarpa*	spiny	Green/light green	Jun./Jul.	129	60.9	14.4	poor
Burrona	Mexico	*O. amyclaea*	spiny	Light green/ light green	Sept./Oct.	217	59.8	12.7	very good
Roja San Martin	Mexico	*O. ficus-indica*	slight	Red purple/ purple	Jul./Aug.	116	44.5	13.7	poor
Naranjona	Mexico	*O. megacantha*	slight	Yellow/Orange	Aug./Sept.	170	51.7	13.1	very good
Roja Vigor	Mexico	*O. ficus-indica*		Bright red/red	Jul./Aug.	174			moderate
Dellahia	Morocco	*O. robusta*	none	Light green/ Light green		100	53.1	14.0	
Moussa	Morocco	*O. ficus-indica*	none	Yellow/Orange	Dec.	101	51.0	14.4	
Aissa	Morocco	*O. ficus-indica*	none	Yellow/Orange		96	50.0		
Gialla	Italy	*O. ficus-indica*	none			103	51.0	13.0	good
Rossa	Italy	*O. ficus-indica*	none						
Bianca	Italy	*O. ficus-indica*	none			112	53.6		
Amarilla sin Espinas	Argentina	*O. ficus-indica*	none	Yellow/Green				13.9	
Ofer	Israel	*O. ficus-indica*	none	Yellow/Orange					
Andy Boy	USA								
Verde (Criolla)	Chile	*O. ficus-indica*	spiny	Green/Green	Feb-Apr.	132	49.6	13.3	good

SA = South Africa; USA = United States of America.

ORCHARD LAYOUT AND DESIGN

Row orientation

Row orientation, unlike tree density, cannot be changed and is fixed for the lifespan of the orchard. According to Nobel (1982), cactus pear cladodes are inclined to face east-west, except at lower latitudes (> 27°) and in areas where vegetative growth occurs during winter. In these situations, row orientation is less important (Nobel, 1982). Once row orientation is decided, it is important to achieve optimal light utilization over the whole tree canopy during the day (García de Cortázar and Nobel, 1991; Stassen *et al.*, 1995). While the generally preferred row orientation is north-south to capture equal daily solar irradiance under sunlit and cloudy weather conditions, it can be adapted to suit the latitude, site and incidence of sunburn. There are other practical considerations, such as sloping fields, where it is recommended to plant on the contour to prevent soil erosion (Inglese, 1995; Stassen *et al.*, 1995).

Planting systems

Choice of planting design and planting distance depends on farm size, farm management, implements, climate, soil fertility, cultivar growth habit, plant training system and occurrence of pests such as cochineal (Wessels, 1988b; Inglese, 1995).

Hedgerow

Various planting systems can be employed for cactus pear fruit production, but in recent years, high-density hedgerows planted in a rectangular system have become the norm in large commercial orchards in South Africa (Unterpertinger, 2006), Israel (Nerd and Mizrahi, 1993), the United States of America (California) (Bunch, 1996) and Argentina (Felker and Guevara, 2001). Hedgerows have the advantage of lower input costs. They also enable more thorough spray coverage, and solar radiation capture is maximized, resulting in higher productivity.

Rectangular or square planting (free-standing trees)
In Italy, trees are usually widely spaced in a square or rectangular layout; however, similar fruit yields have been reported in Israel and Italy under different plant spacings (Inglese *et al.*, 1995a).

Spacing

Plant spacing for cactus pear fruit production varies greatly, depending on the hemisphere, country and environment. In Italy, planting distances are generally wide and vary from 6 × 6 m (278 plants ha^{-1}) to 4 × 6 m (416 plants ha^{-1}) (Inglese, 1995; Inglese *et al.*, 2002b; Tudisca *et al.*, 2015). In other parts of the Mediterranean, plants are spaced much closer. For instance, in Israel, 1.5 m in the row and 4 m between rows (1 666 plants ha^{-1}) is used to increase fruit yield in the early stages of orchard life (Nerd and Mizrahi, 1993). A plant density range of 500-2000 plants ha^{-1} has been reported in Jordan where plants in the rows are 1-2 m apart, with rows 5-10 m apart and usually positioned on the contour line (Nasr, 2015). In California, plant spacing is 1.5-4 m in rows 4-6 m apart (830-1 666 plants ha^{-1}) (Bunch, 1996). On large farms in Mexico, plants are spaced 4 × 5 m (500 plants ha^{-1}) (Pimienta Barrios, 1990). In the Southern Hemisphere, most new orchards in South Africa are established at 2 × 5 to 2 × 4 m in and between rows (1 000-1 250 plants ha^{-1}) in a hedgerow system. Targa *et al.* (2013) reports plant spacings of 1.5 m in row and 6 m between rows (1 111 plants ha^{-1}) as continuous hedgerows in Argentina.

Whatever spacing is used, it is important to keep open a working row of approximately 1.8 m for farm machinery movement (Wessels, 1988b; Gittens, 1993).

High-density planting

A general problem in cactus pear cultivation occurs when plants are allowed to become too large, resulting in "forests" rather than productive orchards. Large portions of these big trees, especially in the lower parts of the canopy, become completely shaded out (Liguori and Inglese, 2015). As a result, fruit-set is limited to the outside of the plant canopy and labour costs are high at harvest. Given the ever-increasing costs of land and production inputs, it is necessary to seriously re-evaluate planting systems, density and tree management in relation to fruit yield and quality (Stassen *et al.*, 1995; Liguori and Inglese, 2015). Low planting densities are not economically justified; nevertheless, there are two schools of thought on plant spacing:

- **Plant trees on an intensive scale and remove some as encroachment occurs.** The aim is to have an early heavy crop. Close spacing (1-1.5 m) within the row maximizes yield in the early years after planting, but may result in overshading after a few years. Therefore, further pruning and tree removal every few years is necessary to avoid a reduction in yield and fruit quality (Inglese *et al.*, 1995a; Inglese *et al.*, 2002a). Barbera and Inglese (1993) recommend more cuttings per planting station, spaced 4 m apart, resulting in a rapid SAI (stem area index) increase. This results in trees with most of the production on the outer cladodes. However, trees rapidly become 3-3.5 m high and 4-4.5 m wide, entailing higher pruning and harvest costs (Inglese *et al.*, 1995a). In addition to the problem of overshading, dense canopies also aid cochineal infestations and reduce pest control efficiency (Inglese, 1995b). High plant density (2 500 plants ha^{-1}) gives high fruit yield (> 30 tonnes ha^{-1}) from 3-year plants; however, more vegetative than reproductive growth occurs as the plant ages (García de Cortázar and Nobel, 1992).
- **Plant trees according to a realistic high-density spacing and utilize tree management systems to shape and contain the tree within the allocated space** (Stassen *et al.*, 1995). Close spacing within a row maximizes fruit yield in young plants as the number of fertile cladodes per unit area increase (Inglese *et al.*, 2002a). This approach is dependent on the use of manipulation techniques to maintain a specific plant volume. Tree height should not surpass 80% of the width between rows to avoid shading of the lower parts of the hedgerow (Stassen *et al.*, 1995), which makes these areas less fruitful. Provided tree management is done on an annual basis, this strategy is more efficient than lower plant densities. However, if tree management cannot for some reason be performed, it is advisable to maintain a low tree density.

ESTABLISHMENT

Cladode rooting and subsequent vegetative growth in the field depend on many factors. Observations in many commercial orchards have revealed a high degree of variability despite the use of vegetative plant material (Brutsch, 1979; Wessels, 1988a), indicating a need for careful selection of planting material.

Plant material selection and preparation

Cactus pear for fruit production purposes is primarily propagated by clonal means to ensure true-to-typeness (Wessels, 1988b). Where farmers do not have their own cactus pear plants, it is advisable to order plant material well in advance from producers that have good quality plant material. Both single and multiple cladode cuttings are used worldwide for orchard establishment.

Single cuttings
One- or two-year single cuttings (cladodes) can be used,

although 1-year cuttings develop more and longer roots than 2-year cuttings (Arba, 2009b). In general, single, mature, large, terminal cladodes of uniform appearance, visually free of any defects, insects and diseases, should be selected as plant material (Potgieter, 2007). Barbera *et al.* (1993b) and Wessels *et al.* (1997) report that the surface area and dry mass of a cutting have a significant influence on successful rooting and budding in the field. A surface area of 500 cm^2 or dry mass of 70-100 g allows good plant growth. Inglese (1995) recommends placing two parallel cuttings spaced 0.4 m apart at a single planting station for rapid canopy development, or alternatively 3-4 single cuttings positioned in a triangle or square and spaced 0.3 m apart. Although this method has the advantage of faster canopy development, it results in wider within-row spacing and requires large quantities of planting material (Inglese, 1995; Mondragón Jacobo and Pimienta Barrios, 1995). Single cladodes as propagation units have the advantages of lower transport costs and easier handling during the planting process

Multiple cuttings

Cactus pear can also be propagated using mature attached (one, two or more) cladodes; this is common practice in Sicily where 2-3-year multiple cuttings are used (Tudisca *et al.*, 2015). Most of the basal cladode is placed underground to ensure plant stability (Inglese, 1995). Multiple cladode cuttings allow more rapid plant development and earlier fruiting than single cladodes after planting (Homrani Bakali, 2013; Nasr, 2015). However, due to their size and mass they are more difficult to handle and transport.

Cuttings can be cured for 4-6 weeks in partial shade on a dry surface to allow the cutting wound to callus (Potgieter, 2001; Inglese *et al.*, 2002a). Alternatively, various copper-based fungicides can be used to treat the cutting wound before planting (Inglese, 1995). To prevent the introduction of insects (e.g. cochineal and cactus pear moth) to new planting areas, it is recommended to disinfect cladodes thoroughly with a registered insecticide before planting. Immature stages of the cochineal insect are barely visible with the naked eye and unsuspecting producers may bring cochineal into an area where it did not previously occur with potentially devastating consequences. Cladodes should be washed with the insecticide mixture using a soft brush to destroy any possible insects.

Planting depth and methods

In sandy soils, cuttings need to be planted deeper than in heavier soils to prevent lodging; likewise, small cladodes should be planted deeper in order to ensure adequate rooting. There are three ways to plant cactus pear: upright; on the side at a 30-45° angle; or flat. The **upright** position is the most commonly adopted (Inglese, 1995) and is preferred for fruit production. Cuttings are planted upright (vertically) with the cut end pointing downwards into the soil. Plants root quickly and a sturdy plant develops (Arba, 2009b; Arba and Benrachid, 2013). Cladodes should be positioned with the flat sides towards the working row. To ensure proper contact between the cutting and soil, the soil needs to be firmed around the cladode after planting. The only disadvantage of this planting method is possible rotting at the cut end (Wessels, 1988b).

Planting time

Roots and cladodes reach their highest growth rate during late spring to early summer (Wessels, 1988b). In summer rainfall areas, newly planted cladodes benefit from rains that occur after planting (Pimienta Barrios, 1990; Singh, 2006). Planting can be extended to midsummer in areas with mild winters. The idea is for the plant to become well established and survive colder winter conditions. However, autumn planting is recommended in Morocco (Nasr and Jamjoum, 2002; Nasr, 2015) and Jordan (Homrani Bakali, 2013), where it resulted in well-established root systems in winter, strong growth in summer and earlier fruiting.

Care of newly planted cladodes

One or two light irrigations (10 litres $plant^{-1}$) in a small earthen dam around the plant promote root development, but care should be taken not to overirrigate young plants (Potgieter, 2001). Newly established cladodes may develop fruit soon after planting. Due to the high sink demands these fruit have on the plant, it is best to remove them in the establishment year (Wessels, 1988b; Inglese, 1995). From the first production year a light crop may be left to mature.

ORCHARD MANAGEMENT

Weed control

While cactus pear is well adapted to arid and semi-arid regions and can survive severe drought conditions, weed control has been shown to enhance productivity (Felker and Russel, 1988), especially in young plantations (Inglese *et al.*, 1995a). The plant's sensitivity to weed competition is due to the very shallow root system (Felker and Russel, 1988; Snyman, 2005), where it competes at the same soil level as weeds for nutrients and water. Nobel and De la Barrera (2003) showed that 95% of the roots of mature cactus pear plants develop at a soil depth of 40-470 mm, while Snyman (2006a) reports that roots can spread as far as 2.5 m from the stem of the plant in 2 years. Various methods of weed control can be used, but soil cultivation should be restricted to a minimum, in order to avoid damaging the shallow root system (Inglese, 1995). Weed control is best performed at an early stage of growth, when competition with the cactus pear crop is minimal (Wessels, 1988a; Inglese, 1995).

Chemical weed control
Due to high labour costs, chemical weed control is the norm in commercial fruit production. A range of herbicides may be used, but farmers are urged to only use products that are registered in their respective countries, especially when the fuit is produced for export. Weeds should preferably be controlled to 1-1.5 m on both sides of the planting rows (Potgieter, 2001); where the danger of soil erosion is limited, complete weed control between rows can be performed (Brutsch, 1979; Felker *et al.*, 2005). Because the early growth of cactus pear is extremely sensitive to herbicide sprays, spraying should be avoided on windy days. Where lower trunk sections contain chlorophyll, stems should be shielded during spraying to prevent herbicide damage.

Mechanical weed control
In a hedgerow planting system, in-row weed control by mechanical means is preferred when cactus pear plants are young due to their sensitivity to herbicides (Potgieter, 2007). However, in square planting systems with free-standing globe-trained plants, weed control remains manual because this training system makes it difficult to work with ordinary farm implements between trees (Inglese and Barbera, 1993). In smaller or more traditional farming systems with limited access to herbicides, the soil between the plant rows may be ploughed to clear the fields of weeds (Nasr, 2015; Tudisca *et al.*, 2015). Although mechanical weed control is not ideal, it is better than no weed control at all (Felker and Russel, 1988).

Permanent grass strips
Where orchards are planted along slopes, it is recommended that a regularly mowed grass strip be maintained between rows to prevent soil erosion (Potgieter, 2001). Weeds can be mowed and left on the soil surface as mulch to retain moisture and reduce weed growth (Inglese, 1995).

Pruning and training systems

The selection of an appropriate pruning and training system for cactus pear is closely related to the planting system, layout and spacing chosen in the planning phase. The main reason for pruning in cactus pear is to ensure maximum photosynthetically active radiation (PAR) interception by terminal cladodes. Most terminal cladodes exposed to adequate sunlight will produce flower buds (Nerd and Mizrahi, 1995b), while shaded cladodes are usually low-yielding or even infertile (Wessels, 1988a; Pimienta Barrios, 1990; Inglese *et al.*, 2010). Therefore, to ensure high CO_2 uptake and cladode fertility, it is important to prevent excessive cladode shading (Pimienta Barrios, 1990; Inglese *et al.*, 1994a) particularly during the last 8 weeks before spring floral budburst (Barbera *et al.*, 1993a; Cicala *et al.*, 1997). Other benefits of pruning include: controlled plant size, training of the plant into a hedgerow, increased fruit yield, improved fruit size, easier pest detection and control, easier harvesting and rejuvenation of old plants (Hester and Cacho, 2003; Inglese *et al.*, 2009, 2010). Between 20 and 50% of the terminal cladodes should be removed by pruning (Oelofse *et al.*, 2006). However, excessive pruning will reduce yield and contribute to strong vegetative growth the following season (Inglese *et al.*, 2002b). All diseased, small and damaged cladodes should be removed.

Formative pruning
Formative pruning begins in the first year of establishment and is changed to production pruning when the plants start bearing (Targa *et al.*, 2013; Nasr, 2015). The aim of formative pruning is to direct vegetative growth into the desired plant shape. In countries where high-density hedgerows are used, plants are pruned to a pyramidal shape (Potgieter, 2001). Where square planting systems with wider spacing are common, vase- or globed-shaped plants are formed (Inglese, 1995). These plants do not have main stems, resulting in large plants with a high number of terminal cladodes distributed around the outer portion of the canopy (Inglese *et al.*, 2002a).

Productive pruning
Productive pruning is used to maintain a good balance between vegetative and reproductive growth with an adequate number of new terminal cladodes for the subsequent year's blooming (Mulas and D'Hallewin, 1992). Environmental conditions, cultivar growth habit and plant spacing all affect canopy density (Inglese *et al.*, 2002a). Reduction of the canopy density through pruning facilitates orchard practices (e.g. fruit thinning, *scozzolatura*, harvesting) and contributes to improved fruit quality (Inglese *et al.*, 2002a, 2010). Plant height should preferably not exceed 1.8 m in order to avoid the use of ladders to perform orchard practices (Potgieter, 2001; Nasr, 2015).

Renewal pruning
In the case of old cactus pear plantations, senescence of the canopy and yield reduction with noticeable alternate yielding are common (Mulas and D'Hallewin, 1992). Rejuvenation of old plants can be achieved by cutting the plant back to a height of 0.5 m above soil level.

Only 3-4 well-spaced main scaffold branches should be left for development of the new plant. To prevent sunburn, the whole plant should be painted with white polyvinyl alcohol (PVA) paint, mixed 1 : 1 with water. With a large established root system, the plant resumes fruiting within 2-3 years after rejuvenation pruning (Wessels, 1988b; Mulas and D'Hallewin, 1992). The newly developing cladodes must be thinned to prevent cladode overcrowding.

Summer pruning
Complete removal of newly developing cladodes in spring is common practice in Sicily to reduce competition between fruit and vegetative growth. However, this practice may result in an alternate bearing pattern (Inglese and Barbera, 1993; Inglese *et al.*, 2002b). Summer pruning is not advisable in areas with cold winters, because cladodes developing late in the season would not have sufficient time to harden-off before winter when they would be subject to frost damage (Wessels, 1988b). However, in South Africa, thinning of some of the excess developing cladodes in spring and early summer is performed. Newly developing cladodes close to flower buds may cause chafing of the fruit epidermis, making it unmarketable due to cosmetic damage (Wessels, 1988b; Potgieter, 2001).

The best time to prune is after fruit harvest but not later than 2 months before floral bud break (Wessels, 1988b). Late pruning, especially in overcrowded trees, will result in cladodes not being exposed to sufficient PAR to make them fertile. In South Africa, pruning takes place from April to July (autumn/winter), when the plant is no longer actively growing (Wessels, 1988c; Potgieter, 2001). Similarly, in Mexico, Pimienta Barrios (1986, 1990) suggests pruning from November to March (winter).

Fertilization

Deficiencies in mineral nutrients affect cactus pear plant metabolism with a resultant negative impact on fruit yield and quality (Nerd and Mizrahi, 1992; Zegbe Dominguez *et al.*, 2014). In order to make fertilizer recommendations for cactus pear, it is essential to consider the plant nutrient status of the terminal cladodes as well as the available nutrient reserves in the soil.

Plant nutrition results reported for cactus pear fruit yield and quality are highly inconsistent and contradictory making fertilization recommendations challenging. Cactus pear plants differ from most other crop plants, both physiologically and morphologically; for this reason, fertilizer recommendations applied to other crops are of little use (Nobel, 1983, 1988; Magallanes Quintanar *et al.*, 2006). In the absence of agreement on cactus pear fertilization, **Table 3** provides growers with broad provisional soil and plant tissue analysis norms, while **Table 4** lays down general fertilization guidelines where no soil analysis results are available.

TABLE 3 Provisional soil and plant tissue norms for cactus pear fruit production

Soil parameter	Norm	Terminal cladode	Norm (% DM)
pH (water)	6.5-7.5	N	[b]
P (mg kg^{-1})	20-30	P	0.1-0.3
K (mg kg^{-1})[a]	80-100	K	1.5-4.0
Ca (mg kg^{-1})	> 400	Ca	2.0-4.5
Mg (mg kg^{-1})	100-150	Mg	1.0-1.5
Na (mg kg^{-1})	< 200	Na	0.02-0.03
Mn (mg kg^{-1})	30-70		
Ca/N	4.0		
K/N	3.4		
N/P	4.5		
Ca/Mg	3.0		

[a] If (Ca + Mg)/K > 8 (sandy soils) or < 5 (clay soils), apply K.

[b] Young trees (0–2 years): 0.6–0.8%. Mature trees (≥ 3 years): 0.9–1.3%.

TABLE 4 Provisional fertilizer recommendations for fruit production where no soil analysis results are available (plant nutrient amounts in kg ha^{-1} $year^{-1}$)

Nutrient element	Year 1	Year 2	Year 3	> Year 4
N	50	50	70	100
P	10	10	20	30
K	20	20	30	50
Mg	10	10	20	40

Mineral nutrition research on cactus pear in various countries shows that fertilizer application, both organic and inorganic, is generally beneficial in fruit production. Nutrient elements influence vegetative and reproductive phenology, fruit yield and quality in cactus pear, with macroelements having the greatest effect on fruit production (Zegbe Dominguez *et al.*, 2014; Arba *et al.*, 2015b). Of all the plant nutrients, N is the most limiting nutrient in cacti (Nobel, 1983), with the highest N values found in young fertile cladodes (Nobel, 1988). However, very high N concentrations (> 2.2%) in 2- and 3-year old cladodes may result in excessive vegetative growth with accompanying higher input cost, reduced cladode fertility, poor fruit colour development and uneven ripening (Potgieter and Mkhari, 2000; Inglese *et al.*, 2002a). Reported P and K plant tissue concentrations range from 0.06-0.3 to 0.06-3.5%, respectively (Nobel, 1983, 1988; Arba *et al.*, 2015b). Ca and K are the most plentiful mineral elements in the cladodes, potentially more abundant than N (Galizzi *et al.*, 2004). Furthermore, Mg in young cladodes can reach levels of 1.47% (Magallanes Quintanar *et al.*, 2006). Therefore, N, P, K, Ca and Mg are all potentially limiting factors in cactus pear fruit production if cultivated in nutrient-deficient soils (Magallanes Quintanar *et al.*, 2006). Nutrient concentration in cladodes is affected by fruit crop load, cladode position, plant age, plant tissue analysed and season (Nerd and Nobel, 1995; Gugluizza *et al.*, 2002a).

In cactus pear, an additional flower flush can be induced with the application of N just after the removal of the summer harvest. According to Nerd *et al.* (1993b), the number of flower buds increases with increasing N levels up to 120 kg N ha^{-1}, while the N concentration in the cladode tissue is positively correlated to the number of flowers formed. Nerd and Mizrahi (1995b) further found that the autumn flower flush is higher in younger (< 6 years) than in older plants. However, high production systems with two fruit harvests in one year from the same plant may have additional nutritional requirements (Groenewald, 1996).

Due to the synergistic relationship between fertilization and irrigation, fertilizer application should take place when adequate rainfall or irrigation is available (Nerd *et al.*, 1989; Mondragón Jacobo, 1999). In countries with a Mediterranean climate, fertilization takes place in winter (Barbera *et al.*, 1992a; Inglese, 1995) with fertigation applied throughout the year in Israel (Nerd *et al.*, 1991b). Nerd *et al.* (1989, 1991b) and Ochoa and Uhart (2006c) report that the application of NPK fertilizer in winter increases the production of floral buds the following spring. However, according to García de Cortázar and Nobel (1991), the best time to apply fertilizer is during the warmer months due to higher photosynthetic photon flux density (PPFD) in summer. In Mexico, half the N and all the P and K are applied with irrigation at the onset of floral budburst, and the other half of the N is applied after harvest (Zegbe Dominguez *et al.*, 2014). Under rainfed conditions (summer rainfall), half the N and K and all the P can be applied directly after fruit harvest and the remainder towards the end of March (Wessels, 1988b), while liming is carried out at any time of the year, but preferably at least 1 month after N fertilization (Claassens and Wessels, 1997).

Irrigation

The exceptional drought tolerance and high WUE of cactus pear plants (Han and Felker, 1997; Zegbe-Dominguez *et al.*, 2015) are the primary reasons for its popularity as a rainfed crop in many areas of the world with low rainfall and a shortage of irrigation water. Although the plant can survive in areas receiving 200 mm $year^{-1}$ (Acevedo *et al*, 1983), the optimal rainfall range for cactus pear production is 400-600 mm $year^{-1}$, but soil type also plays a role in the actual plant water requirement (Le Houérou, 1992, 1994). Although considerable fruit yields can be achieved under low rainfall, rainfed conditions (Potgieter, 2007), supplementary irrigation of cactus pear is advisable in summer rainfall areas where < 300 mm $year^{-1}$ is received (Mulas and D'Hallewin, 1997; Van der Merwe *et al.*, 1997). In addition, irrigation during periods of unfavourable climate – such as dry spells during the rainy season, or when spring rains are late – is advantageous (Wessels, 1988d). In a Mediterranean climate, where most rainfall is in winter, supplementary irrigation in summer is indispensable for high yield and good quality (Mulas and D'Hallewin, 1997; Homrani Bakali, 2013). Irrigation of cactus pear is therefore common practice in Italy, Israel, Jordan, Morocco, Chile and the winter rainfall areas of South Africa.

There are definite advantages with supplementary irrigation of cactus pear, especially during certain critical phases of plant growth and development. García de Cortázar and Nobel (1992), Mulas and D'Hallewin (1997) and Liguori *et al.* (2013b) all report the beneficial effects of irrigation on vegetative plant growth, cladode number and canopy size. Fruit yield per plant is generally higher in irrigated than in non-irrigated plants, and researchers ascribe higher yield to higher average number of fruit per cladode rather than to increase in fruit size (Mulas and D'Hallewin, 1997; Mondragón Jacobo *et al.*, 1995).

According to Nerd *et al.* (1989), delay in irrigation during winter when annual rainfall is < 300 mm results in a substantial reduction of cladode fertility, and off-season winter crop water shortages, particularly during FDP, may adversely affect fruit quality. Application of 2-3 irrigations of 30-50 mm each during FDP increase fruit size and fruit pulp percentage of cactus pear (Barbera, 1984, 1994; Zegbe Dominguez *et al.*, 2015). However, irrigation alone cannot compensate for a reduced fruit size when there is a high number of a fruits per cladode, making fruit thinning essential to achieve good fruit size (La Mantia *et al.*, 1998; Gugliuzza *et al.*, 2002a).

Nobel (1995) points out that as little as 10 mm rainfall is adequate to wet the soil in the root zone of cactus pear, resulting in the plant being able to efficiently utilize small quantities of rainfall. Wessels (1988b) notes that due to the shallow root system of the plant, irrigation amounts of 20-25 mm at a time should be adequate. There is limited information on field parameters for appropriate irrigation scheduling, and the amount and timing of water application vary substantially between countries (Felker and Inglese, 2003). Recently, Consoli *et al.* (2013) determined the crop factor (Kc) for cactus pear within a range of 0.5-0.6. Drip irrigation of 150-200 mm water per year seems adequate for the main summer crop in Argentina, while 4-5 irrigations per year are given for a *scozzolatura* crop (Ochoa and Uhart, 2006a). Gugluizza *et al.* (2002b) report that 2-3 irrigations (60-100 mm) applied during FDP increase productivity and improve fruit quality, while two 50-80 mm applications of water during FDP are essential to achieve export fruit size in the *scozzolatura* crop (Inglese *et al.*, 1995a). According to Homrani Bakali (2013), 3 and 6 irrigations per year produce more fruit than just 1 per year in Morocco. In South Africa, Haulik (1988) suggess ≤ 3 supplementary irrigations per year: beginning in August to stimulate the reproductive flush, then at anthesis, and again in the early stages of fruit development. Where *scozzolatura* is practised, the first irrigation is given at floral induction (40 days before budburst), the next after flowering, then ≤ 5 weeks after fruit-set and during fruit maturation (Targa *et al.*, 2013).

Different irrigation systems are used in cactus pear orchards with drip and microsprinklers common in modern orchards (Inglese, 1995). Microsprinklers covering a fairly large soil surface area with small volumes are very suitable for cactus pear with its shallow and widespread root system (Potgieter, 2001; Snyman 2004, 2005), and they positively influence fruit size and quality (Inglese *et al.*, 2010). Although traditional irrigation methods, such as basin irrigation, may be less efficient, such systems may provide an easy and cheap solution for cash-strapped farmers if irrigation is required only 2-3 times per season (Wessels 1988b).

Cactus pear is sensitive to dissolved salts in its rooting zone and therefore the quality of irrigation water needs to be tested to determine its suitability. Nerd *et al.* (1991c) recommend that NaCl in irrigation water for cactus pear not exceed 25 mol m^{-3} to avoid salinity problems. Water harvesting and mulching to improve the productivity of cactus pear are sound agricultural strategies to be used in arid areas with limited scope for irrigation and to conserve soil water. Mondragón Jacobo (1999) showed that where small water microcatchments are made in the area between plant rows, a great deal of runoff is prevented, leaving more water available for the plant and consequently resulting in higher fruit yields.

Fruit thinning

Fruit size in cactus pear depends on water availability (Barbera, 1984), cultivar differences (Potgieter, 2007; Zegbe Dominguez and Mena Covarrubias, 2010b), length of FDP (Barbera *et al.*, 1992a), mineral nutrition (Ochoa *et al.*, 2002) and, most importantly, cladode fruit load (Brutsch, 1992; Inglese *et al.*, 1995a). In contrast with many other fruit crops, very few cactus pear flowers abscise and 95% of the flowers that set become fruit, unless damaged by late winter frost. However, if crop load is not reduced by fruit thinning, individual fruit size is low and whole branches and cladodes may even break off due to the excessive weight. Fruit prices on local and export markets generally depend on fruit size, with larger fruits selling for higher prices. However, heavy thinning to four fruits per cladode may substantially reduce total fruit yield by as much as 58% without any fruit size increase, and it could even cause a second reflowering (Zegbe Dominguez and Mena Covarrubias, 2010a). According to Brutsch (1992), thinned cladodes produce larger fruit than unthinned cladodes, regardless of the number of fruit per cladode. Thus, good fruit size is achieved with a high fruit-set per cladode followed by timely fruit thinning to reduce the crop load.

In addition to a higher individual fruit mass (Inglese *et al.*, 1995a; Nasr, 2015), fruit thinning has other **advantages**:

- easier harvesting (Wessels, 1989);
- prevention of branches from breaking due to a heavy crop load (Wessels, 1988a);
- reduction of alternate bearing (Wessels, 1988b; Hester and Cacho, 2003);

- regular and earlier ripening (Inglese *et al.*, 2002b);
- increase in total soluble solids (TSS); and
- higher percentage of first class fruits (Zegbe Dominguez and Mena Covarrubias, 2009, 2010a, b).

Fruit thinning can take place as soon as the spherical fruit buds are distinguishable from the elongated vegetative buds (Wessels, 1988), but no later than 3 weeks after anthesis, as later thinning does not improve fruit size (Inglese *et al.*, 1995b; La Mantia *et al.*, 1998; Gugliuzza *et al.*, 2002a).

Investigations showed that export-sized fruits (> 120 g) can only be produced if no more than 6 fruit per cladode are retained (Inglese *et al.*, 1994b). Since not all cladodes are the same size, the norm in the South African commercial sector is to thin fruit to approximately 50-70 mm between fruitlets, rather than to a specific number per cladode (Potgieter, 2001). Leaving adequate space between developing fruits ensures less damage to adjacent fruits during the harvesting process, especially where specialized harvesting secateurs are used. Fruits that develop on the flat sides of the cladode need to be removed as they tend to have a long "fruit stalk", making packing more difficult. Excess fruits can be removed by hand using a polyvinyl chloride (PVC) glove and a sharp knife or pruning secateurs.

Out-of-season cropping

Floral induction in most perennial fruit trees is largely synchronized, resulting in a single harvest at a specific time of the year (Liguori and Inglese, 2015). However, one of the most remarkable characteristics of cactus pear is the capability of the plant to reflower at different times in the same season (Inglese, 1995; Inglese *et al.*, 2002a), naturally or after inductive practices have been applied (Nerd and Mizrahi, 1997). These out-of-season fruit are sold at substantially higher prices than those of the normal summer season (Mondragón Jacobo *et al.*, 2009). Successful application of crop manipulation techniques, such as *scozzolatura* and winter production, has considerably increased the provision of fruit from 5 to 9 months of the year on the local fresh produce markets of South Africa, although the volume is limited from May to September. Nevertheless, cactus pear fruit marketing is generally highly seasonal, with cultivars available for approximately 4 months per season (Inglese, 1995; Liguori and Inglese, 2015). **Increased fruit availability** on markets could be achieved by:

- growing cactus pear in diverse agroclimatic areas (Mondragón Jacobo *et al.*, 2009; Liguori and Inglese, 2015);
- using cultivars with different ripening periods (Brutsch, 1992; Gallegos Vazques *et al.*, 2006);
- improving post-harvest technology (Liguori and Inglese, 2015); and
- adopting crop manipulation techniques (Barbera *et al.*, 1992a; Brutsch and Scott, 1991).

Scozzolatura

The *scozzolatura* technique – discovered by chance in the early nineteenth century (Coppoler, 1827, cited by Barbera *et al.*, 1991, 1992a) – has since become standard crop practice in the cactus pear fruit industry in Italy (Barbera, 1995). Complete removal of all newly developing flowers and cladodes of the spring flush results in a second reflowering approximately 12-16 days later with fruits ripening 6-8 weeks after the spring flush (Barbera *et al.*, 1988, 1991, 1992b; Brutsch and Scott, 1991). Although the second flush normally sets fewer flowers than the spring flush, fruit are marketed when prices are higher (Brutsch and Scott, 1991; Barbera and Inglese, 1993; Boujghagh and Bouharroud, 2015), which to an extent compensates for the lower fruit yield. *Scozzolatura* brings numerous **advantages**, including:

- increased prices;
- improved fruit quality – in particular, improved fruit size, lower seed-to-pulp ratio and higher pulp percentage (Barbera *et al.*, 1992b; Hammami *et al.*, 2015; Boujghagh and Bouharroud, 2015);
- greater flesh firmness and more intense pulp coloration (Mondragón Jacoboet *al.*, 1995);
- more complex and compact plant architecture in addition to more fertile terminal cladodes and higher fruit yield (when practised from an early plant age).

The reflowering index, as defined by the ratio of second flush to first flush flowers (FII : FI), may vary greatly depending on the timing of spring flush removal (SFR) and the environmental conditions at removal (Inglese, 1995). The number of cladodes produced with scozzolatura may be 10-40% less than the spring flush and fruit yield can be as much as 50% lower than in the summer season (Nerd *et al.*, 1991b; Inglese, 1995). Indeed, *scozzolatura* can also have **disadvantages**, including:

- reduced yield;
- higher peel percentage (Mondragón Jacobo *et al.*, 1995) – possibly due to reduced temperatures during FDP (Inglese, 1995; Hammami *et al.*, 2015);
- lower TSS;
- increased peel cracking;
- lower titratable acids; and
- poorly coloured fruit (Inglese, 1995; Mulas, 1997).

A maximum of 25% of the spring season cladodes should be kept on the plant after *scozzolatura*, as a higher percentage reduces the reflowering rate of the following spring and promotes biennial bearing (Inglese *et al.*, 2002b, 1994a).

Climatic conditions, cultivar response and timing of flush removal are important factors affecting *scozzolatura*. Environmental conditions at removal time influence the degree of reflowering and may cause large annual variation in the reflowering response (Barbera *et al.*, 1991; Nieddu and Spano, 1992). For example, a lower reflowering rate may be obtained if high temperatures coincide with bud initiation which will result in more vegetative than reproductive buds (Nerd *et al.*, 1989; Nobel and Castaneda, 1998). In some countries, *scozzolatura* is performed with irrigation (Inglese *et al.*, 2002a) and N fertilization (Flores Valdez, 2003), or farmers may apply a once-off fertigation at SFR (Nerd *et al.*, 1993b). It is essential to select the most suitable cultivar for the technique, as reflowering may be low or even absent in some cultivars (Mondragón Jacobo, 2001; Targa *et al.*, 2013). The timing of the SFR affects the extent of reflowering, the ripening time and fruit characteristics (Barbera *et al*, 1992b). Inglese (1995) reported reflowering rates of between 0.7 for pre-anthesis flower removal and 0.5-0.3 for post-anthesis flower removal. Pre-bloom removal produces the highest reflowering rate (Brutsch and Scott, 1991), but the latest stage of removal normally gives the highest economic returns, although fruit yield may be lower than for other SFR times (Mulas, 1992; Boujghagh and Bouharroud, 2015). In addition to Italy (Barbera *et al.*, 1991), scozzolatura is also regularly practised in South Africa (Brutsch and Scott, 1991), Morocco (Boujghagh and Bouharroud, 2015) and Tunisia (Aounallah *et al.*, 2005; Hammami *et al.*, 2015). In other parts of the world, *scozzolatura* produced poor results. For example, *scozzolatura* under Mexican conditions with 'Cristalina'and 'Reyna' gave negative results (Mondragón Jacobo *et al.*, 1995); similarly, Ochoa *et al.* (2009) reported a very low reflowering index of 0.05 in Argentina with 'Amarilla sin espinas'.

Following the *scozzolatura* performed at SFR, the process can be repeated with the complete removal of the first *scozzolatura* cladodes and fruit (Inglese *et al.*, 2010). Liguori *et al.* (2006) demonstrated that the double removal of new fruits and cladodes induced a third flush of flowers and cladodes in late August with fruit production ripening in winter (January-March) in the Northern Hemisphere. Winter fruits obtained by double *scozzolatura* and covered under PVC polymeric film in late autumn were regular in size and flesh percentage, but with slightly lower TSS. However, the rate of the second reflowering was low (20-40%) (Liguori and Inglese, 2015). Low temperatures in December stop fruit growth and ripening; for fuit to develop normally, it is necessary to cover the plants with PVC tunnels (Liguori *et al.*, 2006).

Winter fruit production

Flowering of the cactus pear plant is not restricted to spring. A smaller budburst occurs naturally in Argentina (Inglese, 1995), California (Curtis, 1977) and Chile (Sudzuki Hills *et al.*, 1993), as well as in the hot subtropical areas of Limpopo, South Africa (Groenewald, 1996; Potgieter, 2001). In addition to the natural out-of-season budburst in areas with mild winters, a second flowering flush can be obtained: Nerd *et al.* (1993b) and Nerd and Mizrahi (1994) showed that following the main summer crop harvest, immediate irrigation and N application at a rate of 120 kg ha-1 produced an autumn budburst; production of flower buds increased with increasing rates of N application and was highly correlated with the soluble reduced N content in the terminal cladodes (Nerd and Mizrahi, 1994).

Although the winter crop gives yields 50–80% smaller than the main summer crop (Nerd *et al.*, 1993b), higher prices are obtained (Mondragón Jacobo and Bordelon, 1996). Groenewald (1996) reported that even without irrigation, this technique can be successfully applied under rainfed conditions such as in summer rainfall areas of South Africa.

Furthermore, the flowering response to N is affected by the age of the plants. Floral bud production is much higher in young plants (≤ 6 years) than in older plants (Nerd and Mizrahi, 1994). However, this technique is only feasible where winter temperatures are sufficiently high for fruit development (Nerd *et al.*, 1993b). The peel-to-pulp ratio is higher in winter than in summer fruit, due to the thicker peel (Nerd *et al.*, 1993b; Groenewald, 1996). Producers should take note that cultivars producing high fruit yields in summer (e.g. 'American Giant') do not respond at all to the applied N (Groenewald, 1996). In addition, pruning needs to be delayed until after winter fruit ripening, by which time flower buds of the main summer crop have already appeared, making pruning difficult (Groenewald, 1996).

Orchard sanitation

Winter cladode prunings, cladodes that break off during normal orchard practices and fruitlets removed during thinning need to be removed from the orchard on a regular basis and destroyed. Pruned cladodes should not be dumped near the orchard, as detached cladodes and thinned fruitlets form roots and begin to grow, serving as host plants for cochineal, *Cactoblastis* and various other diseases, which results in increased plant protection costs (Potgieter, 2001).

Productivity

The fruit yield of cactus pear is extremely erratic and yields vary greatly, not only between and within countries, but within orchards of the same cultivar. Fruit yields vary from 1-5 tonnes ha^{-1} under traditional methods to 15-30 tonnes ha^{-1} with intensive orchard practices under rainfed conditions of 400–600 mm per year (Monjauze and Le Houérou, 1965a). Fruit yield is relatively low in most of the plantings in Mexico (2-8 tonnes ha^{-1} – Pimienta Barrios, 1990, 1994); however, some irrigated orchards may yield 25 tonnes ha^{-1} (Gallegos Vazques *et al.*, 2009). In Chile, fruit yields are generally low (6-9 tonnes ha^{-1} – Saenz, 1985), while in Argentina they range from 8-11 ha^{-1} (rainfed) to 22 tonnes ha^{-1} (irrigated) (Ochoa, 2003). Total fruit yields in excess of 50 tonnes ha^{-1} have been reported in the Karoo, South Africa (Brutsch, 1979) and Texas, the United States of America (Parish and Felker, 1997). In other rainfed areas of South Africa, such as the Free State Province, the highest mean fruit yield obtained was 17.44 tonnes ha^{-1} in a trial comparing 42 cultivars (Coetzer and Fouche, 2015). In Israel and Italy, yields of 20-30 tonnes ha^{-1} are regularly reported (Barbera and Inglese, 1993; Nerd *et al.*, 1993b).

If well managed, orchards can have a life span of > 100 years, as witnessed in North Africa (Le Houérou, 1994). Fruit yield is expected to increase yearly from planting through to approximately the fifth production year when plants have reached full maturity (Potgieter, 2007). Most of the flowers develop on 1-year terminal cladodes, while new cladodes usually develop on 2-year or older cladodes (Inglese *et al.*, 1994a; Wessels, 1988a). The fertility of the cladodes depends on environmental conditions, plant age and dry matter (DM) accumulation (García de Cortázar and Nobel, 1990; Inglese *et al.*, 2002b; Valdez Cepeda *et al.*, 2013). Cladodes with a higher than average DM content tend to produce more fruits (García de Cortázar and Nobel, 1992).

The possible reasons for high variability in fruit yield lie in four main areas: environmental conditions, genotype characteristics and their interactions, orchard planning and design, and orchard practices (Nerd *et al.*, 1991b; Inglese, 1995; Inglese *et al.*, 2002a; Potgieter 2007).

Environmental conditions

In contrast to vegetative growth, little is known about the influence of environmental factors on cladode fertility and fruit yield in cactus pear (Inglese *et al.*, 1995a; Nerd and Mizrahi, 1995b). According to Barbera *et al.* (1991), García de Cortázar and Nobel (1991), Nerd and Mizrahi (1995b) and Inglese *et al.* (2002a), cladode fertility depends on environmental conditions such as plant water status, temperature, photosynthetic photo flux density (PPFD) and soil nutrients. Wessels (1989) related **seasonal variation in fruit yield** to:

- differences in agroclimatic conditions (chill requirement, rainfall, temperature);
- differences in soil fertility status; and
- poor pollination and fertilization due to absence of pollinators and unsuitable climatic conditions during the pollination period (cold, rain).

Potgieter (2007) showed that soil P and soil N levels had the largest influence on fruit yield of 11 cactus pear cultivars. It is also well known that more than one crop can be obtained for the same environment by natural or artificially induced reflowering (Barbera *et al.*, 1991; Brutsch and Scott, 1991; Nerd *et al.*, 1993b; Sudzuki Hills *et al.*, 1993).

Genotype characteristics and interaction

Brutsch (1979), Pimienta Barrios (1990, 1994) and Wessels (1988a, 1989) indicated that cultivars differ in their reproductive vigour and cladode fertility. According to Wessels (1989) and Pimienta Barrios (1990), this **wide variation in productivity between cultivars** is due to:

- inherent genetic fertility differences;
- fertility of the mother plant; and
- cladode fertility of the mother plant.

On the other hand, **variation within a cultivar** is due to:

- variation in fertility of the mother plant; and
- fertility differences between cladodes according to position on the mother plant.

According to Barbera (1995), large variances in cactus pear fruit yield are due to inadequate understanding of **plant × environment interaction**. In an 8-year field trial with 11 cactus pear cultivars in three diverse agroclimatic areas in South Africa, Potgieter (2007) showed that there were significant differences between cultivars, diverse environments and production years in terms of fruit yield and its components. The variance observed in fruit yield was due first to soil P levels and second to applied N. The study results demonstrate clearly not only that environmental factors have a definite influence on fruit yield, but that there is strong interaction between the 11 cultivars tested and the environmental conditions. Broad cultivar adaptation was only seen in one cultivar and yielding ability in some cultivars is a genetic trait rather than a G × E response (Potgieter, 2007).

Orchard planning and design

Fruit productivity in cactus pear can be improved by increasing the number of fertile cladodes per plant and/or by increasing the plant population (Inglese *et al.*, 2002a). Extremely high fruit yields at an early plant age can be obtained at high plant densities. In Israel, spacing plants 1.5 m in the row and 4 m between rows (1 666 plants ha^{-1}) substantially increased the number of fertile cladodes in the early stages of orchard life, with fruit yields of 18 tonnes ha^{-1} for 4-year trees reported (Nerd and Mizrahi, 1993). According to Inglese *et al.* (2002a), to obtain an annual yield of 20 tonnes ha^{-1} – with an average fruit weight of 100-120 g and cladode fertility of six fruit per cladode after thinning – 28 000-30 000 fertile cladodes per hectare are needed. This implies 80-90 fertile cladodes per plant on free-standing plants spaced 6 × 5 m apart (335 plants ha^{-1}) or 28-30 fertile cladodes per plant for high-density hedgerow plantings with plants spaced 5 × 2 m apart (1 000 plants ha^{-1}) (Inglese *et al.*, 2002a). In order to further increase fruit yield, it would be necessary to increase the number of fertile cladodes rather than increase cladode fertility (Inglese, 1995).

Orchard practices

Large variations in fruit yield are regularly observed, even in well-managed orchards of the same cultivar (Potgieter, 2007). The low fruit yields reported in Mexico are partially due to the fact that a large percentage of growers do not use cultural practices such as fertilization and pruning, resulting in poor vegetative growth and low fruit yields (Pimienta Barrios, 1994). In comparison, the relatively high yields obtained in Sicily (14 tonnes ha^{-1}) are mainly due to irrigation, fertilization and thinning (Tudisca *et al.*, 2015).

Biennial or alternate bearing has been reported in cactus pear (Brutsch, 1979; Pimienta Barrios, 1990) and it is one of the reasons for large differences in annual fruit yield. Inglese *et al.* (1995) and Brutsch (1979) noted that the possible **reasons for alternate bearing** are:

- incorrect pruning;
- cultivar differences;
- plant age;
- competition between floral and vegetative growth; and
- bud induction timing.

Nevertheless, farmers prefer a cultivar that bears consistently – even if at a lower yield level – rather than a cultivar that bears well one year and poorly the next, as this pattern has a serious economic impact which negatively affects the cash flow position of the enterprise (Potgieter and Smith, 2006; Potgieter, 2007). Indeed, competition between reproductive and vegetative growth, as well as reduction in the number of new cladodes following SFR, are potential sources of plant alternate bearing behaviour (Inglese *et al.*, 2002b). Although Barbera *et al.* (1991) found that alternating plants in the off-year had the same number of 1-year cladodes as in the on-year, most of these cladodes were unfertile under scozzolatura conditions. Practical approaches for **reducing alternate bearing** are to:

- adopt appropriate pruning systems (García de Cortázar and Nobel, 1992);
- ensure fruit thinning regimes (Wessels, 1989; Hester and Cacho, 2003); and
- avoid *scozzolatura* and winter production on the same orchards every year.

HARVESTING

Quality is a very important factor in fruit production, since consumers prefer attractive fruit with a good taste and high nutritional and functional value. The overall quality is generally highest at harvest; it then declines at rates which vary according to genetic background, pre-harvest treatments, environmental conditions, degree of maturity at harvest, handling processes, post-harvest treatments, and storage and distribution conditions. Overall quality includes a very complex set of features not always positively correlated: depending on the targeted consumers, market destination and planned storage time, the importance of the various qualitative aspects varies. As the fruits mature, their nutritional value, flavour and taste improve, but the tissue's natural defence mechanisms against pathogens, susceptibility to some physiological disorders and potential life span all decrease. Therefore – as with other species (Crisosto and Valero, 2008) – for direct delivery to local markets, harvest should take place when the highest eating quality is reached; for delivery to distant markets, earlier harvesting is more appropriate to prolong the post-harvest life span.

In order to identify the best harvest time, objective and subjective maturity indexes have been developed, based on factors such as cultivar, producing country, fruit destination and utilization. The most popular harvest maturity indexes include:

- percentage of peel colour-break;
- total soluble solids (TSS) ≥ 13%;
- pulp firmness (measured with an 8-mm plunger) ≥ 8 kg cm^{-2} (Pimienta Barrios, 1990; Barbera *et al.*, 1992);
- reducing sugar level around 90% of that of full ripe fruit – however, in some cultivars the reducing sugars never exceed 50% of the total sugars (Pimienta Barrios and Mauricio, 1989);
- abscission of glochids;
- flattening of the floral cavity of the receptacle;
- percentage of pulp;
- peel thickness and ease of removal; and
- peel resistance to physical handling (Cantwell, 1995).

Cactus pears are particularly difficult to harvest because of the presence of glochids and spines, which can pierce the skin and enter the eyes and respiratory tract. Fruit are therefore harvested in the morning when humidity is sufficiently high to prevent glochids from dislodging and floating in the air. Pickers should be provided with protective clothing (gloves and safety glasses). Despite the plant's tough appearance and its ability to withstand harsh environmental conditions, the fruit are very tender and cannot withstand rough treatment (Wessels, 1992a).

For most cultivars, the physiological loosening of the articulation connecting the fruit to the mother cladode is low at harvest time, and injury at the stem end is inevitable if the fruit is harvested by snapping, pulling or twisting. Therefore, for commercial purposes, a knife must be used, a sharp cut made at the base of the fruit and a small piece of cladode left attached. Pickers usually collect the fruit in plastic baskets or lugs and empty them into plastic boxes holding 15-20 kg of fruit for transport to the packing house.

Physical damage during harvest and transport can markedly compromise fruit quality and storage length and increase fruit susceptibility to physiological disorders and decay. Bruises and wounds can occur due to finger pressure when cutting the fruit or impact when fruit are dropped into the baskets, and also during transport and handling in the packing house. Injuries are also inflicted by cutting and by glochids. The susceptibility of fruit to physical injuries increases with maturity. High cellular pressure can also cause cracks and microcracks of the peel, especially in second-crop fruit, which ripen in more humid environmental conditions.

Post-harvest handling

The presence of spines and glochids is one of the main constraints limiting cactus pear consumption and marketability; worldwide, their removal is the primary post-harvest operation before commercialization. In many countries, especially with fruit destined for the local market and consumed within a few days of harvest, despination is still done manually: the fruit are spread on the grass or areas covered with straw, and then the fruit are brushed with brooms (Cantwell, 1995). However, with fruit destined for distant markets, despination is done in packing lines.
Unlike other kinds of fruit, post-harvest operations of cactus pear are quite simple and restricted to despination, grading and packing. Regardless of the scale of the packing house, despination is generally accomplished by dry brushing. Given the limited post-harvest treatments, the production of several associated growers can be handled in a small-scale on-farm packing house with a **small, simple packing line** comprising the following components:

- dumping devise – fruit are dry-dumped before passing onto a series of rollers;
- tunnel – a series of brushes, each one rotating in the opposite direction to the next, remove the glochids, which are either vacuum-sucked out of the unit and deposited in a disposable bag or left to drop beneath the rollers;
- second set of rollers – fruit are conveyed onto a large round rotating table, where workers sort, grade and package them.

Larger packing houses comprise the following:

- dumping area;
- moving conveyer belt – workers preselect fruit;
- despining section – designed with the same criteria as for a small-scale packing house;
- sizing devise – either mechanical or electronic;
- delivery and packing devise – for final sorting and packing.

Fruit are usually packaged on the day of harvest and directly delivered to destination markets in refrigerated conditions. They can be transported alone or in combination with other commodities, by truck, ship or aircraft. When fruit are handled a few days after harvest, they can be stored at ambient conditions for curing or in storage rooms at 6-10 °C. In a small number of countries (e.g. South Africa), fruit are waxed to replace the natural waxes lost with despination, in order to reduce transpiration and enhance skin gloss. No synthetic fungicide is registered for post-harvest purposes; therefore, much care must be taken to avoid injuries and prevent microbiological decay.

In Italy, **fruit grading** is based on:

- cultivar ('Gialla' or 'Surfarina'; 'Red' or 'Sanguigna'; and 'Bianca' or 'Muscaredda' or 'Sciannarina');
- category (EXTRA and I); and
- weight (class B, 105-140 g; class C, 140-190 g; class D, 190-270 g).

Depending on the cultivar, peel shades can range from green to orange–yellow for the yellow cultivar ('Gialla'), from green to ruby-red for the red cultivar ('Rossa') and from green to straw-white for the white cultivar ('Bianca'). Depending on producing area, fruit destined for the fresh market must have the following characteristics:

- weight ≥ 120 g
- TSS ≥ 13-14% °Brix
- flesh firmness ≥ 6 kg cm^2

Larger fruit can be packed in one-layer plastic nest trays inserted in carton or plastic trays or directly in carton trays. Small fruit, generally destined for local markets, are packaged in plastic trays or punnets containing 6-8 fruits.

Post-harvest physiology

Cactus pears are classified as non-climacteric, as they do not exhibit a rise in respiratory activity during the ripening period. Respiration rates are generally considered quite low compared with other fruits (Lakshminarayana and Estrella, 1978; Cantwell, 1995). However, respiratory intensity is strongly affected by:

- genetic background (quite wide in cactus pear);
- ripening stage at harvest;
- crop type; and
- environmental conditions.

In a study of different varieties from the Mexican germplasm conducted by López Castañeda *et al.* (2010), respiratory activity ranged from 22 in 'Rojo Pelón' to 31 ml CO_2 kg^{-1} $hour^{-1}$ in 'Sangre de Toro' and 'Alfajayucan'. In studies conducted in Italy with fruit from the first crop of 'Gialla', respiration intensity showed very pronounced variability from year to year, ranging from 4-14 mg CO_2 kg^{-1} $hour^{-1}$ (Chessa and Schirra, 1992) to 13 ml CO_2 kg^1 $hour^{-1}$ (D'Aquino *et al.*, 2014) and 60-92 mg CO_2 kg^{-1} $hour^{-1}$ (Piga *et al.*, 1996). As in other non-climacteric species, respiration declines gradually when fruit are held at warm temperatures (D'Aquino *et al.*, 2014), but when moved from cold storage to room temperature, respiration increases greatly (Schirra *et al.*, 1999b) in response to chilling temperature. Incipient infections from microorganisms, and physical or mechanical stresses caused by bruising, impact or wounds, can also lead to sudden increases in respiratory activity. Ethylene production is very low, generally 0.1-0.2 µl C_2H4 kg^{-1} $hour^{-1}$ and, as for respiration, significant increases may occur after prolonged exposure to chilling temperatures, or because of pathogen infections or abiotic stresses (D'Aquino *et al.*, 2104; Schirra *et al.*, 1996, 1997).

As with most non-climacteric fruit, cactus pear does not contain starch. Therefore, after harvest, TSS, sugars and organic acids tend to decrease, depending on storage conditions, ripening stage and cultivars; the pattern of decline can be gradual or uneven. For example, in a comparative study with six cultivars of cactus pear stored at 9 °C for 1, 2 or 3 months plus 4 days at room temperature, the loss of TSS was very high in 'Amarillo Montesa', 'Copena T-5' and Copena-Torreoja', but gradual in 'Cristalina' and 'Pinochulo', while in 'Burrona' losses were highest during the first month of storage (Corrales Garcìa *et al.*, 1997).

Vitamin C content at harvest ranges from about 10 to 80 mg 100 g^{-1} depending on the cultivar (Butera *et al.*, 2002; Kuti, 2004). It can vary greatly from year to year (Sumaya Martìnez *et al.*, 2011), but also depends on the ripening stage. In fruit of yellow and orange cultivars of Opuntia megacantha harvested at 2-week intervals, 4 weeks before commercial maturity and then 4 weeks after commercial maturity, the vitamin C content increased constantly even when fruit were overripe (Coria Cayupàn *et al.*, 2011). In fruit stored at low temperature, the vitamin C content is quite stable despite the relatively high pH of the juice (Schirra *et al.*, 1996), but it declines rapidly at room temperature (D'Aquino *et al.*, 2014) or after fruit are moved from cold storage to warm temperatures (Schirra *et al.*, 1996).

Physiological disorders

Similar to most species of tropical origin, cactus pear is susceptible to chilling injury when exposed for prolonged periods to temperatures below 10-12° C. Indeed, the intrinsic **sensitivity of fruit to low temperature** is markedly affected by:

- environmental conditions;
- agronomic practices;
- crop type (summer or late crop); ripening stage at harvest; cultivar; and
- post-harvest treatment.

Generally fruit at an advanced stage of maturity are less susceptible to chilling injury than less ripe fruit, while pre-harvest treatment with gibberellic acid (Schirra *et al.*, 1999a) or calcium chloride (Schirra *et al.*, 1999b) do not affect or increase fruit susceptibility to chilling injury. Symptoms of chilling injury can manifest on the peel as scalded or bronzed areas varying in size and intensity, black-brownish pits and sunken brown spots (D'Aquino *et al.*, 2012). However, chilling injury can also cause metabolic alterations in addition to visible symptoms; likewise, the appearance and severity of peel disorders are accompanied by non-visible qualitative alterations. Indeed, peel alterations are usually a combination of disorders induced by low temperature and other causes (superficial wounds inflicted by glochids, excessive transpiration, dry rots) that can appear at non-chilling temperatures (D'Aquino *et al.*, 2012, 2014). Metabolic imbalances may alter the respiratory metabolism, induce the production of undesirable volatiles (acetaldehyde, ethanol) and ethylene, and lower the overall host defence mechanisms to pathogens (Schirra *et al.*, 1999a; D'Aquino *et al.*, 2014). As a result, chill-injured fruit may show peel disorders without any change in eating quality or chemical composition (D'Aquino *et al.*, 2014); or they may show negligible symptoms of chilling injury at the end of cold storage but become highly susceptible to decay when moved to warm temperatures (Schirra *et al.* 1996, 1997, 1999b; D'Aquino *et al.*, 2014).

Post-harvest decay

Fruit composition and tissue consistency make cactus pear highly susceptible to decay incited by various pathogenic fungi, yeast and bacteria. The stem end is the main site of infection due to wounding caused by harvesting operations. However, a curing treatment of 1-2 days at room temperature in ventilated conditions helps heal wounded tissue. Even a slight dehydration of the little piece of cladode left at harvest can effectively reduce the risk of decay (Cantwell, 1995; Inglese *et al.*, 2002a). Other sites of infection are the microwounds caused by glochids and microcracks in the peel, especially if second-crop fruit are harvested under wet conditions. The main filamentous fungi that cause decay are *Botrytis cinerea*, *Fusarium* spp., *Aspergillus* spp. and various *Penicillium* species, including *P. digitatum*, *P. italicum*, *P. expansum* and *P. polonicum* (Chessa and Barbera, 1984; Rodriguez Felix *et al.*, 1992; Granata and Sidoti, 2000; Swart *et al.*, 2003; D'Aquino *et al.*, 2015; Faedda *et al.*, 2015a). However, since fruit are generally not stored for long periods, the risk of decay does not represent a serious problem.

Post-harvest treatments

Despite limited treatments at commercial level and occasional refrigeration for short periods, the increasing worldwide demand for cactus pear – especially from markets located far from producing areas – will pose new challenges for the cactus pear industry in the future. In order to extend the market window beyond the harvest season and delay the decline in appearance, appropriate **post-harvest treatments and handling procedures** are required to:

- reduce transpiration and respiration rates;
- increase fruit tolerance to chilling temperatures; and
- prevent microbiological spoilage.

While refrigeration is undoubtedly the main means for prolonging the post-harvest life of fresh fruit and vegetables, the susceptibility of cactus pear to chilling injury poses limits to its use. On the other hand, as with other commodities, as storage life increases, the natural defence mechanism of tissue against pathogens declines and fruit become progressively more susceptible to microbiological attacks, especially when moved from cold storage to a warm environment.

Experiments conducted with post-harvest fungicides approved for other commodities revealed various degrees of effectiveness in reducing decay incidence in cold-stored cactus pears:

- Benomyl, captan or vinclozolin treatments were ineffective in controlling post-harvest decay (Gorini *et al.*, 1993).
- Imazalil (IMZ) and thiabendazole (TBZ) treatments prevented natural decay induced by *Penicillium* spp., *Botrytis cinerea* and *Alternaria* spp. in first-crop 'Gialla' fruit over a 2-month storage period at 8° C followed by 1 week of simulated marketing conditions at 20° C; chilling injury symptoms were also reduced (D'Aquino *et al.*, 1996). Sodium ortophenilphenate, either alone or in combination with TBZ or IMZ, was phytotoxic, resulting in increased decay and weight loss (D'Aquino *et al.*, 1996). TBZ efficiency was markedly increased when applied at 52° C even at a concentration six times lower than that applied at 20° C (Schirra *et al.*, 2002).
- Fludioxonil, a synthetic fungicide registered over the last decade to control a wide range of decay-causing fungi in different commodities, very efficiently controlled decay when applied at 20 or 50 °C before storage; on the other hand, its effectiveness was reduced when it was applied at the end of cold storage (D'Aquino *et al.*, 2015).
- Hot water – either as dip treatment at 50-55° C for 2-5 minutes (Schirra *et al.*, 1996, 2002; Rodriguez *et al.*, 2005; D'Aquino *et al.*, 2012) or by water brushing at 60, 65 or 70° C for 30, 20 or 10 seconds, respectively (Dimitris *et al.*, 2005) – inhibited the growth of pathogens naturally present on the fruit surface.
- Curing (at 38° C for 24, 48 and 72 hours in a vapour-saturated environment) not only controlled decay, but also improved fruit sensitivity to chilling temperatures (Schirra *et al.*, 1997). Yet, curing the fruit at 38° C with 75-80% relative humidity (RH) hastened detachment of the piece of mother cladode left at harvest. Additionally, the healing process of the stem-end scar with respect to curing at the same temperature but with 100% RH decreased decay incited by pathogens developing from the stem (D'Aquino *et al.*, 2014). High temperature conditioning delayed fruit ageing and weight loss, possibly due to melting and rearrangement of the epicuticular wax layers with consequent filling of microcracks separating wax platelets, the main fruit transpiration pathway (Schirra *et al.*, 1999a; López Castañeda *et al.*, 2010).

Other treatments which can delay loss of freshness and increase tolerance to low temperature are: controlled atmosphere storage (Testoni and Eccher Zerbini, 1990); intermittent warming (Chessa and Schirra, 1992); salicylic acid dip treatments (Al Qurashi and Awad, 2012); and film wrapping (Piga *et al.*, 1996, 1997; Shumye *et al.*, 2014), although the latter may induce anaerobic conditions and a build-up of undesirable volatiles (Piga *et al.*, 1996) if film permeability to gases does not match the O_2 requirement of packaged fruit.

READY-TO-EAT CACTUS PEAR

Over the last two decades, the fresh-cut fruit market has seen steady growth due to consumers' tendency to eat healthy and convenient foods at any moment and in any place. Ready-to-eat fruit and vegetables are attractive because the consumer requires no labour and generates no waste through peeling and coring (Rojas Graü *et al.*, 2011). This is particularly relevant in the case of cactus pear, where the presence of glochids makes the fruit difficult to peel, especially for people not familiar with it.

Fresh-cut fruit and vegetables are very perishable products; wounds caused by processing operations stimulate respiration and ethylene production rates, hastening the loss of respirable substrates, firmness and senescence.

Damaged tissues are also subject to oxidative browning due to the enzyme polyphenol oxidase (PPO) (Beaulieu and Gorny, 2004). The increasing demand for fresh-cut cactus pear has had a marked impact on companies involved in processing and distribution: more attention is paid to hygienic requirements and new packing solutions are adopted to meet logistics and consumer requirements (Timpanaro *et al.*, 2015a).

The main factors affecting the quality of fresh-cut cactus pear are loss of acidity, firmness, juice leakage and, above all, microbiological spoilage. Spoilage is a considerable hazard, especially when there is contamination by pathogenic microorganisms with potentially harmful effects on consumer safety (Yahia and Sàenz, 2011). When fruit are stored at the optimal temperature of 4-5°C, TSS are quite stable and sometimes increase; on the other hand, titratable acidity and juice pH are quite stable but may decrease (Piga *et al.*, 2000). Higher temperatures reduce the potential storage life, while increased O_2 requirements due to increased metabolic activity may not be matched by the packaging permeability to gases, leading to abnormal increases in titratable acidity, ethanol and taste alterations as a result of anaerobic respiration (Piga *et al.*, 2000).

Its low acidity and high sugar content make cactus pear – more than any other fruit – an ideal substrate for microbiological proliferation. In order to maintain bacteria and yeast populations below the legal limits of 10^7 and 10^8 CFU g-1 established in Spanish legislation (BOE, 2001), it is essential to use appropriate processing equipment and adopt an effective sanitizing programme, with personnel trained in hygienic processing and maintenance of low storage temperatures. Surface sterilization of the fruit surface prior to peeling is generally achieved by dip treatments in sodium hypochlorite; however, new alternatives that are safer for workers and consumers as well as environmentally friendly and cheap, such as electrolyzed water (Pannitteri *et al.*, 2015), are gaining in popularity.

Provided processing operations maintain low initial microbiological load, storage temperature is the main factor affecting the microbiological population. The recommended storage temperature range of 8-12° C to prevent chilling injury of the whole fruit is not optimal for storage of ready-to-eat cactus pear; indeed, the best results in terms of maintenance of overall chemical, sensory and microbiological quality are at 4-5° C (Piga *et al.*, 2000; Corbo *et al.*, 2004; Del Nobile *et al.*, 2007; Cefola *et al.*, 2014). The permeability of the film used for packaging and in-package gas composition have a minor impact on chemical composition and microbiological population when fruit are stored at 4-5° C. However, temperature increments and reduced levels of O_2, coupled with increased concentration of CO_2, may lead to anaerobic conditions and in turn induce production of undesirable volatiles, compromising the sensory quality and altering the microbiological population both quantitatively and qualitatively (Piga *et al.*, 2000; Del Nobile *et al.*, 2009).

Coatings based on sodium alginate, agar and fish protein gel did not affect yeasts and mesophilic bacteria but stimulated the load of lactic acid, psycrothrophic and coliform bacteria (Del Nobile *et al.*, 2009). When acetic acid was combined with chitosan, an overall decrease in the microbial population was achieved compared with the control fruit (Ochoa Velasco and Guerrero Beltrán, 2014). Coating fresh-cut cactus pear is not common at commercial level and the literature indicates no clear and consistent benefits from their application (Del Nobile *et al.*, 2009; Ochoa Velasco and Guerrero Beltrán, 2014; Palma *et al.*, 2015).

Storage response may also be affected by the stage of ripeness and the ripening time of the fruit. The overall quality of the summer crop declines faster than that of the *scozzolatura* crop, while fruit harvested at the commercial stage maintains its quality longer than fruit harvested later, when fully ripe, especially in the case of fruit coming from the *scozzolatura* crop (Allegra *et al.*, 2015). Both aerobic mesophilic bacteria and mould population are affected more – albeit in different ways – by the stage of ripeness than by the time of ripening, with fruit harvested at an advanced stage of maturity showing a higher load than fruit harvested at the commercial stage (Allegra *et al.*, 2015).

CONCLUSIONS AND FUTURE PERSPECTIVES

While there has been a general improvement in orchard practices over the past two decades, much remains to be done to convince producers that cactus pear can achieve high yields and good quality if it receives appropriate care and attention – just like any other crop. It is hoped that by providing the latest technical and scientific information on the cultivation and post-harvest management of the crop, productivity levels and especially fruit quality standards worldwide will improve, enabling the fruit to compete on an equal footing with other mainstream fruits on international markets. In order to attract new consumers to cactus pear fruit and create higher demand, consistent high-quality fruit must be available on the market. Increased fruit productivity is easier to achieve than improved fruit quality; special attention should be therefore given to all horticultural practices potentially affecting fruit quality, both pre- and post-harvest.

Figure 1
Cumulative growth cDespination of cactus pear fruit by rotating brushes: besides removing glochids the brushed make the fruit shiny.

Figure 2
Sorting table used to sort, grade and pack the fruit

Figure 3
Chilling injury as scald staining (a) and tissue depression underneath the peel around the receptacle scar (b).

Figure 4
Chilling injury symptoms in the form pits (a) and brownish scars (b).

Figure 5
Fruit splitting occurring in fruit stored at high humidity levels.

Figure 6
Soft rot on cactus pear starting from the stem end.

Figure 7
Decay caused by Penicillium spp. in cold stored cactus pear.

Figure 8
Dry rot (Alternaria spp.) develops slowly in cactus pears stored for long time.

Figure 9
Preparation of ready-to-eat cactus pears: fruit are first manually peeled and placed in plastic punnets (a) and then sealed with a polymeric film (b).