RESEARCH STRATEGIES AND IMPROVEMENT OF CACTUS PEAR (*Opuntia ficus-indica*) FRUIT QUALITY AND PRODUCTION

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Abstract

Cactus pear (*Opuntia ficus-indica* L.) is cultivated worldwide for fruit production either in the subsistence agriculture of dry-land areas or as a cash crop. However, little horticultural research has been devoted to this species Research needs related to reproductive biology as well as productivity and orchard management are outlined. A better knowledge of environmental influences on reproductive biology and fruit quality, the control of fluctuations in plant cropping, as well as reduction of seed number and size, are the major challenges for future research. Cactus pear will transcend the ethnic markets only if adequate marketing strategies are promoted and fruit quality enhanced and standardized.

Introduction

Cactus pear (*Opuntia ficus-indica* L.) is cultivated in both hemispheres and all the continents (Table 1). Its products have always been very popular among rural populations of arid and semiarid areas in its native regions of Mexico and in the Mediterranean basin, where it was introduced at the beginning of the 16th century (Barbera and Inglese, 1993). Products include fruits and cladodes for human nutrition and cattle feeding (fodder and forage), as well as by-products such as the red dye extracted from the Cochinilla (*Dactilopius coccus* Costa) body. Moreover, cactus utilization is common in popular medicine (flowers and cladodes), and field management (windbreaks, soil erosion control, hedges) (Table 2).

Despite the large range of commodities cactus could provide in areas with scarce available resources, cactus pear has received scarce attention by horticultural research. In Italy, cactus pear has been cultivated for fruit production since the beginning of the last century; however, no more than 120 scientific articles, and two textbooks, have been published (Barbera et al., 1988b). Furthermore, the Melvyl Catalog, which currently reviews the greatest number of refereed scientific journals, cites (1989 to July 1993) 65 articles, dealing with different cacti (35 on *Opuntia ficus-indica*) (Table 3). Most of them refer to botany and plant physiology, whilst only few articles discuss problems related to fruit or forage production. Most of the research in plant physiology and ecology comes from the USA, while Israeli, Italian, and South African researchers produce most of the horticultural research.

In the last decade, cactus pear orchards for fruit production have been planted worldwide due to an increase of tropical fruit consumption in the rich European and North American markets. At the same time, advancing desertification coupled with the urgent need for appropriate technologies and crops capable of developing sustainable and valuable production in arid and semiarid areas, has raised new interest for the environmental role and the potential productivity of cacti. Recently, an international network has been established within the Food and Agriculture Organization of the United Nations (FAO) framework (Pimienta Barrios et al., 1993) with the aim of improving research activity and cooperation. Fortunately, several new books on cacti biology, uses, and orcharding have been published or are about to be published (Barbera and Inglese, 1993; Pimienta Barrios, 1990; Barbera, Inglese, and Pimienta Barrios, 1994; Nobel, 1988, 1994; Wessels, 1988).

The complexity of the species, together with the relevance of its different uses, would certainly deserve more attention. Therefore, the goal of this paper will be to review the limited biological and technical data related to fruit production to develop research priorities to improve the horticultural potential of this species.

Environmental Aspects and Plant Performance

Many aspects of the environmental biology of the crassulacean acid metabolism (CAM) species *Opuntia ficus-indica*, particularly the influence of temperature, light, water availability, and air CO_2 level on plant survival and growth, cladode CO_2 uptake, as well as water relations and root activity, have been investigated (Nobel, 1988). Plant biomass productivity and cladode growth have also been investigated and described in relation to environment and plantation design (Garcia de Cortazar and Nobel, 1986, 1990, 1992; Luo and Nobel, 1993). However, only a limited amount of research has been devoted to the effect of the environment on the reproductive biology or on the competitive growth of reproductive and vegetative organs of this species. Moreover, little is known (Luo and Nobel 1992) about the competitive allocation of photosynthates within the different root and canopy sinks. Fruit quality has never been investigated in relation to environment.

The major questions involve the effect that temperature plays in physiological processes such as flower bud evocation, initiation, and differentiation. Basal temperature as well as thermal time (growing degree-hours) for spring burst and fruit development are unknown. Early investigations (Alfonso Spagna, 1884) claim that daily temperatures lower than 20 °C prevent the reflowering of cactus pear that is induced by the removal of the spring flush of flowers and cladodes (Barbera et al., 1991). Portolano (1962) reports that low, yet not defined, temperatures may alter the vegetative-reproductive growth balance, with a low number of flowers being produced under low-temperature conditions. On the other hand, Nerd (Nerd et al., 1989) hypothesized the need for some winter chilling for flower bud differentiation. Indeed, the plant experiences a period of apparent reduced growth in winter, but there is no biological or hormonal evidence of true rest, and the lack of apparent growth in winter time could be the result of ecodormancy rather than endodormancy (Faust, 1989). The same authors (Nerd et al., 1989) gave evidence of the counteracting effect that high temperatures (above 30 °C) have on flower bud production. Eventually, plant response to photoperiod and thermoperiod in terms of flower bud production will require specific investigations.

The fruit development period (FDP) occurs over a great range of climatic conditions throughout the world and the development period varies from 70 to 150 days (Inglese and Barbera 1992; Brustch, 1979; Kuti, 1992; Nerd et al., 1990; Pimienta, 1990). In Chile, Israel, and Italy, indeed, differences in temperature most likely account for the longer FDP of the off-season crop as compared to the summer crop and also involve changes in fruit characteristics such as size, shape, peel thickness and color, seed number, and sugar content (Barbera and Inglese, 1993; Nerd et al., 1991). Ripening is also very sensitive to temperature, and if FDP lasts until late fall, when average daily temperature is 15 ±1.6 °C, fruits will eventually overwinter and ripen the next spring (Barbera and Inglese, 1993). On the other hand, summer fruits, which usually ripen when average daily temperatures reach 25 ±2.5 °C, could ripen abruptly, and harvest time will be difficult to set, since they rapidly lose their commercial quality. Physiological high-temperature-induced disorders have been reported to affect the fruits at various stages of the FDP (Brutsch, 1992), However, neither the influence of temperature on fruit growth rate and FDP length nor the optimal or critical temperatures for fruit growth and ripening have been specifically investigated, particularly in relation to fruit quality.

Light environment deeply affects plant growth and cladode characteristics because nighttime CO_2 uptake depends on total daily photosynthetically active radiation (PAR) (Nobel, 1988). Inhibition of flower bud initiation may result from cladode shading during the inductive period (Barbera et al., 1993a). Moreover, preliminary observations aimed to evaluate the flower bud induction time showed a clear effect of the length of shading period on flower bud initiation and the balance between vegetative and reproductive bud production (Figure 1). Evaluating the effect of shading during the year on the different developmental stages of cladodes, flower buds, and fruits is important. Light effect on fruit size, and quality parameters, such as skin color and sugar content, have been demonstrated in different tree crops such as peach (Erez and Flore, 1986) kiwifruit (Grant and Ryugo, 1984) and apple (Chalmers and Faragher, 1977). These light effects involve both the shading of the main source for fruit assimilates, that is the leaf, and the shading of the fruit itself. Such effects have not been studied in *Opuntia ficus-indica* although fruits growing in shaded portions of the canopy appear smaller, less colored, and ripen later than fully exposed fruits.

Water availability influences both productivity potential and fruit quality, namely, size and percentage flesh (Garcia de Cortazar and Nobel, 1990; Nerd et al., 1989, 1991; Barbera, 1984). Water shortage might affect extent and timing of flower bud production (Nerd et al., 1989), and depress the off-season crop (Nerd et al., 1991). However, the mechanism that controls the water shortage effect on flower bud differentiation, and the response of the plant in terms of vegetative to flower bud production has not been defined. Moreover, little is known about fruit gas exchanges and water relations with the mother cladode.

Fluctuations in water availability during fruit ripening may cause fruit disorders, such as splitting, and the extent of damage is likely to depend on fruit developmental stage and cultivar sensitivity.

Productivity, Reproductive Biology, and Fruit Quality

Productivity of *Opuntia ficus-indica* is extremely variable from country to country. In Israel and Italy, yields of 20-30 tons ha^{-1} are reported (Barbera and Inglese, 1993; Nerd et al., 1993), while yields are much lower in Chile (6-9 tons ha^{-1}) (Saenz, 1985) and Mexico (4-8 tons ha^{-1}) (Pimienta, 1992). This wide variability in yield most likely depends on orchard design and management; however, cultivar behavior in terms of plant fertility and productivity needs to be investigated in comparative trials under different environmental conditions.

Productivity ranges also vary at orchard and plant level. Alternate bearing has been reported in *Opuntia ficus-indica* (Brutsch, 1979; Pimienta Barrios, 1990; Barbera et al., 1991), and might account for differences in plant productivity at orchard level. However, it is not clear whether this behavior depends on mismanagement, cultivar, plant age, or on competitive interactions between cropping and both vegetative growth and flower bud induction. Differences in planting material, particularly rooting ability and root development, might account for discrepancies in cropping performance during the first years after planting (Brutsch, 1979).

Most of the fruits grow on terminal 1-year-old cladodes. However, mature plants that produce few new cladodes every year bear fruits on 2-year-old cladodes that are usually less fruitful (Inglese et al., 1994; Nerd et al., 1993). Eighty to ninety percent of 1-year-old cladodes are fruitful (Inglese et al., 1994). The cladodes' ability to produce fruits varies greatly with cladode position and orientation, and can be related to the dry weight accumulation relative to the cladode surface area (Garcia de Cortazar and Nobel, 1992). Indeed, a different developmental stage of cladodes may affect flower bud induction under highly stimulative conditions (Nerd et al., 1993). However, the relationship between cladode developmental stage and flower bud induction and development deserves further investigation.

One of the most striking features of *Opuntia ficus-indica* is the ability of the cladodes to reflower. In Chile, cladodes reflower without any specific technique being applied and the resulting off-season crop will give yields 50-60% lower than the major summer crop. In Israel, the off-season crop, 20-30% of the summer crop, is induced by mean of extensive (120 kg ha^{-1}) N fertigation (Nerd et al, 1993). In Italy (Barbera et al., 1991) and South Africa (Brutsch and Scott, 1991) a second flowering is obtained by removing the first flush of flowers and cladodes. Hence, cladodes still show the ability to reflower, but they will crop once a year. However, two crops of the same size can be obtained at orchard level, one ripening in summer and the other one in fall.

Many questions arise about the reflowering ability of the cladodes involving major physiological and technical aspects, such as flower bud induction timing, sink interaction, environmental influence, and cultivar behavior. It seems that flower buds are induced just before differentiation (Barbera et al., 1993a) and, indeed, there is no morphological evidence of differentiation until a few days after bud emergence from the areolae (Rivera et al., 1981; Nieddu and Spano, 1992).

Thus, if the cladodes' flowering characteristics account for differences at the whole-plant level (Barbera et al., 1991), the prevailing environmental condition at the flower-removal time might play a critical role in determining the extent of reflowering. These reflowering characteristics differ from year to year with the environment (Barbera et al., 1991; Brutsch, 1991; Nieddu and Spano, 1992).

Reflowering is strongly depressed when all flowers, but no developing cladodes, are removed or when flowers are removed only after set (Inglese et al., 1994; Barbera et al., 1991). Hence, manipulation of sinks affects flower bud production, most likely through an altered hormonal balance. The critical role of hormones, namely GA_3, in flower bud production and fruit characteristics (shape, percent flesh, seed content) has been recently demonstrated (Barbera et al., 1993a). Preliminary evidence suggests that polyamines may play a role in flower initiation (Nerd et al., 1993). However, more extensive research will be needed to understand the hormonal regulation of plant processes and morphogenesis in cacti.

Size, percent flesh, color, total soluble solids (TSS), and seed content are the main parameters characterizing fruit quality. Fruit size depends on seed number (Barbera et al., 1992c), cladode load (Barbera et al., 1993b; Brutsch, 1992; Wessels, 1988), water availability (Barbera, 1984), and ripening time (Barbera et al., 1992c; Brutsch and Scott, 1991; Nerd et al., 1991). Differences in fruit size are more evident in Mexico, with the Mexican green-clear fruits being larger than fruits in South Africa or Italy (Pimienta Barrios, 1992; Brutsch, 1979; Barbera et al., 1992a, 1992c). In Italy, fruits are selected commercially according to their size: extra large fruits, over 160 g; first class, 120-160 g; second class fruits, 80-100 g; and third class fruits, below 80 g. In South Africa, export-size fruits must exceed 120 g (Brutsch, 1979). In Italy, thinning recommendations limit cladode load to 6-8 fruits (Barbera et al., 1993b), while in South Africa, higher cladode loads are recommended (Wessels, 1988). Cladode conditions might account for these differences and the relation between cladode size (surface area, thickness) and fruit load and size need further investigations. Most important is the percentage of flesh, which should not be lower than 55-60% in export fruits. In Italy, *Gialla, Rossa*, and *Bianca* cultivars show a range from 55-60% both in summer and late crop (Barbera et al., 1992c). *Ofer*, the Israeli cultivar, ranges from 42% (winter crop) to 55% (summer crop), while a wider range, 30-60%, has been found in South Africa, most likely because of different management and environmental conditions (Wessels, 1988). In Mexico, a comparison between nine cultivars revealed a 40-60% range (Pimienta Barrios, 1992). Low temperatures during ripening might account for a reduction in flesh growth and ultimate size, while extensive N fertilization would increase peel thickness, reducing the flesh-to-peel ratio and the peel color (Barbera and Inglese, 1993).

The most appreciated fruits on the international market are yellow-orange (peel and flesh), like *Amarilla huesona* and *Amarilla pico-chulo* in Mexico; *Blue motto, Gymnocarpa*, and *Malta* in South Africa; *Ofer* in Israel; and *Gialla* in Italy. Red-purple fruits, like *Algerian* in South Africa, *Pelon liso* and *Rojo pelon* in Mexico, and *Rossa* in Italy are also appreciated, particularly in North America markets, but their cultivation is still limited. Green-clear or white cultivars as well as the pink-orange ones are relevant only in regional markets and have major problems of handling and storage.

Sugar content plays a decisive role in defining fruit quality because consumers favor sweet fruits. Sugars, mainly glucose and fructose, accumulate faster during the final weeks of flesh development and it is generally recognized that TSS optimum values at harvest should be 13-15% (Barbera et al., 1992b; Kuti, 1992). We do not have much information on factors such as a Hivar environment, a management that might influence influence TSS. Ripening time does not seem to be particularly significant as far as summer and fall crop as compared (Barbera et al., 1991; Brutsch and Scott, 1991; Nerd et al., 1991). However, the irrigation regime might reduce TSS (Barbera, 1984). Fruits ripening early in winter might reach a low TSS level because of a suboptimal temperature regime (Barbera et al., 1988a). The fruits do have a very low acidity (0.02-0.06% expressed as malic acid).

One of the major constraints limiting the consumption of cactus pears is, no doubt, the presence of thick, hard seeds in the flesh. Seed number depends on initial ovule number (Pimienta Barrios, 1990) pollination efficiency, and varies with cultivar and ripening time (Barbera et al., 1992c; Pimienta Barrios, and Leguizamo, 1989). Indeed, there is a close relationship between seed number/weight and fruit/flesh weight (Barbera et al., 1992c), and anatomical evidence of the relation between seed and flesh development (Pimienta Barrios and Engleman, 1985; Wessels, 1992). Empty rudimentary seeds, caused by early failure of embryo growth, are common in cactus pears and allow flesh development (Pimienta Barrios and Engleman, 1985).

The ratio between empty and normal seeds is one of the most important parameters that define fruit quality. This ratio is higher in the Italian (0.44) than in the Mexican (0.11) cultivars (Barbera et al., 1992c; Pimienta Barrios, and Leguizamo, 1989). No data are available on the South African or Israeli and Chilean cultivars. However, stenospermocarpic fruits, with empty rudimentary seeds, are common in the Mexican and Italian *Opuntia* spp. genetic pool (Barbera et al., 1992a; Pimienta Barrios, 1990). Seed size also varies by cultivar (Pimienta Barrios and Leguizamo, 1989; Barbera et al., 1992a, 1992c) and by species in cacti (Nerd et al., 1990). Selection within the existing germ plasm and breeding to reduce either seed number and size or to increase the percentage of empty seeds, is needed and deserves the strongest cooperative effort in the near future.

Field solutions, such as the use of GA_3 intended to cause embryo abortion, hence seed failure, without reducing flesh development, have been attempted (Diaz, and Gil, 1978; Gil and Espinosa, 1980). However, the results are controversial and the technique is not yet practical for field applications.

The nutritional value of the fruits (Sawaya et al., 1983) deserves more investigation in terms of mineral element content, amino acid and vitamin content, and variability induced by cultivar-environment interaction.

Finally, relations between harvest indices, such as peel color or TSS, and overall fruit quality have to be investigated to better define harvest time.

Orchard Management

Orchard design and management vary greatly worldwide. Extensive plantations with many cultivars of different *Opuntia* species (*O. ficus-indica, O. amyclaea, O. streptacanta*) and hybrids are common in Mexico (Pimienta Barrios, 1992). Only one green-clear cultivar is currently grown in semi-intensive plantations in Chile (Saenz, 1985). Intensive small-scale plantations, mostly (90%) based on one yellow-orange cultivar, characterize the cactus pear industry in Italy (Barbera et al., 1992a) and Israel (Nerd et al., 1989). Large intensive plantations occur in South Africa (Wessels, 1988) where a few cultivars of different origin are grown commercially. Large plant spacings are typical of the rain-fed agriculture of Mexico, while very close spacings are common in the fertigated orchards of Israel. Surprisingly, very little research has been devoted to plant spacings for fruit production, while data are available for biomass productivity (Garcia de Cortazar and Nobel, 1986). The relation between row orientation and PAR interception has been extensively investigated worldwide (Nobel, 1982).

Plantations in Israel and Italy give similar yields but differ greatly in plant spacing. As a matter of fact, differences occur also in relation to planting material (age and number of daughter cladodes) and number of cuttings per planting hole (Barbera, Inglese, 1993). Eventually, the influence of such different planting strategies have to be investigated in relation to precocity of yield, environmental sustainability, and maintenance costs. Garcia de Cortazar and Nobel (1986) defined the stem area index (SAI) that maximizes productivity in terms of biomass. However, optimal SAI for fruit production, as well as the way to achieve it, are not defined yet. Close spacing (1-1.5 m) within the row will maximize yield in the years after planting, but should result in overshading after a few years. Then more pruning will be necessary to avoid sharp reduction in yield and fruit quality. A fast SAI increase would be attained by planting more cuttings per planting hole, spaced 4 m apart, a strategy that is common in Italy (Inglese and Barbera, 1992). This will result in globe-shaped trees with most of the production in the outer cladodes; however, these trees will rapidly become 3-3.5 m high and 4-4.5 m wide, with greater pruning and harvest costs.

Pruning represents one of the major cost in the Italian industry (Basile, 1989). Interaction between annual or long-term productivity with pruning are unknown. A better knowledge of plant architecture in terms of flowers and young cladode production is needed to rationalize the pruning. Frequency and timing of pruning should also be investigated to elucidate plant response in terms of quantity and quality of newly produced cladodes. Plant response to pruning changes with age; pruning should be scheduled accordingly.

Because of its high water-use efficiency, cactus pear water requirements for fruit production are very low, although they still vary with the prevailing environmental conditions. However, only in Israel and Italy do orchards commonly benefit from irrigation: 500 mm are supplied throughout the year in Israel with drip irrigation systems, while 50-80 mm of water, distributed in two intervals during the fruit development period, are essential to achieve export fruit size in the late Italian production. Nevertheless, field parameters for appropriate irrigation scheduling are not available. The capacity of the water storage tissue of the cladode (the parenchyma) to buffer environmental stresses makes it difficult to rely on soil-water parameters. To maximize irrigation efficiency, correlations will have to be developed between agrometeorological data, such as Class A pan potential evapotranspiration, and fruit production.

Fertilization of cactus pear does not rely on any specific biological or technical information. Little knowledge specific to *Opuntia ficus-indica* has been achieved so far. Nobel (1989) proposed a nutrient index (NI) and Gathaara, et al. (1989) evaluated the role of phosphorous (P) and nitrogen (N) in cladode cropping performance of *O. englemannii*. Nitrogen extensive fertilization soon after summer crop harvest, promotes an early budding which results in an off-season production in Israel (Nerd et al., 1993). However, information on nutrient effects is still controversial in terms of plant fruiting response; reference parameters for nutrient content diagnosis have still to be set. It would be necessary to standardize sampling procedures, taking into account metabolic differences between chlorenchyma and parenchyma (Nobel et al., 1987). Early recommendations (Monjauze and Les Houerou, 1965) were for a 3-year frequency in N and P supply in arid areas, where N is rapidly depleted due to the light soils. Plant nutrient storage could make up for a brief nutrient deficiency in the soil. Nutrient storage at plant and cladode level, as well as translocation to sinks within the tree, has never been investigated. Information on fertilization timing and fertilizer characteristics that would best fit plant requirements for growth and fruiting is not available.

Information on root growth, distribution, and ultimate size as affected by plant spacing, irrigation (timing and systems), and nutrition, is completely lacking. Such information would be very helpful in improving the efficiency of both irrigation and fertilization management.

Finally, technical aspects related to orchard floor management or fruit thinning do not represent major problems in orchard management as sufficient information is already available (Barbera et al., 1993b; Brutsch, 1992; Felker and Russel, 1988; Wessels, 1988).

Conclusions

Different authors predicted a large expansion of cactus pear cultivation (Nobel, 1988). These predictions are based on the unique environmental biology of cacti that makes it possible to develop sustainable intensive production of both cladodes (forage, fodder, nopalitos) and fruits in areas with a limited resource base. Moreover, both cladodes and fruits have a high nutritional and human-health potential (Hegwood, 1990).

Ecological reasons, as well as the predicted increase of air CO_2 content and temperature, support use of plants with high water-use efficiency and wide ecological adaptability, such as *Opuntia* spp.

Indeed, *Opuntia* spp. have naturalized widely over the continents since the 15th century and are common in the subsistence agriculture of many communities in dry-land areas. However, fruit consumption is still limited to local or ethnic markets and cactus pear is still far from being a major fruit crop on a worldwide basis. Export flows never exceed 5-8% of the whole production and rely on immigrant communities in Europe and North America (Basile, 1989). Moreover, the cactus pear industry reaches a relevant size only in Mexico (80% of the cultivated area), while in all other countries it is considered a minor crop, limited to areas where nothing else could be cultivated profitably.

Two main questions arise: what is limiting the horticultural potential of this species and how can consumption of the cactus pear fruit be encouraged? Horticultural knowledge gained so far is very scarce although horticultural problems play a critical role in limiting the expansion of the cactus pear industry.

Productivity itself should not be considered a major constraint because *Opuntia* spp. give biomass productivity even higher than most of C_3 and C_4 species (Garcia de Cortazar and Nobel, 1990) while fruit production exceeds that of many other fruit crops largely cultivated in arid and semiarid regions, such as pistachio, almond, carob, date palm, or olive. However, great discrepancies in yield within regions and years persist as a result of poor management.

The common opinion that cactus pear needs low inputs to give high yields have been so misconceived that very limited scientific information is available to farmers and the importance of appropriate orchard management has been largely neglected. The Italian experience proves that rational orchard management makes it possible to improve and standardize yields and fruit quality with low establishment, management, and energetic costs (Baldini et al., 1982).

The poor knowledge about plant-environment interaction in relation to fertility and flower bud development is also responsible for fluctuations in yield over time and by environment. Improving knowledge about the environmental influence on fruit productivity and quality, coupled with the environmental productivity index (EPI) proposed by Nobel (1988), will allow a comprehensive evaluation of land suitability for a profitable growing of *Opuntia ficus-indica* for fruit production. Moreover, the existing germ plasm should be characterized in terms of ecological adaptation, fertility, productivity, ripening time and fruit quality.

Most likely, the main factor limiting horticultural potential of cactus pear is the poor economic value of its products, particularly fruits, which, although appreciated by rural communities, still fail to appeal to rich international markets of North America and Europe. To improve consumption, fruit quality standards need to be set and fruit quality enhanced.

Cactus pear fresh fruits could be present in virtually all markets year round (Table 4). This potential is common to a few other fruit crops, but, in cactus pear, is largely underestimated. However, postharvest technologies should be improved and international agreements signed to regulate sales transactions. Any further enlargement of the productive area should be accomplished only if new consumers could be reached. In fact, any marginal increase in acreage will result in great losses if the market is not enlarged accordingly (Basile, 1989; Inglese, Barbera, 1992). In this respect, the presence of glochids and hard thick seeds are the most serious constraints for greater cactus pear consumption. Glochids can be removed after harvest, but technologies must be improved and consumers have to be educated. Eventually, selection and breeding for glochid-free varieties should be encouraged.

The reduction of seed content is the major challenge for future research. The large variability in wild populations and cultivated varieties gives good reason to expect successful selection and breeding.

Indeed, when *pruning to produce a late crop (scozzolatura)* was introduced in the early 19th century, fruits became familiar to wealthy people, just because they were perceived as low seeded fruits (Barbera et al., 1992a). Actually, late fruits have more seeds than summer fruits but the lower seed to pulp ratio makes the fruit more appreciated by consumers (Barbera et al., 1992c).

Marketing research should discover which fruit color and size consumers like most. This information is crucial for future investments. Finally, cactus pear will succeed outside ethnic markets only if research and marketing resources are improved with the aim to standardize production, regulate sales transactions and attract new consumers.

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Table 1. Representative Areas Cultivated for *Opuntia* Fruit Production

Country	**Area** (hectares)	**Annual harvest** (tons fresh weight)
Argentina	500	2,500
Bolivia	1,200	3,000
Chile	1,100	8,000
Israel	300	6,000
Italy	2,500	50,000
Mexico	52,000	300,000
South Africa	1,000	12,400
United States	120	-

Source: Nobel (1994), modified.

Table 2. Actual and Potential Uses of *Opuntia ficus-indica*

Food production	*Fruits* *Nopalitos* *Fruit Juice* *Oil extracted from seeds* *Miel de tuna* *Queso de Tuna* *Jellies and marmelades*
Energy production	*Alcohol* *Fresh biomass*
Cattle feeding	*Forage* *Fodder* *Fruit wastes*
Medical uses	*Flowers for diuretic purposes* *Cladodes for diabetes* *Mucilages*
Agronomical uses	*Soil fixation* *Soil mulching* *Soil water supply* *Hedges* *Wind breakers*
Colorant uses	*Betacyanin in fruits* *Carminic acid (red cochinilla dye)*

Table 3. Articles Cited by Melvyl Catalog

Species	Number
Almond	128
Apple	1,292
Apricot	72
Citrus	954
Olive	538
Opuntia spp.	65
Opuntia ficus-indica	35
Peach	454
Pear	275
Pistachio	29

Melvyl Current Contents (1989-1993), investigated 31 July 1993

Table 4. Ripening Time of Cactus Pear Fruits Worldwide

Country	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Chile		mmmmmm					wwwwww					
Israel		wwwwww					mmm			aaaaaaaaaa		
Italy								mmmmm		aaaa		
Mexico					mmmmmmmmmmmmmmmmmm							
North Africa							mmm					
South Africa	mmmmmmm			aaaa								
USA	mmmmmmmmmmm							mmmmmmmmmmm				

Various Sources. m= main crop; a=autumn crop; w=winter crop.

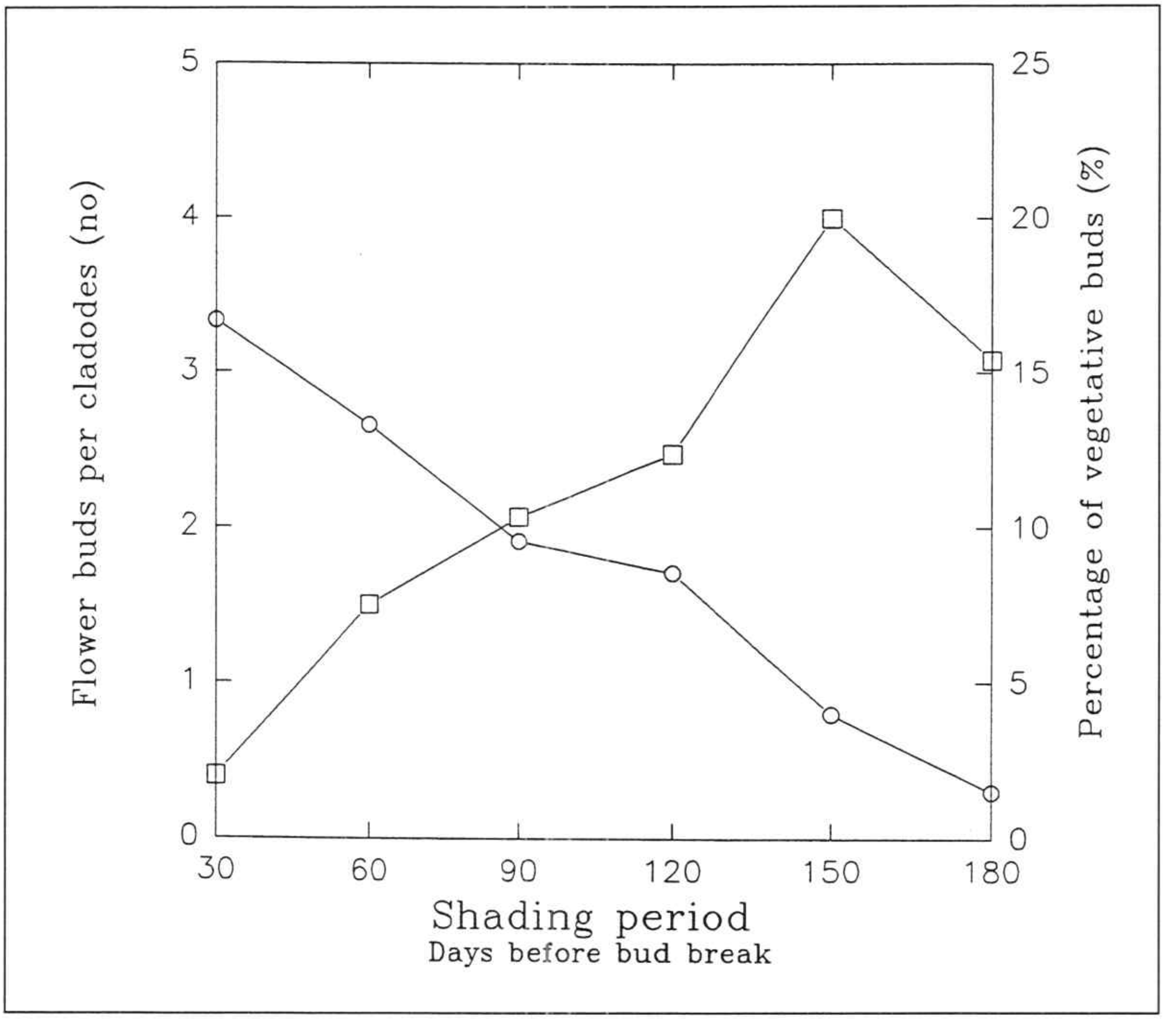

Figure 1. Effect of Shading Applied Continuously on One-Year-Old Cladodes (n=15) from 180 to 30 Days before Spring Bud Break. (At bud break, the average number of flower buds in control, sun-exposed cladodes was 6.45 ±2.04 and the percentage of vegetative buds was 1.5%.