Genet Resour Crop Evol (2015) 62:21–33
DOI 10.1007/s10722-014-0133-2

RESEARCH ARTICLE

Opuntia spp. biodiversity conservation and utilization on the Cape Verde Islands

G. L. Beccaro · L. Bonvegna · D. Donno · M. G. Mellano · A. K. Cerutti · G. Nieddu · I. Chessa · G. Bounous

Received: 20 November 2013 / Accepted: 11 May 2014 / Published online: 19 June 2014

Abstract Cactus pear is the common name of *Opuntia ficus-indica* (L.) Mill., the arid-resistant plant that is grown worldwide for its multifunctional proprieties. The paper gives an overview of local genetic resources of *Opuntia* spp. and describes the results of the recent introduction of some *O. ficus-indica* varieties, hybrids and other cactaceas on Fogo Island during a cooperation international project carried out by the Italian Universities of Torino and Sassari aimed to build a sustainable supply chain for the local growers, in order to fight their extreme poverty and malnutrition. The ten introduced genotypes were selected from a repository located Sardinia (Italy) held by the University of Sassari. They were selected for fruits and/or cladodes productivity, and potential use as livestock feed, and no invasive behaviour. The propagation test started in May 2007 and data on the emerging and the growth of new cladodes were recorded until March 2008: propagation was carried out by cloning via cutting. Once planted and identified, usual agrotechniques for *Opuntia* cultivation were applied and data on growth were periodically collected. To evaluate and compare the growth of the different genotypes, a productivity index was used. Cladodes of the *Nopalea* genotype were significantly smaller in size than all the other genotypes, in length (20.50 cm), width (11.25 cm), and thickness (0.98 cm). In the present study, the active preservation of biodiversity has become a tool to enhance sustainable agroforestry.

Keywords Arid-resistant crops · Cactus pear · *Opuntia* · Poverty reduction · Soil erosion · Sustainable agroforestry

G. L. Beccaro · L. Bonvegna · D. Donno (✉) · M. G. Mellano · A. K. Cerutti · G. Bounous
Dipartimento di Scienze Agrarie, Forestali e Alimentari, Università degli Studi di Torino, Largo Braccini 2, 10095 Grugliasco, TO, Italy
e-mail: dario.donno@unito.it

G. Nieddu · I. Chessa
Dipartimento di Economia e Sistemi Arborei, Università degli Studi di Sassari, Via Enrico De Nicola 9, 07100 Sassari, Italy

Introduction

Cactus pear (*Opuntia ficus-indica* (L.) Mill.) is a perennial dicotyledonous plant native to the tropical areas of North America, particularly in Mexico, where the highest richness of *Opuntia* spp. cultivated and wild variants are found (Reyes-Aguero and Rivera 2011; Reyes-Agüero et al. 2006). The uncertainties still remaining in the taxonomy of the genus has been evidenced by various authors and linked to polyploidy, high occurrence of interspecific and intergeneric hybridization, as well as to the high variability of phenotype depending on environmental conditions (Rebman and Pinkava 2001; Majure et al. 2012). Among the morphological features easily changing upon growing conditions, the presence or absence of thorns have shown to be strongly influenced by stress condition (Le Houérou 1996) or related to juvenility (Nieddu et al. 2006). In a seedlings progeny, obtained from open pollinated cultivar Gialla, intermediate types from the spineless to the spiny form were found (Chessa and Nieddu 2002). Moreover, naturalized spineless *O. ficus-indica* in areas where the plants have become invasive have converted to the spiny forms (Zimmermann 2010). The spiny forms naturalized in Sardinia (Italy) have been considered as the wild form of *Opuntia ficus-indica*, and assigned to the *O. megacantha* species (Guiggi 2008; Mulas and Mulas 2004). Molecular fingerprinting analysis have evidenced a close relatedness between the spineless cultivated *O. ficus-indica* and the spiny *O. megacantha* Salm-Dyck, *O. streptacantha* Lemaire and *O. amyclaea* Ten., (Labra et al. 2003; Griffith et al. 2004; Caruso et al. 2010; Chessa 2010), thus showing the inadequacy of the current taxonomical classification based on morphological features.

Polyploidy is found in a large number of populations that are propagated by sexual and vegetative ways. The family Cactaceae has a basic chromosome number $x = 11$, while the number of somatic chromosomes is 22. For *O. ficus-indica*, numerous sources indicate that both the spineless and the thorny forms have $2n = 88$, which means that both are octoploid (Majure et al. 2012; Griffith et al. 2009). Other sources consider the species as diploid ($2n = 22$), even if this is an identification error, while other authors allude to eptaploid hybrids derived from crosses between octoploid and hexaploid individuals (Kiesling 1998).

The presence of hybrids, as well as crosses between individuals with different ploidy, even by contemporary flowering of different species, are caused by the lack of natural barriers that avoid hybridization (Griffith et al. 2009). Individuals of the genus *Opuntia* actually show both autogamous and heterogamous pollination, thus determining cases of hybridization (Reyes-Agüero et al. 2006).

Several authors have developed different classifications of the genus *Opuntia* and the one most used as primary references was developed by Britton and Rose in 1919 and revised in 1963. In this classification, the genus *Opuntia* is placed in the Cactaceae family. The Cactaceae family of stem succulent plants is divided into: Pereskieae, Opuntieae, and Cereae.

The genus *Opuntia* is divided into four subgenera: *Platyopuntia*, *Cylindropuntia*, *Tephrocactus*, and *Brasiliopuntia*. The subgenus *Platyopuntia* includes from 150 to 300 described species, including the group *Ficus-indicae*, which includes *O. ficus-indica* (L.) Mill. (Mulas and Mulas 2004; Guiggi 2008; Scheinvar 1999). The taxonomic scheme relative to *O. ficus-indica* is summarized in Table 1.

Table 1 Taxonomic classification of *Opuntia ficus-indica* (L.) Mill.

Class	Magnoliopsida
Subclass	Caryophyllidae
Order	Caryophyllales
Family	Cactaceae
Subfamily	Opuntiodeae
Genus	*Opuntia*
Subgenus	*Platyopuntia*
Species	*Opuntia ficus-indica* (L.) Mill.

The fruit of the prickly pear is a simple, fleshy berry, although for the expansion of the receptacle that surrounds the fruit, it should be considered a false fruit. The receptacle, which forms a kind of skin, maintains the characteristics of the cladode; therefore, glochids and areolas are present and persistent. The fruit may contain between 80 and 300 seeds, as a function of the initial number of ova. (Peña-Valdivia et al. 2008). Some commercial varieties show parthenocarpy, even if the fruits derived from them have a greater part of the outer skins to the detriment of the pulp (Weiss et al. 1993). The evolution of the fruit follows a double sigmoid growth model and the entire process can take from 80 to 90 days, also according to environmental conditions; with high temperatures, there is a quicker ripening while a colder climate slows ripening (Nerd and Mizrahi 1995).

Worldwide, the economic importance of the species is not particularly high and this is reflected in the low production of scientific publications in the field of the agronomic utilization of its biodiversity. However, in the economy of several countries in arid or semi-arid regions, cactus pear takes on considerable importance and the development of a culture emphasizing its multifunctionality has great potential.

Uses of *Opuntia* spp.

The common uses can concern both food production (fruits and pads) for human and animal consumption

Table 2 Nutritional composition of 100 g prickly pear fruit

Nutrients	Units	Quantity
Water	g	87.55
Energy	kJ	172
Protein	g	0.73
Fat	g	0.51
Ash	g	1.64
Carbohydrate	g	9.57
Fiber	g	3.6
Vitamin C	mg	14.0
Calcium	mg	56
Iron	mg	0.30
Magnesium	mg	85
Phosphorus	mg	24
Potassium	mg	220
Sodium	mg	5
Zinc	mg	0.12
Copper	mg	0.080

and the cultivation of the plant for different agroforestry intents (e.g., to form hedges to fight desertification and erosion).

O. ficus-indica is widespread in both hemispheres and on all the continents, and it is cultivated in specialized plantations on more than 120.000 ha (70,000 ha in Mexico, 25.000 ha in Tunisia).

The consumption of the fruit, coming from plantations or wild, is widespread in different areas of the world, where production is usually not only for the domestic market but there are also some export channels. The most commonly used species is *O. ficus-indica*, even if in Mexico, the fruits of both cultivated and spontaneous species are consumed. The nutritional composition of cactus pear (Table 2) is comparable to apple, cherry, kiwifruit and apricot (Donno et al. 2012, 2013a), with a high calcium and vitamin C content (Sáenz 1999). The sugar fraction is mostly composed of glucose and fructose, while the acidity is very low (0.05–0.18 %, similar to citric acid), giving a sweet taste to the fruit (Piga 2004). The fruit of the prickly pear contains polyphenols with antioxidant properties, as isorhamnetin, and quercetin and its derivatives: the total polyphenolic compound content is similar to other common fruit (Canterino et al. 2012; Donno et al. 2013b). Regarding free aminoacid content, proline, glutamine, and serine are present, and the taurine content is very interesting

Table 3 The average nutritional composition of cladodes used for animal feed

Water (%)	85–90
Raw protein (%)	5–12
P (%)	0.08–0.18
Ca (%)	42
K (%)	2.3
Mg (%)	1.4
Energy (kcal kg^{-1})	2,610
Carotenoids (mg 100 g^{-1})	29
Ascorbic acid (mg 100 g^{-1})	13

(323.6–407.3 mg/l) (Mosshammer et al. 2006). The storage of fruits, that are considered non climacteric, is carried out at temperatures around 6 °C and at 90–95 % relative humidity (RH) (Barbera and Inglese 1993).

The consumption of the young pads (nopalitos) spread in Mexico has remained unknown in the other countries where *Opuntia* is grown. In Mexico are currently cultivated 10.500 ha for the production of these young cladodes, consumed as vegetables (Felker 1999). The use of *Opuntia* as fodder shows remarkable advantages: it grows quickly, it is not expensive and fairly attractive, and can also withstand long periods of drought. These features make it an important source of food especially during the dry season (Mulas and Mulas 2004; Nefzaoui 2010). *Opuntia* has been used to feed cattle, sheep, goat, camels and other animals. The average nutritional composition of cladodes used for animal feed is reported in Table 3. The cultivation for forage production is important mainly in Mexico, South America and south USA (in Brazil the cultivated surface is extended on more than 300,000 ha).

Cactus pear is also used as anti-erosion and windbreak species. Thanks to its root system, capable of colonizing sterile and rocky soils, it contributes to the evolution of soils (Patel 2013; Barbera and Inglese 1993; Mulas and Mulas 2004).

Cactus pear can form a dense palisade to counteract the thrust of the land, replacing admirably support walls and defining steps and embankments (Patel 2013).

Finally, the production of bioethanol from prickly pear started as early as the mid-nineteenth century, even if the process led to a rather low yield of alcohol (7–12 %). Biogas (methane) is obtainable by anaerobic fermentation of a compound formed by manure and cladodes reduced to pulp. In Chilean studies, it has been highlighted that to obtain a biogas with at least 60 % of methane, it is necessary to maintain a pH of about 6.0 by varying the composition of the mixture (Varnero and García de Cortázar 2006). However, an analytical assessment on the eco-efficiency of this process should be carried on (Cerutti et al. 2013a, b, 2011).

Materials and methods

Introduction and utilization of *Opuntia* biodiversity in the Cape Verde archipelago: preliminary considerations

The inhabited Cape Verde Islands were discovered by Portuguese navigators, and were colonized by European people in 1460 (Cardoso 1902). Listed among the invasive species of archipelago, *O. ficus-indica* has been checked in Santo Antão; São Nicolau; Santiago and Fogo (Romeriras et al. 2011).

The economy of Cape Verde is characterized by a very low level of exports and a high level of imports; in fact, almost the total of the commercialized products come from abroad (FAO 2004). Cape Verde is at the 102nd place in the world ranking for the Human Development Index (HDI) (López-Guzmán et al. 2013). The Cape Verdean climate has been ever more characterized by dryness over the last 20 years. One of the biggest problems is soil erosion, due to a combination of various factors such as the slope of the land, torrential rains, and poor vegetation. The water resources used are mainly ground water and surface water; to a lesser extent, they are obtained by using water desalination (Carpenter et al. 2010). The surface resources are not fully exploited because of the lack of uptake facilities (Aquastat 2005).

Dryland farming is still the most common form of agriculture, both on Fogo Island (99.3 %) and in the archipelago (86.2 %). The fruit growing sector has grown since the mid-80 s and has now reached a certain importance, thanks to the support of international cooperation, which began several projects (Forni and Bounous 2004).

The potential of fruit production on Fogo Island has been studied in the context of the project “Social Action on Fogo Island Local Population: Self-Sustaining Production of Primary Agriculture”, carried on by the University of Torino starting from 2004. The project aimed to promote the development of agriculture and, in particular, of a sustainable fruit production, introducing species able to withstand prolonged drought conditions as Sahelian, arid-resistant species that are suitable for fighting desertification. Among the species that are potentially suitable to the unfavourable pedoclimatic conditions of the island, *Opuntia* spp. has considerable interest and development potentialities. The present work was aimed to introduce new *Opuntia ficus-indica* genotypes in the Fogo Island and evaluate the possibility of its propagation from the cladodes (pads). In particular, this research has provided the introduction and multiplication on site of new thorny and thornless cultivars of *Opuntia* spp., in order to allow the spread of its cultivation on Fogo and in all the other surrounding islands. As part of the project activities, some *Opuntia* cultivars and hybrids were introduced in experimental fields on Fogo in 2007, with the aim of using the species biodiversity to build a sustainable supply chain, involving local villagers to fight their extreme poverty and malnutrition.

Plant material

The introduced cactus pear accessions were harvested in May 2007 from a biodiversity repository located in Italy (Oristano, 39°53′N; 08°37′E) (Chessa 2010), thanks to the collaboration of the Department of Economics and Woody Plant Ecosystems of the University of Sassari. Eigth accessions of *Opuntia* spp., six spineless and two thorny, and one of *Nopalea*, were propagated in a nursery on Fogo, property of the Cape Verde Ministry of Agriculture and Environment. The amount of cladodes was different for each accession (Table 4). The following genotypes were selected for the study.

Gialla di Sarroch (GSH) (O. ficus-indica)

Originally from Pantelleria (Sicily, Italy), has been introduced in Sarroch, a town in the south of Cagliari (Sardinia, Italy) (Chessa and Nieddu 2005). The plant is globular, with a spreading habit, and very vigorous. The cladodes are oval-shaped and without thorns. Productivity is high. The fruits are medium-small, egg-shaped, and orange. Of the whole fruit, 54 % is pulp, which has

Table 4 List of *cactaceas* introduced on Fogo Island

Accession	No cladodes	Main use	Notes
Opuntia ficus-indica selections			
GO	3	Fruit	Spineless
GSH	6	Fruit	Spineless
M3	6	Fruit	Spineless
RC	6	Fruit	Spineless
BB	4	Fruit	Thorny
GB	3	Fruit	Thorny
Opuntia ficus-indica hybrids			
95i59	5	Forage	Spineless
GxR	4	Fruit	Spineless
Opuntia cochenillifera			
NP	7	Vegetable	Spineless

a good texture and high content of seeds (324), of which 35 %, on average, are aborted. The ripening period, in Italy, takes place during the first 10 days of September. Organoleptic characteristics are fair.

Bianca di Macomer (M3) (O. ficus-indica)

This cultivar has been found in central Sardinia. The plant habit is globular, with average vigour. The cladodes are elliptical and spineless. This genotype's productivity is moderate and fruits ripen, in Italy, between the middle and the end of August. The fruits are large and oval in shape, with a green colour and only a few glochids. The pulp is 55 % of the whole fruit and the number of seeds per fruit is, on average, 255; 39 % of the seeds are aborted (Chessa and Nieddu 2005). The organoleptic traits are medium, with only a little aroma. In the overall assessment, this is a promising cultivar for the size of fruits, the high number of aborted seeds, and qualitative traits of the fruit, compared with other varieties with white fruit.

Rossa di Castelsardo (RC) (O. ficus-indica)

This genotype is cultivated especially in the north of Sardinia. The plant's habit is globular, and the cladodes are spineless and elliptical in shape. Productivity is medium and harvesting takes place in Italy during the second half of August. The fruits, characterized by high firmness, are medium in size, oval in shape, with red skin and a small number of glochids. The percentage of pulp, which has a good texture, is 55 %, with an intermediate number of seeds (288), and a high percentage of aborted seeds (55 %) (Chessa and Nieddu 2005). The flavour is fair, with an excellent aroma. The genotype is interesting for the quality of the fruit and the high content of aborted seeds.

Gialla di Bonacardo (GB) (O. ficus-indica)

This is a cultivar local to central Sardinia and is currently in culture (Chessa and Nieddu 2005). The plant has a shrubby habit and high vigour. The cladodes are thorny and ovate. Productivity is medium–high and the harvest takes place between the end of August and the first week of September. The fruits are medium-small, egg-shaped, and dark yellow-orange, and the glochids are numerous. The flesh has a good firmness and represents 54 % of the fruit. The number of seeds is high (334), 33 % of which are aborted (Nieddu et al. 2002). The organoleptic quality is medium, but it lacks flavour. The genotype is interesting because of its high productivity.

Gialla di Ozieri (GO) (O. ficus-indica)

This is a biotype that is wild in Sardinia (Bellini and Giordani 2008). The plant has a globular habit and high vigour. The cladodes are ovate and spineless. Productivity is high and harvesting, in Italy, is carried out in the last week of August. The fruits are ovoid, small-sized, and orange. Glochids are numerous. The flesh has a good texture and sweet flavor, and the number of seeds is high.

Bianca di Bronte (BB) (O. ficus-indica)

This Sicilian genotype (Bellini and Giordani 2008) has a globular habit. The cladodes are thorny and ovate. Productivity is high and the harvest period is mid-September. The fruits are oval in shape, small sized, and have many glochids. The flesh is very sweet, white, firm, and with few seeds.

Hybrid Gialla × Rossa (GxR) (O. ficus-indica)

This hybrid was obtained at the University of Sassari, in the field of germplasm in Oristano, by crossing the cultivars "Yellow" and "Red", both of Sicilian origin and cultivated for their fruits. The plant has medium vigour. The cladodes are ovate and without thorns. The fruits are particularly abundant (Nieddu and Chessa 2005).

Nopalea (NP) (Nopalea cochenillifera Salm-Dyck)

Originally from Central America, the plant is small in size and rather branched. The cladodes are spineless, ovate, and small-sized, with a limited number of areolas; the appearance is waxy and the colour is bright green. The flowers are reddish-pink and remain semi-closed during flowering (Cavalcante and Carvalho 2006). This genotype is interesting because young cladodes are highly valued as a vegetable (nopalitos).

Selection 95i59 (O. ficus-indica)

This is a selection obtained by the University of Sassari, from free pollination of the cultivar Gialla di Sarroch (Nieddu et al. 2006). The plant's habit is globular. The cladodes are ovate and without thorns. This accession is particularly interesting for the purpose of fodder because of the high vigour of the plant.

Propagation and plantation

The propagation test started in May 2007 and data on the emerging and the growth of new cladodes were recorded until March 2008. The plants were propagated in a nursery located on Genebra Mountain (+14°53′57.91″, −24°29′20.53″). The area is characterized by a semi-arid climate, with an average temperature ranging between 14 and 24 °C, low humidity, and low rainfall (annual average 200–300 mm). The propagation of pads was carried out in an area of the nursery constantly covered by a shading net, to avoid damage of the cladodes from sunburn (Mondragón-Jacobo and Pimienta-Barrios 2001; Arba and Sbihi 2013). The plants were propagated both in the trench and in a climate chamber. The soil used for filling both the trench and the climate chamber was obtained by mixing mature manure with soil found on the site (Pareek et al. 2003).

Propagation was carried out by cloning via cutting (Barbera and Inglese 1993). After their removal from the field of Oristano, cladodes were left to dry in a greenhouse to promote the healing of the cut. The cutting of thorns was necessary for the two thorny varieties in order to avoid any damage to the pads during the transport by airplane.

On site, the measurements of the propagation material included the length, width, thickness, and weight of each pad. The pads were then separated into two portions by cutting in the half. Considering the difficult conditions of propagation, the use of a half cladode was preferred, in order to obtain a good compromise between the final number of plants and strength of the cuttings (Barbera et al. 1993; Mondragón-Jacobo and Pimienta-Barrios 2001). Portioned pads were used for all varieties except for NP (whole pads), because of the small size of the cladodes (Mondragón-Jacobo and Pimienta-Barrios 2001).

10 portions for each genotype were identified with an alphanumeric code. Dissected and identified cladodes were placed on the ground to dry for 3 days. The planting distance was 0.4 m in the row, measured at the centre of each cladode and 0.4 m between rows. The portions of the pads were buried up to about half of their height and planted in a vertical position (Inglese 2001).

Once planted and identified, usual agrotechniques for *Opuntia* cultivation were applied and data on growth were periodically collected. Applied agrotechniques included: weed control; irrigation (manually every 2 weeks); the removal of any flower buds that would have resulted in an unnecessary investment of energy by the plant in the process of multiplication. For each cutting, the number of new cladodes and the date of growth and, for each new cladode, the length (cm), width (cm), and thickness (cm) at intervals of about a month were recorded. The evaluations also concerned the rooting rate. The growth of the first three cladodes by each accession was also measured.

To evaluate and compare the growth of the different genotypes, the productivity index (IP) was used (Barbera et al. 1993), given by the ratio between the photosynthetic surface produced and that of the cladodes planted. The photosynthetic surface was calculated using the regression model proposed by Barbera et al. (1993), which allowed us to calculate the photosynthetic surface according to the length (LU) and the width (LA) of the cladode: $y = 7.604 + 1.462\ LA^2 + 0.358\ LU^2$.

The area of the planted portion was obtained by dividing the entire surface of the pad by 2. Data

Table 5 Average of measurements per accession

Cultivar	Length (cm)	Width (cm)	Thickness (cm)
95i59	37.60 a	17.10 a	2.68 a
BB	33.00 ab	18.25 a	2.20 ab
GB	33.66 ab	18.17 a	2.00 ab
GO	33.83 ab	19.17 a	2.23 ab
GSH	30.33 b	15.33 a	2.30 ab
GxR	37.75 a	18.50 a	2.53 a
M3	31.33 ab	15.25 a	1.95 ab
NP	20.50 c	11.25 b	0.98 c
RC	35.33 ab	16.42 a	1.60 bc

Means with the same letter are not significantly different ($p > 0.05$)

Table 6 Mean cladode surface at planting

Cultivar	Surface (cm^2)
95i59	942.81 ab
BB	874.29 ab
GB	885.17 ab
GO	943.98 ab
GSH	676.48 b
GxR	1,025.73 a
M3	691.60 b
NP	348.00 c
RC	846.01 ab

Means with the same letter are not significantly different ($p > 0.05$)

analysis was performed using univariate analysis of variance (one-factor ANOVA).

Results and discussion

The measurements carried out on the initial plant material are given in Table 5. Cladodes of the NP cultivar were significantly smaller in size than all other fruit and fodder genotypes, in length (20.50 cm), width (11.25 cm), and thickness (0.98 cm). The genotypes 95i59 and GXR showed higher length values than all the others (37.60 and 37.75 cm, respectively). Measurements of the surface, carried out through the equation proposed by Barbera et al. (1993), allowed us to obtain the data summarized in Table 6. Statistical processing of these data showed significant differences. In particular, they confirmed that the NP genotype (348 cm^2 average surface per cladode) showed a smaller surface than the others. The accession with the highest cladode surface (1025.73 cm^2) was GxR.

Measurement of the planted pads showed that most of the apical fractions did not grow any new shoots, probably due to the attack of rots. Only a few apical portions (genotypes BB11, GO11, M341, and M351) of the total planted pads took root (survival rate 10.8 %). Regarding the basal portions, 81.1 % of the total survived. The difference between the rooting of apical and basal portions was very remarkable. This was different in the case of the NP genotype, for which whole pads were used due to their small size; 75 % of the planted cladodes survived.

Regarding the percentage of survival of the single accessions (Fig. 1), the results showed that in three accessions, survival was below 50 % (95i59, GxR, and RC, 30, 37.5, and 41.7 %, respectively); in four, it was 50 % (GB, GO, GSH, and M3); and with BB, it was 62.5 %. As already mentioned above for NP, for which entire pads were used, the percentage was 75 %.

The first new cladode produced by cuttings was observed 12 days after plantation and the last was recorded 163 days after plantation. Statistical analysis of the number of days required for the emerging of cladodes (Table 7) was performed on the first three produced. The results showed no significant differences. The days spent, on average, to produce the first cladode ranged between 14.8 and 45.8, respectively for BB and RC. The second cladode emerged between 26.7 and 56.0 days, respectively for NP and RC. The third cladode emerged, on average, after 32.7 days for NP and 81.6 days for RC. Although there were no significant differences, RC seemed to be the slowest genotype to produce new cladodes while the NP seemed to be the fastest. Results on the total number of cladodes produced (Fig. 2) showed that NP was the genotype with the best performance (7.8 new cladodes/plant), followed by 95i59, GO, and M3 (with values ranging from 5.7 to 6.2 cladodes/plant). The other accessions presented values between 3.7 and 4.8 new cladodes/plant.

Comparison of the photosynthetic surface of the first three cladodes (Fig. 3) suggested that they had a similar growth rate. Significant differences were observed from the fourth month. The total photosynthetic surface of each accession (Table 8) at the end of

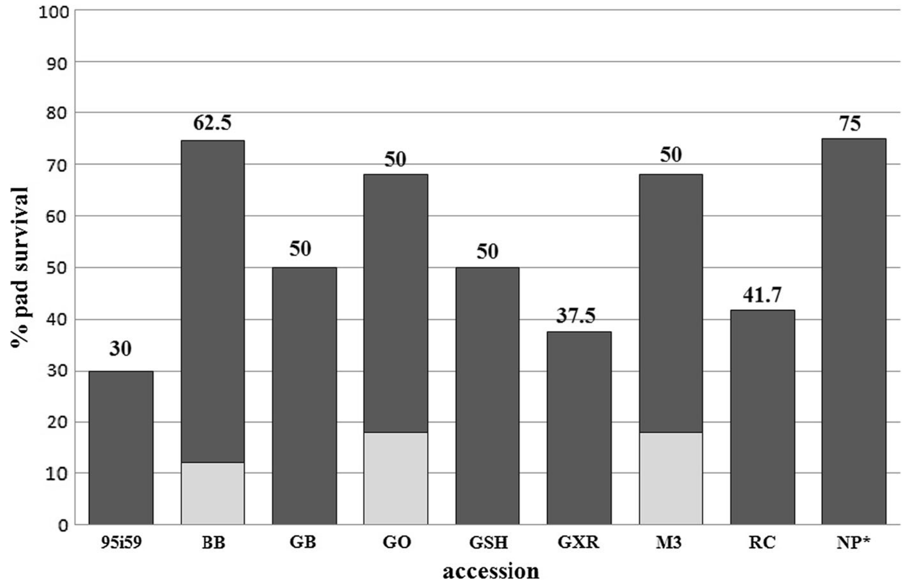

Fig. 1 Percentage pad survival. The *yellow part* of the *bars* represents the survival of basal portions. *For NP, entire cladodes were planted

Table 7 Number of days needed, on average, to produce the first cladode

Accession	1° cladode (days)	2° cladode (days)	3° cladode (days)
95i59	30.7	51.0	65.7
BB	14.8	29.6	57.2
GB	16.7	28.0	41.3
GO	45.0	50.7	59.0
GSH	23.2	42.8	71.2
GxR	15.3	33.7	63.3
M3	37.7	52.7	73.7
NP	19.2	26.7	32.7
RC	45.8	56.0	81.6

the study period was calculated by summing the areas of all the cladodes obtained from each initial pad. The accessions with the largest new areas/plant were M3, 95i59, and NP.

Regarding the IP, significant differences were observed only in the case of NP (IP = 41.0), the one with the highest productivity. As shown in Fig. 4, the difference between NP and other accessions was remarkable and almost two-fold. In fact, the other genotypes presented IP values between 8.0 and 21.4 (GB and M3, respectively). The size of the planted cladodes, expressed as length and width, was variable, and depended on the characteristics of each genotype. Using the equation described by Barbera et al. (1993), it was possible to reduce the two variables to a single one, simplifying comparisons between different accessions.

The survival data showed that the survival rate was strongly influenced by the propagation material (Barbera et al. 1999). The reduced rate of survival observed in the apical portions (10.8 %), compared with that of the basal portions (81.1 %), was mostly due to attacks of rots. The rots in the planted apical portions were the result of poor healing of cutting surfaces of the cuttings (Fig. 5).

To respect the geotropism of the plant and limit rot infections, the cutting surface of the apical portion was buried. The exposure of the cutting surfaces outdoors to promote healing was limited, for logistical reasons, to only 3 days, while some authors recommend a period of 1 week (Barbera et al. 1993). The highest survival rate was observed with NP, which was planted without portioning cladodes, which did not present infections and consequent death. In a study on the propagation of *Opuntia* using entire cladodes belonging to five different genotypes, Singh (2003) reported rates of survival close to 100 and 66 % only for one cultivar.

Regarding the time of emergence of the first three cladodes, the time between planting and germination was very variable and also presented differences greater than 2 months between the different portions of the pad. The first cladode was produced in an amount of time similar to that described by Singh

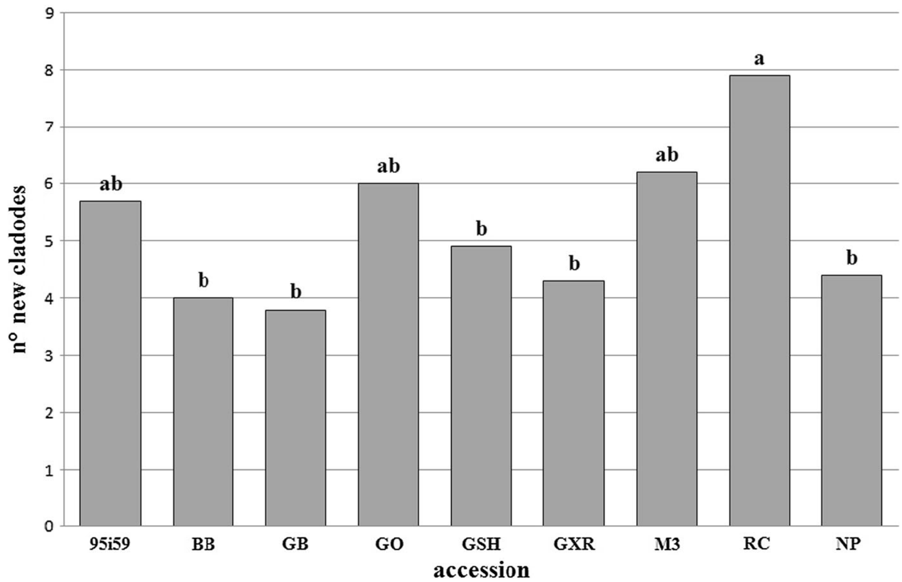

Fig. 2 New cladodes produced by each genotype. Values with the *same letter* are not significantly different ($p > 0.05$)

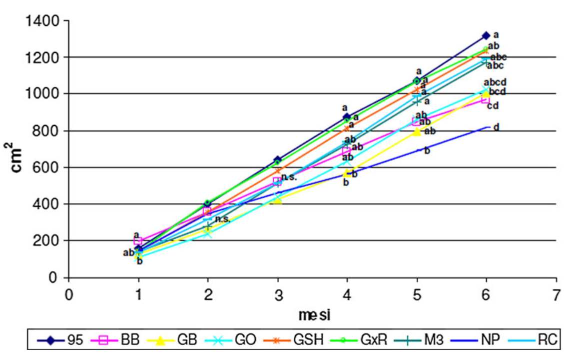

Fig. 3 Growth of new cladodes (average total surface of the first three cladodes). Values with the *same letter* are not significantly different ($p > 0.05$)

Table 8 Photosynthetic surface/plant

Accession	Surface/plant (cm^2)
95i59	7,308.9 a
BB	3,960.9 c
GB	3,511.2 c
GO	6,436.8 ab
GSH	5,983.6 b
GxR	5,398.6 b
M3	7,366.8 a
NP	7,193.3 a
RC	5,188.0 b

Means with the same letter are not significantly different ($p > 0.05$)

(2003). The genotype NP, in the present study, took 19.2 days for the production of the first cladode, while for the same accession in India, this value was 26 days in a spring plantation and 51.6 days in an autumn plantation (Pareek et al. 2003). The number of new cladodes was highest in NP, probably because of the use of entire cladodes. Singh and Singh (2003) has shown how the planting of entire cladodes allows the development of a higher number of new cladodes with respect to planting of portions of the pad. In a study conducted in north-west India on 47 clones of prickly pear, the number of cladodes produced after 6 months of plantation was higher than five only in 11 % of cases, while 66 % produced a number between three and five, and the remaining 23 % produced fewer than three cladodes (Pareek et al. 2003; Saenz 2006). In the present study, in 44.4 % of plants, the number of new cladodes was greater than five, and in the remaining plants, it was never fewer than three cladodes per plant. In particular, in the case of NP, after 6 months of plantation, 7.8 new cladodes/plant were produced, a higher number than the 6.10 obtained by Singh (2003). This comparison may be indicative of good conditions for the development of prickly pear on Fogo Island. Accessions 95i59 and GxR had a larger size than other

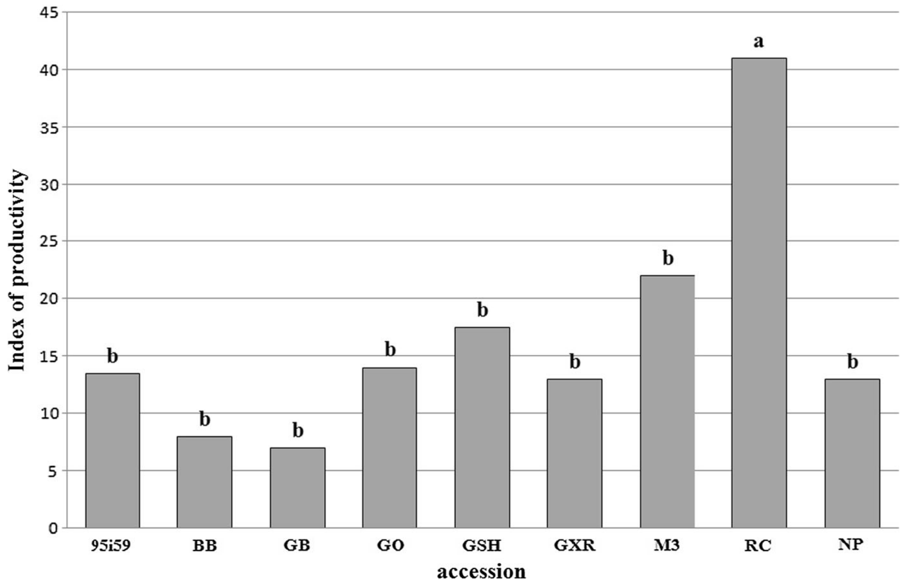

Fig. 4 Index of productivity (IP) of the accessions. Data with the *same letter* are not significantly different ($p > 0.05$)

Fig. 5 **a**, **b**. *Opuntia* and *Nopalea cochenillifera* cuttings in the biodiversity collection field in Fogo Island; **c** emergence of the first cladodes from the cuttings; **d** a field plantation realized with the introduced material

cultivars, even in new cladodes, highlighting genotype differences. The final size of new cladodes was greater than the size of the initial material, and this was due to the fact that the planted pads were chosen to be small, to reduce the overall weight of the plant material and facilitate transportation.

The ratio between the surface of the new cladodes, measured at the end of the test, and the initial surface of the cuttings, defined as the IP, showed that NP was the most productive genotype. The high value of IP suggests a particular adaptation of this cultivar to the specific conditions of the island. Nieddu (personal communication) has, in fact, confirmed that the productivity observed on Fogo is much higher than that in Sardinia. Also, all the other accessions, which showed a lower IP than NP, presented relevant IP values compared with data obtained in similar studies. Barbera et al. (1993) showed that in 6 months, cuttings of the cultivar Gialla, obtained by 1/4 of cladode, presented an IP of 11.26, while the new cladodes obtained by one entire cladode presented an IP of 1.98.

Conclusions

Prickly pear is well known in the Cape Verde ethnobotany culture. In fact, it is supposed to have been introduced by the colonizers, because the Cape Verde archipelago was a destination of many slaves trading during the 1,600 and 1,700 s (Forni and Bounous 2004).

The introduction and propagation of *Opuntia* biodiversity in Cape Verde was only the first step of a larger research program. The introduced genotypes, do not present invasive behaviour, are more productive and more suitable for different utilizations. A productive orchard was also realized in the same area with the same introduced genotypes and, as the nursery, its management is actually carried on by local villagers with good productive results. What is completely locally missing is the concept of the multifunctional potential of the plant, although some technicians of the Ministry of Agriculture and Environment of Cape Verde are aware of the use of this plant for forage in Brazil and in the rest of the American continent. In Cape Verde, the production of fodder under irrigation is unthinkable, so the only viable solution is to use drought-resistant plants (Lepape 1980). For these reasons, the production of fodder interested many of the local technicians. Cape Verde and Fogo Island, in fact, produce a particular fresh goat cheese, which is a source of protein and minerals for the population. Find new sources of food for livestock is, therefore, very important (Mondragón-Jacobo and Chessa 2013). The consumption of cladodes as a vegetable is an important element for the Cape Verdean population, heavily afflicted by food insecurity. Although it is still not widespread in the world, in some countries, such as Ethiopia, prickly pear was recently introduced for human consumption (Nieddu 2008; Nefzaoui 2010).

Fogo Island has many species of endemic plants that are commonly used in traditional medicine. It is, therefore, particularly important to control the spread of the new introduced species with the greatest caution because, as happened in Australia, this could take over and threaten local species. That is why only non-invasive *Opuntia* genotypes were introduced (Mondragón-Jacobo and Perez-Gonzalez 2003).

One of the other Cape Verde islands that could potentially benefit from prickly pear cultivation is Santo Antão, where goat farming is highly developed. On this island, drought has drastically reduced the number of animals, putting at risk their survival and dairy production.

On Fogo island, the interest of local technicians in the project and the awareness of the importance of this species on the island, could strongly contribute to a new evolution of the crop. The experience represents a clear example that the active preservation of biodiversity can become a tool to enhance sustainable agroforestry (Beccaro et al. 2012; Mellano et al. 2012).

References

Aquastat (2005) L’irrigation en Afrique en chiffres—Enquête AQUASTAT 2005. Cap Vert. Rapports sur l’eau. FAO 29, 1–80

Arba M, Sbihi H (2013) Rooting of cuttings and pads fragments of cactus pear. Acta Hort 995:183–187

Barbera G, Inglese P (1993) La coltura del ficodindia. Edagricole-Edizioni Agricole della Calderini s.r.l, Bologna, pp 1–188

Barbera G, Carimi F, Inglese P (1993) Influenza dell’epoca di impianto e del tipo di talea sulla radicazione e sullo sviluppo di barbatelle di *Opuntia ficus-indica* Mill. Rivista di frutticoltura 10:67–71

Barbera G, Inglese P, Pimienta Barrios E (1999) Agroecologia, cultivo y usos del nopal. Estudio FAO produccion y proteccion vegetal. FAO, Roma

Beccaro GL, Torello-Marinoni D, Binelli G, Donno D, Boccacci P, Botta R, Cerutti AK, Conedera M (2012) Insights in the chestnut genetic diversity in Canton Ticino (Southern Switzerland). Silvae Genetica 61:292–300

Bellini E, Giordani E (2008) The online European minor fruit tree species database—EMFTSDatabase. Cactus pear: accessions and descriptor list. Disponibile al sito: [http://www3.unifi.it/ueresgen29/netdbase/s5/dbs5.htm]

Britton NL, Rose JN (1963) The Cactaceae: description and illustrations of plants of the Cactus family, Vol. 1 and 2 edn. Dover, New York

Canterino S, Donno D, Mellano MG, Beccaro GL, Bounous G (2012) Nutritional and sensory survey of *Citrus sinensis*

(L.) cultivars grown at the most Northern limit of the Mediterranean latitude. J Food Qual 35:108–118
Cardoso JA (1902) Subsidios para a materia medica e terapeutica das possesões ultramarinas portuguesas—Tomo I. Academia das Ciências, Lisboa
Carpenter LJ, Fleming ZL, Read KA, Lee JD, Moller SJ, Hopkins JR, Wallace DWR (2010) Seasonal characteristics of tropical marine boundary layer air measured at the Cape Verde atmospheric observatory. J Atmos Chem 67(2–3): 87–140
Caruso M, Currò S, Las Casas G, La Malfa S, Gentile A (2010) Microsatellite markers help to assess genetic diversity among *Opuntia ficus-indica* cultivated genotypes and their relation with related species. Plant Syst Evol 290:85–97. doi:10.1007/s00606-010-0351-9
Cavalcante CFS, Carvalho LS (2006) Palma Forrageira (*Opuntia ficus-indica* Mill.) como alternativa na alimentação de ruminantes (Forage Palm (*Opuntia ficus-indica* Mill.) as alternative in ruminant feeding). Revista Electrónica de Veterinaria, Vol. VII, 10, Octubre/2006, 1–13
Cerutti AK, Bruun S, Beccaro GL, Bounous G (2011) A review of studies applying environmental impact assessment methods on fruit production systems. J Environ Manage 92:2277–2286
Cerutti AK, Bruun S, Donno D, Beccaro GL, Bounous G (2013a) Environmental sustainability of traditional foods: the case of ancient apple cultivars in Northern Italy assessed by multifunctional LCA. J Clean Prod 52:245–252
Cerutti AK, Beccaro GL, Bagliani M, Donno D, Bounous G (2013b) Multifunctional ecological footprint analysis for assessing eco-efficiency: a case study of fruit production systems in Northern Italy. J Clean Prod 40:108–117
Chessa I (2010) Cactus pear genetic resources conservation, evaluation and uses. FAO Cactusnet Newsletter, Special issue 12:43–53
Chessa I, Nieddu G (2002) Investigations on variability in the genus *Opuntia* as fruit crop for genetic improvement. Acta Hort 575:345–353
Chessa I, Nieddu G (2005) Evaluacion de los recursos geneticos de la *Opuntia* spp. para la seleccion de variedades. FAO Cactusnet Newsletter, Special issue 10:12–20
Donno D, Beccaro GL, Mellano MG, Torello Marinoni D, Cerutti AK, Canterino S, Bounous G (2012) Application of sensory, nutraceutical and genetic techniques to create a quality profile of ancient apple cultivars. J Food Qual 35:169–181
Donno D, Beccaro GL, Mellano MG, Canterino S, Cerutti AK, Bounous G (2013a) Improving the nutritional value of kiwifruit with the application of agroindustry waste extracts. J Appl Bot Food Qual 86:11–15
Donno D, Cavanna M, Beccaro GL, Mellano MG, Torello Marinoni D, Cerutti AK, Bounous G (2013b) Currants and strawberries as bioactive compound sources: determination of antioxidant profiles with HPLC-DAD/MS. J Appl Bot Food Qual 86:1–10
FAO (2004) FAO statistical yearbook, country profiles, Cape Verde. www.fao.org
Felker P (1999) Produccion y utilizacion de forraje y pastura. In: Barbera G, Inglese P, Pimienta-Barrios E (eds) Agroecología, cultivo y usos del nopal. Estudio FAO producción y protección vegetal, vol 132, pp 151–162
Forni E, Bounous G (2004) Azione Sociale sulla Popolazione Locale dell'Isola di Fogo: Produzioni autosostenibili di Agricoltura Primaria—Diagnostico. Facoltà di Agraria, Università di Torino
Griffith MP (2004) The origins of an important cactus crop, *Opuntia ficus-indica* (Cactaceae): new molecular evidence. Am J Bot 91:1915–1921
Griffith MP, Porter JM (2009) Phylogeny of opuntioideae (Cactaceae). Int J Plant Sci 170(1):107–116
Guiggi A (2008) Catalogue of the Cactaceae naturalized in Italy with notes on their taxonomy, nomenclature and distribution. Riv Piem St Nat 29:103–140
Inglese P (2001) Plantação e manejo do pomar. In: Barbera G, Inglese P, Pimienta-Barrios E (eds) Agroecologia, cultivo e usos da palma forrageira. Estudio da FAO em produção e proteção vegetal, vol 132, pp 79–93
Kiesling R (1998) Origen, Domesticación y Distribución de *Opuntia ficus-indica*. J Prof Assoc Cactus Dev 3:1–9
Labra M, Grassi F, Bardini M, Imazio S, Guiggi A, Citterio S, Banfi E, Sgorbati S (2003) Genetic relationships in *Opuntia* Mill. genus (*Cactaceae*) detected by molecular marker. Plant Sci 165:1129–1136
Le Houérou HN (1996) The role of cacti (*Opuntia* spp.) in erosion control, land reclamation, rehabilitation and agricultural development in the Mediterranean Basin. J Arid Environ 33:135–159
Lepape MC (1980) Browse in the Cape Verde Islands. A preliminary study. In: Browse in Africa: the current state of knowledge. H.N. Le Houérou. International Livestock Center for Africa, ILCA, Addis Ababa, Ethiopia
López-Guzmán T, Borges O, Hernandez-Merino M, Cerezo JM (2013) Tourism in Cape Verde: an analysis from the perspective of demand. Tour Econ 19(3):675–688
Majure LC, Puente R, Griffith M, Judd WS, Soltis PS, Soltis DE (2012) Phylogeny of *Opuntia* s.s. (*Cactaceae*): clade delineation, geographic origins, reticulate evolution. Am J Bot 99(5):847–864
Mellano MG, Beccaro GL, Donno D, Torello Marinoni D, Boccacci P, Canterino S, Cerutti AK, Bounous G (2012) *Castanea* spp. biodiversity conservation: collection and characterization of the genetic diversity of an endangered species. Genet Resour Crop Evol 59(8):1727–1741
Mondragón-Jacobo C, Chessa I (2013) A global perspective on genetic resources of cactus pear; an asset for the future sustainability of semiarid lands. Acta Hort 995:19–26
Mondragón-Jacobo C, Perez-Gonzalez S (2003) El nopal (*Opuntia* spp.) como forraje. Estudio FAO production y proteccion vegetal. FAO, Roma
Mondragón-Jacobo C, Pimienta-Barrios E (2001) Propagação. In: Barbera G, Inglese P, Pimienta-Barrios E (eds) Agroecologia, cultivo e usos da palma forrageira. Estudio da FAO em produção e proteção vegetal, vol 132, p 65–71
Mosshammer MR, Stintzing FC, Carle R (2006) Cactus pear fruits (*Opuntia* spp.): a review of processing technologies and current uses. J Prof Assoc Cactus Dev 8:1–25
Mulas M, Mulas G (2004) Utilizzo strategico di piante dei generi *Atriplex* e *Opuntia* nella lotta alla desertificazione. Short and Medium-Term Priority Environmental Action Programme (SMAP)
Nefzaoui A (2010) Use of cactus as feed: review of the international experience. In: Nefzaoui A, Inglese P, Belay T (eds)

Improved utilization of cactus pear for food, feed, soil and water conservation and other products in Africa. In: Proceedings of International Workshop, Mekelle (Ethiopia), 19–21 October, 2009. p 224

Nerd A, Mizrahi Y (1995) Biologia reproductiva. In: Barbera G, Inglese P, Pimienta-Barrios E (eds) Agroecología, cultivo y usos del nopal. Estudio FAO producción y protección vegetal, vol 132, p 51–60

Nieddu G (2008) A cultura da figueira-da-Índia. Università di Sassari, Dipartimento Economia e Sistemi Arborei

Nieddu G, Chessa I (2005) Ensayos de cruzamientos sobre *Opuntia* spp. en Italia. Cactusnet 10:58–63

Nieddu G, Chessa I, Satta D, De Pau L, Pala M (2002) Description of Six Cactus Pears (*Opuntia ficus-indica* Mill.) Fruit Cultivars from Italy. In: Nefzaoui A, Inglese P (eds) Proceedings of 4th IC on Cactus Pear and Cochineal. Acta Hort. 581:125–129

Nieddu G, Chessa I, Barberis A (2006) Characterization of seedlings obtained from open pollinated "Gialla" cactus pear (*Opuntia ficus-indica*). Acta Hort 728:105–110

Pareek OP, Singh RS, Vashishtha BB (2003) Performance of cactus pear [*Opuntia ficus-indica* (L.) Mill.] clones in hot arid region of India. J Prof Assoc Cactus Dev 5:121–130

Patel S (2013) Reviewing the prospects of *Opuntia* pears as low cost functional foods. Rev Environ Sci Biotechnol 12(3): 223–234

Peña-Valdivia CB, Luna-Cavazos M, Carranza-Sabas JA, Reyes-Agüero JA, Flores A (2008) Morphological characterization of *Opuntia* spp.: a multivariate analysis. J Prof Assoc Cactus Dev 10:1–21

Piga A (2004) Cactus pear: a fruit of nutraceutical and functional importance. J Prof Assoc Cactus Dev 6:9–22

Rebman JP, Pinkava DJ (2001) *Opuntia* Cacti of North America—an overview. Florida Entomol 84(4):474–483

Reyes-Aguero JA, Aguirre Rivera JR (2011) Agrobiodiversity of cactus pear (*Opuntia*, Cactaceae) in the Meridional Highlands Plateau of Mexico. J Nat Resour Dev 01:01–09

Reyes-Agüero JA, Aguirre RJR, Valiente-Banuet A (2006) Reproductive biology of *Opuntia*: a review. J Arid Environ 64:549–585

Romeriras MM, Catarino L, Torrão MM, Duarte MC (2011) Diversity and origin of medicinal exotic flora in Cape Verde Islands. Plant Ecol Evol 142(2):214–225. doi:10.5091/plecevo.2011.560

Saenz C (2006) Utilizacion agroindustrial del nopal. Boletin de servicios agricolas de la FAO. FAO, Roma

Sáenz C (1999) Elaboración de alimentos y obtención de subproductos. In: Barbera G, Inglese P, Pimienta-Barrios E (eds) Agroecología, cultivo y usos del nopal. Estudio FAO producción y protección vegetal, vol 132, p 29–36

Singh G (2003) General review of Opuntias in India. J Prof Assoc Cactus Dev 5:30–46

Singh RS, Singh V (2003) Growth and development influenced by size, age, and planting methods of cladodes in cactus pear (*Opuntia ficus-indica* (L.) Mill.). J Prof Assoc Cactus Dev 5:47–54

Scheinvar L (1999) Taxonomia de las Opuntias utilizadas. In: Barbera G, Inglese P, Pimienta-Barrios E (eds) Agroecología, cultivo y usos del nopal. Estudio FAO producción y protección vegetal, vol 132, p 21–28

Varnero MT, García de Cortázar V (2006) Producción de bioenergía y fertilizantes a partir de los nopales. In: Sáenz C, Berger H, García JC, Galletti L, García de Cortázar V, Higuera I, Mondragón C, Rodríguez-Félix A, Sepúlveda E, Varnero MT (eds) Utilización agroindustrial del nopal. Boletín de servicios agrícolas de la FAO, 162(8):113–119

Weiss J, Nerd A, Mizrahi Y (1993) Vegetative parthenocarpy in the cactus pear *Opuntia ficus-indica* (L.) Mill. Ann Bot 72:521–526

Zimmermann H (2010) Managing prickly pear invasions in South Africa. FAO Cactusnet Newsletter, Special issue 12:157–166