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Assessment of prickly pear *(Opuntia ficus-indica)* varieties and their possible planting systems

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Abstract

The vegetative growth and productivity of four prickly pear varieties grown under two planting systems (single cladode and double cladode) was evaluated over a period of five years (1995-1999) in the San Juan province of Argentina. The three Argentine varieties examined (possibly ecotypes of the variety known locally as 'yellow prickly pear without spines') came from the Santiago del Estero, Córdoba and San Juan provinces. The fourth variety used was 'Gialla' from Italy. The double cladode plants reached a greater photosynthetic area and total cladode number than the single cladode plants. The double cladode system produced earlier fruits and the highest yields from the second year onwards. 'Gialla' gave the highest fruit yields, and showed the greatest vegetative growth. No differences were observed between the Argentine varieties in terms of yield and plant growth. Planting double cladodes significantly improved fruit production and vegetative growth in the Gialla variety. Most of the fruit produced (80%) by the national varieties fell into the medium (96-140 g) and large (> 140 g) categories, while 'Gialla' produced mostly medium and small sized fruits (< 96 g).

Key words: ecotype, cladode, vegetative growth, early production, productivity, fruit quality.

Resumen

Evaluación de sistemas de implantación y variedades de tuna *(Opuntia ficus-indica)*

El crecimiento vegetativo y la productividad de cuatro variedades de tuna y dos sistemas de implantación, cladodio doble y cladodio simple, fueron evaluados durante cinco años (1995-1999) en la provincia de San Juan (Argentina). La procedencia de tres de las variedades (posibles ecotipos dentro de la variedad conocida localmente como 'tuna amarilla sin espinas'), fueron las provincias de Santiago del Estero, Córdoba y San Juan. La restante variedad fue 'Gialla', procedente de Italia. Las plantas formadas a partir del sistema cladodio doble presentaron mayor superficie fotosintética y número total de cladodios. Este sistema de implantación ocasionó una entrada anticipada en la etapa productiva y mayores rendimientos a partir del segundo año. 'Gialla' superó a las restantes variedades en crecimiento vegetativo y producción. Las variedades nacionales no se diferenciaron en su comportamiento productivo y vegetativo. El efecto del sistema cladodio doble sobre la producción y el crecimiento vegetativo fue significativamente superior en la variedad italiana. La mayor parte de la producción (> 80%) se concentró en las categorías mediana (96 a 140 g) y grande (> 140 g) en las variedades nacionales, y en las categorías mediana y chica (< 96 g) en 'Gialla'.

Palabra claves: ecotipo, cladodio, crecimiento vegetativo, precocidad productiva, productividad, calidad de fruto.

Introduction

The prickly pear *Opuntia ficus-indica* (L.) Mill. (family Cactaceae), a plant with crassulacean acid metabolism (CAM), is mainly cultivated in hot, arid and semi-arid countries, including Tunisia, Algeria, South Africa, Italy, Brazil, Argentina, Chile and Mexico (Monjauze and Le Houérou, 1965; Le Houérou, 1996). The species grows well under these conditions since it is adapted to high temperatures and reduced water supplies. In Argentina, it is grown in the arid and semi-arid centre and northwest. It is considered a subsistence fruit since it is mostly grown by smallholders who obtain low production and rather random profits – a consequence of poor crop management and marketing strategies (Ochoa, 1994). In recent years, however, interest has been growing in this fruit as a means of diversifying agricultural production, and a number of modern plantations have appeared in different Argentine provinces.

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The fruit of this species has many uses (Russell and Felker, 1987; Barbera *et al.*, 1988; Barbera, 1991), but in Argentina it is mainly eaten fresh. Mature cladodes are also used for forage during the dry season. Some 90% of the area given over to this crop is planted with the variety known as 'yellow prickly pear without spines' ('tuna amarilla sin espinas') (Ochoa, 1994). In recent years, some growers have introduced Italian varieties, including 'Gialla'.

For many fruit trees, increasing the amount of light intercepted increased their yield (Robinson and Lakso, 1989; Barrit *et al.*, 1991). The trend is therefore towards the use of planting systems that reduce the number of years required to achieve maximum light interception and full production. When starting a prickly pear plantation, Frank (2000) and Sudzuki *et al.* (1993) recommend the use of double or triple cladodes since this leads to rapid growth and earlier fruit production than when single cladodes are used. Inglese *et al.* (1995) reported that higher levels of production can be achieved by increasing the number of one year-old fruiting cladodes per plant, or by increasing plant density.

The aim of the present work was to compare the vegetative growth and productivity of different prickly pear varieties planted as single or double cladodes.

Material and Methods

Four varieties of prickly pear were evaluated: three from the Argentine provinces of San Juan, Córdoba and Santiago del Estero, and the Italian variety known as 'Gialla'. The Argentine varieties studied may not, in fact, be strict varieties, but ecotypes of a variety known locally as 'tuna amarilla sin espinas'. Nonetheless, in this work, the term 'variety' is applied to groups of plants with relative phenotypic uniformity.

Mature cladodes of the studied varieties were obtained from commercial plantations. These were planted on the 29th September 1994 (except those corresponding to the variety from Córdoba, which were planted on the 13th December 1994) at the *Estación Experimental Agropecuaria San Juan (E.E.A. San Juan)* Research Station, part of the *Instituto Nacional de Tecnología Agropecuaria (INTA)*, in San Juan province, Argentina (latitude 31° 37' S, longitude 68° 32' W, altitude 618 m). According to meteorological data collected by the *Estación Agrometeorológica de la E.E.A. San Juan – INTA* for the period 1968-1999, the mean temperature for the area was 17.8°C, the mean maximum temperature was 24.8°C, and the mean minimum temperature was 10.1°C. Annual rainfall is some 99.5 mm with a summer maximum.

Two planting systems were used to start the plantations: double cladode (DC, i.e., two cladodes joined together) and single cladode (SC). Plants were spaced 2.7 m apart, rows 5 m apart (density: 741 plants ha^{-1}).

The soil of the area belonged to the order of Entisols. From the surface to a depth of 0.6 m it had a loam/clay-lime loam texture, from 60 cm-1.10 m it changed to a sandy loam, and beyond this depth it changed to gravel and sandy loam. Analysis of the top 0.6 m gave the following results: pH = 7.3, EC = 1,500 umhos cm^{-1}, N = 931 ppm, P = 685 ppm and K = 265 ppm.

Irrigation was provided from mid-August till the end of May to ensure adequate growth. Weeds in the planted rows were chemically and/or manually controlled; those between rows were removed mechanically or chemically.

The plants were pruned during the winter to give them an open shape. Malpositioned or damaged cladodes were removed.

All flower buds were removed during the first flowering to favour vegetative growth. In 1995 and 1996, owing to an excessive spring flush of cladodes, the new cladodes were thinned at the end of flowering. At the same time, the flowers-fruits were thinned, leaving five or six prickly pears per cladode.

The data collected for the assessment of vegetative growth were the total number of cladodes (NC) and the photosynthetic area (PA) per plant. These variables were measured in the winter of 1995 (before pruning) and the spring of 1995 and 1996 (before the thinning of flowers-fruits and new cladodes). The photosynthetic area of each cladode (both faces) was estimated using the following equation:

$$y = 6.31 + 0.8\ (L \times W)\ (r^2 = 0.93)$$

where L= length of the cladode, and W = maximum width of the cladode (Caloggero, 1995).

Total fruit production was registered. Between four and six harvests were made, one per week from the first week of January. Fruits whose skins showed the first signs of change in colour were deemed ripe and ready for picking. The picked fruits were classified according to their fresh weight as either large (> 140 g), medium (96-140 g), or small (< 96 g) (Conafrut, 1978).

The experimental design was a split plot in a randomised complete block with four replications: the

Table 1. Photosynthetic area (PA) and number of cladodes (NC) for all varieties under both planting systems (1995-1996)

	PA (m^2 $plant^{-1}$)			NC ($plant^{-1}$)		
	1995		1996	1995		1996
	Winter	Spring	Spring	Winter	Spring	Spring
Planting system (PS)						
Double cladode	0.4 a	1.3 a	5.9 a	5.5 a	22.6 a	76.9 a
Single cladode	0.2 b	0.8 b	3.8 b	4.2 b	12.9 b	49.6 b
Variety(V)						
Gialla	0.4 a	1.7 a	7.5 a	6.2 a	23.2 a	96.6 a
S. del Estero	0.3 ab	1.0 b	3.9 b	4.5 b	14.9 b	51.4 b
Córdoba	0.2 b	0.7 c	3.2 b	4.9 ab	13.9 b	41.6 b
San Juan	0.3 b	0.9 b	4.2 b	3.6 b	14.9 b	54.6 b
PS × V	ns	*	*	ns	***	*

ns: not significant. *,***: significant at P = 0.05 or 0.001 respectively. Means in the same column followed by the same letter are not significantly different according to the Duncan test (P = 0.05).

plots representing the planting systems, their subplots representing the different varieties.

The experimental period lasted from July of 1995 to February of 1999. The results were examined by analysis of variance (ANOVA). Means were compared using the Duncan test. Percentages data were arcsine transformed.

Results

Both planting system and variety had a significant effect on vegetative growth (Table 1). The DC system produced significantly greater PA and NC than the SC system in all the seasons studied. In the winter of 1995, the variety Gialla showed the greatest vegetative growth. However, its PA was not significantly different to that of the Santiago del Estero variety, nor was its NC significantly different to that of the Córdoba variety (Table 1). From spring of 1995, the DC Gialla plants became the largest, showing a significant interaction between variety and planting system. The increases in PA and NC due to the DC planting system was significantly greater in Gialla than those seen for all other varieties in both the 1995 and 1996 growing seasons (Fig. 1). In the SC system, no significant differences were seen in 1995 with respect to NC, and the PA of the Gialla and Santiago del Estero varieties were the same. In 1996, however, Gialla showed significantly greater vegetative growth.

At the first harvest, no significant differences were seen between the two planting systems with respect to yield. Starting in 1997, however, the DC system led to significantly better yields (Table 2). These differences increased with the age of the plantation. Similar results were obtained with respect to the number of fruits. The cumulative production of the DC system was double that of the SC system. Gialla stood out with a greater number of fruits and greater yield in all harvests. The greatest increases in yield seen with this variety occurred between 1997 and 1998 (second and third harvests), while the remaining varieties showed their greatest increases in 1998 and 1999 (third and fourth harvests). The cumulative yield of Gialla (28.9 kg $plant^{-1}$) was significantly greater than those of all the Argentine varieties (around 14 kg $plant^{-1}$).

In the 1997 harvest, there were no significant differences in yield between any of varieties when grown under the SC system, even though Gialla produced more fruits (Fig. 2). In the DC system, Gialla doubled the yield of the Argentine varieties.

Planting system had no significant effect on the distribution of fruits by size category (data not shown). For all varieties, the medium category was the most abundant (> 50% of fruits) (Fig. 3). This was not seen, however, for the Córdoba variety in 1999, when only 26.6% of fruits were in this category. In 1977, the highest percentages of large fruits were produced by the Córdoba and San Juan varieties. At the following harvests, all the Argentine varieties produced more large fruits than Gialla (which had < 10% in this category). An increase was seen in the percentage of prickly pears > 140 g as the plants of the Argentine varieties became older. These

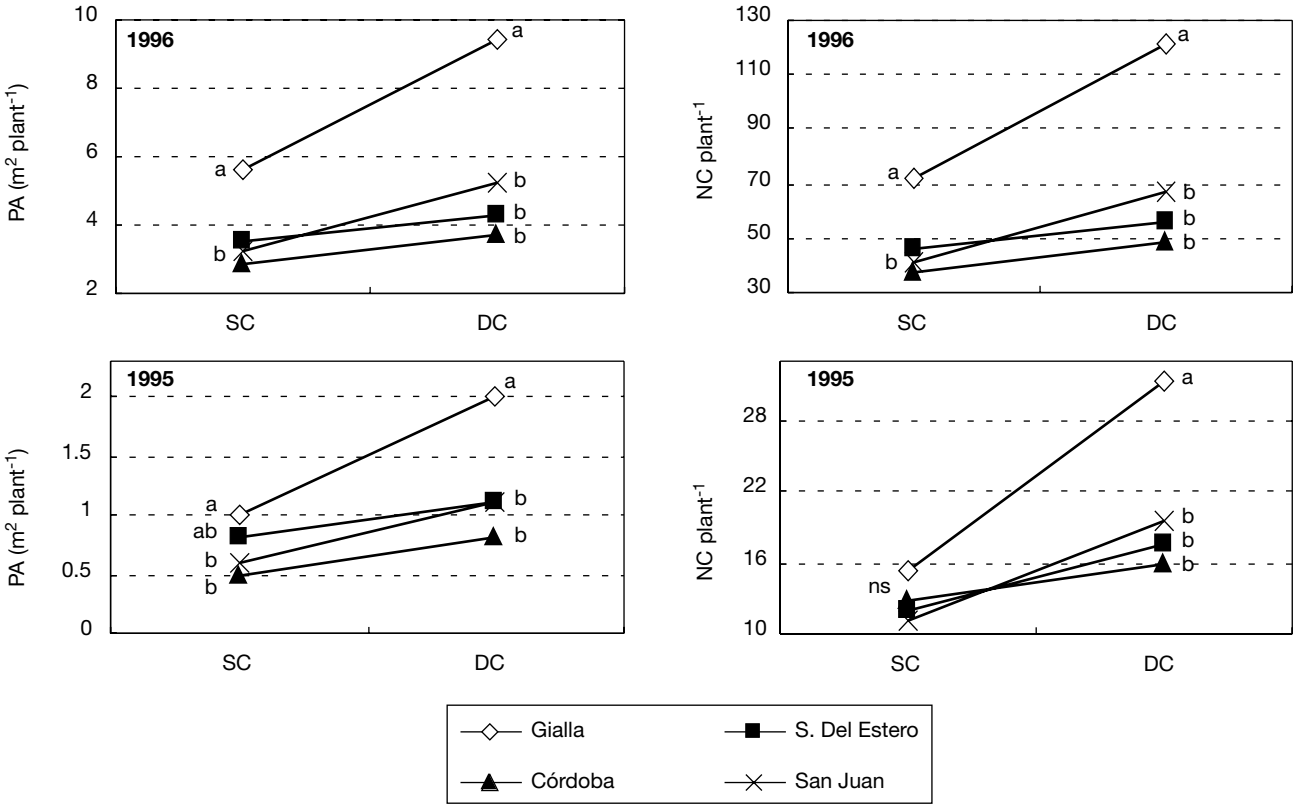

Figure 1. Photosynthetic area (PA) and number of cladodes (NC) for the different prickly pear varieties under both planting systems (1995-1996). SC: single cladode. DC: double cladode. Means in each planting system followed by the same letter are not significantly different according to the Duncan test (P = 0.05).

mainly replaced the fruits in the medium category, whose numbers fell. This was more pronounced for the Córdoba variety, which produced its largest fruits in 1999. Gialla had the most fruits belonging to the small category in the 1997, 1998 and 1999 harvests.

Discussion

These results show that the PA of both SC and DC system plants increases over the first two growth seasons, although more so in DC plants. Acevedo *et*

Table 2. Yield and number of fruits for all varieties under both planting systems (1996-1999)

	Production (kg plant^{-1})					Number of fruits (plant^{-1})^{z}		
	1996	**1997**	**1998**	**1999**	**Accumulated**	**1996**	**1997**	**1999**
Planting system (PS)								
Double cladode	0.3 a	2.9 a	7.9 a	12.9 a	24.1 a	3.5 a	26.1 a	107.9 a
Single cladode	0.2 a	1.5 b	3.8 b	7.2 b	12.8 b	2.2 a	14.2 b	59.3 b
Variety(V)								
Gialla	0.5 a	3.7 a	11.7 a	13.0 a	28.9 a	6.5 a	35.3 a	132.7 a
S. del Estero	0.2 b	1.5 b	4.2 b	8.6 b	14.4 b	2.0 b	13.9 b	66.6 b
Córdoba	0.1 c	1.7 b	3.2 b	9.6 b	14.7 b	0.8 c	13.0 b	65.8 b
San Juan	0.1 bc	1.9 b	3.3 b	8.2 b	13.5 b	1.3 bc	15.1 b	58.9 b
PS × V	ns	**	ns	ns	ns	ns	**	ns

[z] Data for 1998 not available. ns: not significant. **: significant at P = 0.01. Means in the same column followed by the same letter are not significantly different according to the Duncan test (P = 0.05).

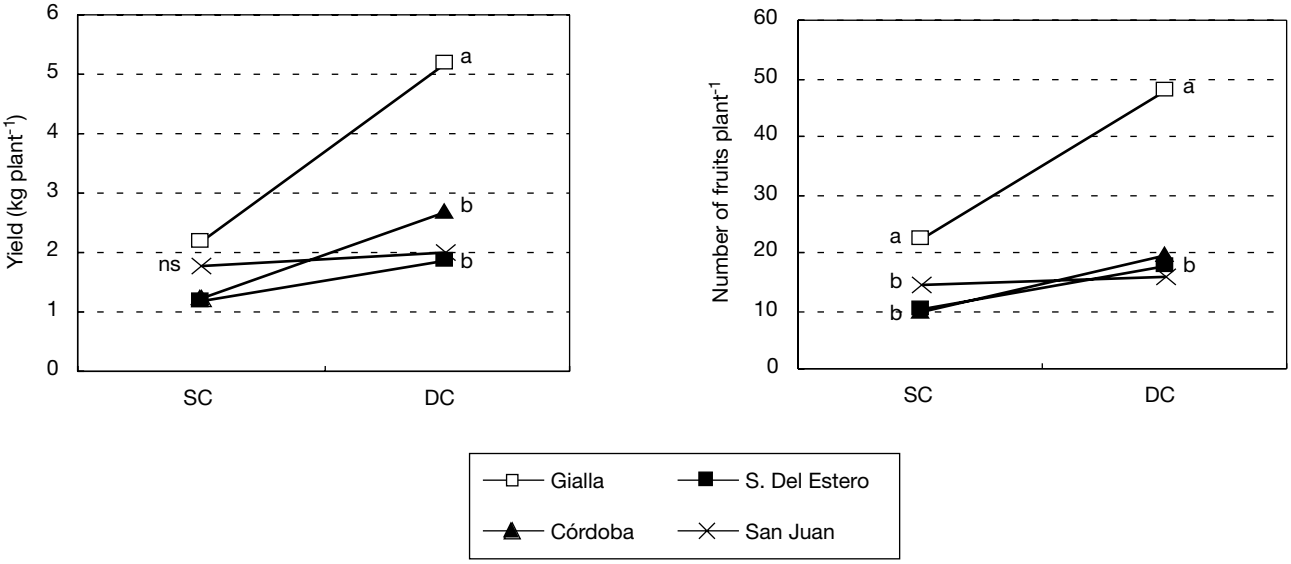

Figure 2. Yield and number of fruits of the different varieties under the two planting systems for 1997. SC: single cladode. DC: double cladode. Means in each planting system followed by the same letter are not significantly different according to the Duncan test (P = 0.05).

al. (1983) also obtained an approximately linear increase in PA in prickly pear plantations until their plants reached six years of age. The pattern for NC was similar, increasing over time in both systems but more so in the DC system. The potential production of an orchard is positively correlated with the amount of light intercepted by its plants (Robinson and Lakso, 1989; Barrit *et al.*, 1991). In the present work, the DC system allowed an earlier and greater production of PA, leading to greater light interception and therefore earlier and highest yield from the second year onwards.

For the first four harvests, the yield and number of fruits increased for both planting systems. Similar results were obtained for the same species by Acevedo *et al.* (1983), who reported increases in fruit yield with age. In the present study, starting the plantation with

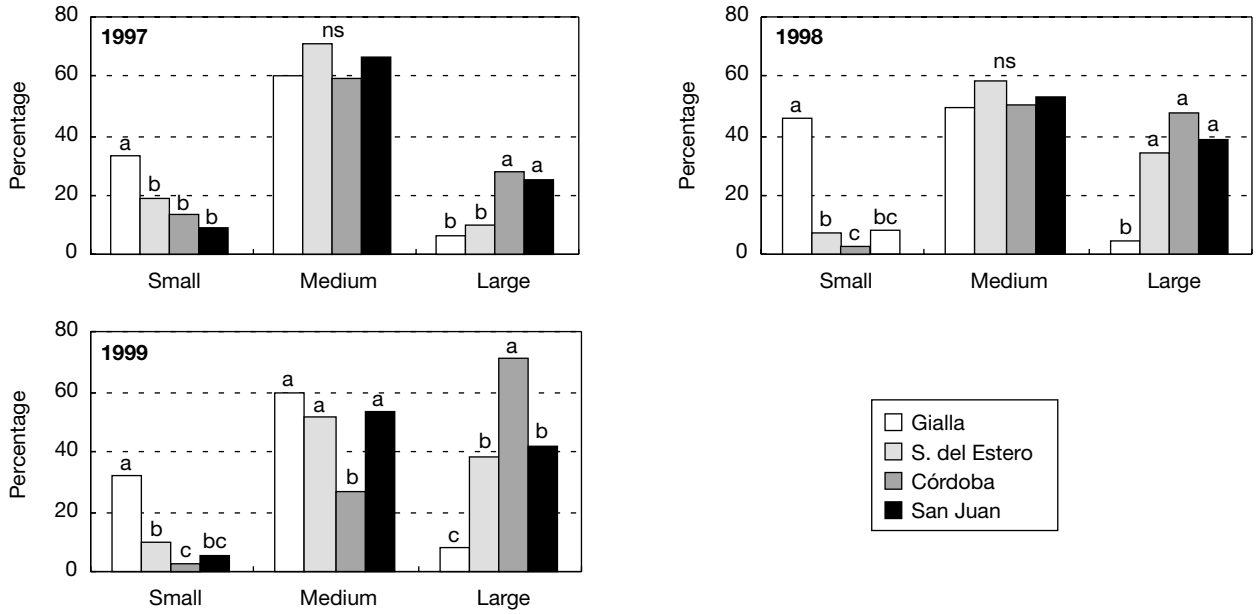

Figure 3. Distribution of fruits of each variety across small, medium and large size categories according to fresh weight. Bars with the same letter in each category are not significantly different according to the Duncan test (P = 0.05).

double cladodes brought the plants into production earlier, as reported by Sudzuki *et al.* (1993) and Frank (2000).

In agreement with Inglese *et al.* (1995), high yields were obtained by increasing the number of one year-old cladodes. Cortázar and Nobel (1992), however, concluded that fruit production was related to the dry weight of cladodes more than to their age. The greatest fruit harvest was obtained when a large number of vegetative structures had accumulated the necessary reserves to reach minimum fruiting weight. The greater increase seen in the number of cladodes in the DC system may have been accompanied by a high accumulation of dry weight, leading to greater fruit yield.

Gialla was better than the Argentine varieties in terms of vegetative growth – a difference that increased over time. It also showed earlier production and comparatively higher yields. Casóliba *et al*. (2003) compared varieties of different origins in the province of Santiago del Estero and also found greater yields to be obtained with introduced material.

The three Argentine varieties of the present work showed similar vegetative behaviour and production, reaching a mean of 6,521 kg ha^{-1} at five years of age, similar to that obtained by Casóliba *et al.* (2003). As suggested by Inglese *et al.* (1995), it might be necessary to increase the plantation density of these varieties to achieve the earliness and the production capabilities shown by Gialla.

The advantages of starting a plantation with the DC system were most obvious with Gialla. This combination produced the biggest plants and the highest yield in the second harvest (1997) confirming the positive relationship between PA and early production recorded for other fruit species (Robinson and Lakso, 1989; Barrit *et al.*, 1991).

In agreement with Pimienta Barrios (1990), the production and fruit quality are some of the factors that should be borne in mind when selecting a variety for cultivation. The fruits of Gialla (the most productive variety of the study) fell most frequently into the medium size category. The same is true for the Argentine varieties. However, the remaining Gialla fruits were mostly small (< 96 g) while those of the Argentine varieties were large (> 140 g). Gialla is very common in Italy where «scozzolatura» (the elimination of all spring flowers in order to induce a second flowering) is performed (Barbera *et al.,* 1988). Barbera *et al.* (1994) obtained prickly pears weighing 146 g or more with this technique, while control fruits only reached 96 g (similar to that achieved in the present study: 96-140 g). Inglese *et al.* (1995) indicated that this variety provides the best quality fruit when six prickly pears are left per cladode after the «scozzolatura», the same as in the present study after thinning, although this was performed at a different time. Categorising fruits by their fresh weight, the latter authors obtained size category percentages similar to those of the present work; approximately 60% in the medium category (110-140 g), 35% in the small category (< 110 g), and the rest in the large category (140 g).

The Argentine varieties gave lower yields but larger fruits than Gialla. The Córdoba variety was the best of the Argentine varieties, having the greatest number of large fruits in 1999. It may be that these national varieties are, in fact, different ecotypes of the local variety 'tuna amarilla sin espinas', which occupies more than 90% of the area given over to prickly pears in Argentina (Ochoa, 1994). In Chile, Sudzuki *et al.* (1992) characterised prickly pear ecotypes and found significant difference between their fruits, although the plants were morphologically similar.

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