Original article

Influence of within-tree and environmental factors on fruit quality of cactus pear (*Opuntia ficus-indica)* in Italy

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***RESUMEN ESPAÑOL**, p. 189*

Influence of within-tree and environmental factors on fruit quality of cactus pear (*Opuntia ficus-indica)* in Italy.

Abstract — **Introduction**. *Opuntia ficus-indica* fruit quality was studied, in the main sites for cactus pear cultivation in Italy, with the ultimate goal of understanding the main sources of variability and increasing crop value. **Materials and methods**. A first study was carried out in 2006 on mature *Opuntia ficus-indica* trees, cvs. Gialla and Rossa, grown in ten commercial orchards located in the main sites for their cultivation in Italy. Trees were managed to produce an out-of-season crop in October, through the removal of the spring flush at bloom time, during the first week of June. Trees had a similar crop [(52 ± 10) kg of fruits·tree^{-1}], and no more than six fruits were left on each of the fruiting cladodes. At commercial harvest time, indicated by the peel colour breakage, 75 fruits in each orchard and 750 fruits for each site were picked, analysed and evaluated by a consumer panel. A second experiment was carried out in 2006 on 8-year-old *O. ficus-indica* trees, cv. Gialla, grown in a commercial orchard. Within-tree factors, such as fruit position within the canopy, number of fruits per tree and per cladode, and cladode dry weight were studied. **Results and discussion**. Fruit weight, shape and total soluble solid content significantly changed with the environmental conditions, *i.e.,* site and altitude, while flesh percent, pH and total titratable acidity did not. Cultivars had a significant influence only on fruit weight and seed content. Fruit weight changed greatly within the tree, while total soluble solid content and flesh percent variability was much reduced. Fruit weight decreased with fruit number per tree and both fruit weight and total soluble solid content decreased with more than six fruits per cladode. Light interception and cladode dry weight were the main sources of fruit dry weight variability and sugar content, while cladode surface area was poorly related to fruit quality. The role of cultivars in determining fruit quality did not change with site and, moreover, the sensory analysis was unable to discriminate for cultivar and environment.

Italy / *Opuntia ficus-indica* / variety trials / fruits / yield factors / site factors

Influence des facteurs intra-arbre et environnementaux sur la qualité des fruits du figuier de Barbarie (*Opuntia ficus-indica*) en Italie.

Résumé — **Introduction**. La qualité des fruits du figuier de Barbarie a été étudiée, dans les principaux sites de culture de *Opuntia ficus-indica* en Italie, afin de comprendre les principales sources de variabilité et d'augmenter la valeur des récoltes. **Matériel et méthodes**. Une première étude a été réalisée en 2006 sur des arbres adultes d'*O. ficus-indica*, cvs. Gialla et Rossa, développés dans dix vergers commerciaux situés dans trois localités des principaux sites de cette culture en Italie. Les arbres ont été conduits de façon à produire en octobre, en contre-saison, par suppression des pousses de printemps au moment de la floraison pendant la première semaine de juin. Les arbres étaient de production équivalente [(52 ± 10) kg de fruits par plant], et au plus six fruits par cladode fructifère ont été laissés sur chacun d'eux. Au moment de la récolte commerciale indiquée par le virement de couleur de la peau, nous avons collectés 75 fruits par verger et 750 fruits pour chaque site ; ces fruits ont été analysés et évalués par un panel de consommateurs. Une deuxième expérience a été réalisée en 2006 sur des figuiers de Barbarie, cv. Gialla, âgés de 8 ans et cultivés dans un verger commercial. Des facteurs propres à l'arbre, tels que la position des fruits dans la canopée, le nombre de fruits par arbre et par cladode et le poids sec des cladodes ont été étudiés. **Résultats et discussion**. Le poids, la forme, et la teneur totale en solides solubles des fruits ont changé de manière significative en fonction des conditions d'environnement, à savoir le site et l'altitude, alors que le taux de pulpe, le pH et l'acidité totale du fruit n'ont pas différé. Le cultivar n'a influencé significativement que le poids des fruits et la teneur en graines. Le poids des fruits a beaucoup varié au sein d'un même arbre alors que la variabilité de teneur totale en sucres solides et en pulpe a été nettement réduite. Le poids de fruits a diminué avec l'augmentation du nombre de fruits par arbre ; les deux caractères poids de fruits et teneur totale en solides solubles ont diminué pour les cladodes portant plus de six fruits. L'interception de la lumière et le poids sec de cladode ont été les principales sources de variabilité du poids sec des fruits et de la teneur en sucre alors que la surface des cladodes n'a pas eu d'effet sur la qualité des fruits. Le rôle du cultivar dans la détermination de la qualité des fruits n'a pas différé d'un site à l'autre ; par ailleurs, l'analyse sensorielle a pas permis de discriminer le cultivar et l'environnement.

Italie / *Opuntia ficus-indica* / essai de variété / fruits / facteur de rendement / facteur lié au site

1. Introduction

Cactus pear (*Opuntia ficus-indica* Mill.) is commercially cultivated for fruit production in Southern Italy, particularly in the island of Sicily, where more than 4 000 ha of specialised plantations produce 60 000 t of fruits. More than 90% of the Italian production comes from the cultivars Gialla (yellow flesh) and Rossa (red flesh), which differ in term of flesh colour, fruit size, ripening time, seed content and yielding performances [1, 2]. Fruit ripening time is one major source of variability in fruit quality, regardless of the cultivar [3, 4]. Fruits of the same variety can be harvested in summer, from late July to mid-September, if they come from the spring bloom which takes place from late May to early June; fruits can also be harvested from late September until early November, if they come from a return bloom which occurs in July as a result of the complete removal of the spring flush of flowers and cladodes done before or during the first bloom time. Eventually, a third flush can be induced by the removal of the second flush, resulting, in August, in a further return bloom with a winter crop ripening in January - February [4]. The wide range of environmental conditions in which the fruits grow and ripen results in a great variability in fruit yield and fruit ripening time [5, 6], and in fruit quality, in terms of shape, size, percent flesh, sugar content, flavour and taste [3, 4, 7].

Fruit size depends on crop yield per plant and per cladode [8], as well as on crop management in terms of irrigation and fruit thinning [9], while within-tree factors such as plant architecture, fruiting cladode position within the canopy and cladode characteristics have been poorly explored as sources of variability in fruit yield and quality [10].

Cladode shading affects fruit quality, depending on the extent of shade imposed on the cladode in which the fruit develop [11]. Completely shading the main source of photoassimilates from 45 d to 75 d after bloom has no influence on fruit weight and quality, and fruit ripening occurs later in shaded than in sunlit cladodes. On the other hand, a short period (15 d) of imposed shade during earlier stages of fruit growth affects fruit weight, but not total soluble solid content, fruit firmness or ripening time. Fruit thinning is most effective in increasing fruit size when applied not later than 3 weeks after bloom [8]. No more than six fruits can be left on each of the 1-year-old fertile cladodes, since a greater crop load results in a sharp reduction of fruit size, even if plants are irrigated.

Water stress reduces growth and irrigation is necessary to obtain commercial fruit size (> 120 g) if no rainfalls (or less than 30–50 mm) occur during the fruit development period [12, 13].

High temperatures affect the carbon exchange rate more than transpiration (Inglese *et al.*, unpublished data) and always result in a reduced fruit development period and advanced maturity [3], even under irrigation. On the other hand, low temperatures during the fruit development period reduce total soluble solid content and fruit flavour and increase peel thickness [5].

Although the factors influencing fruit size have been investigated, the sources of variability in fruit quality in terms of flavour, taste, flesh sweetness and crunchiness are completely unclear, particularly for the [cultivar × environment] interaction.

The ultimate goal of our research was to study the relative relevance of the within-tree and environmental sources of fruit quality variability, in the main sites for cactus pear cultivation in Italy, since the reduction of fruit quality variability may result in an increase in orchard incomes, without necessarily increasing yields.

2. Materials and methods

2.1. Fruit variability in relation to orchard location

Our study was carried out in 2006 on mature trees of *Opuntia ficus-indica*, cv. Gialla and Rossa, grown in commercial orchards, in three of the main sites for cactus pear production in Sicily: San Cono (Catania, Italy, lat. 37° 17’ N, long. 14° 22’ E); Santa Margherita Belice (Agrigento, Italy, lat. 37° 41’ N, long. 14° 22' E) and Roccapalumba (Palermo, Italy, lat. 37° 48' N, long 13° 38' E).

The San Cono area is characterised by sandy soils, with altitude ranging from (350 to 700) m a.s.l.; average annual rainfall is 530 mm and most of the orchards (80%) are drip-irrigated. Cactus pear acreage is 2500 ha, with 40%–45% of the orchards being younger than 8 years old, and 50%–55% ranging from 8 to 25 years old.

The Santa Margherita Belice area is characterised by shallow, sandy-loam, Mediterranean red soils, with an altitude ranging from (400 to 480) m a.s.l. Annual rainfall is 650 mm and most of the orchards (60%) have no irrigation system. Cactus pear acreage is 800 ha, with only 25% of the orchards being younger than 8 years old.

The Roccapalumba area is characterised by clay-loam soils, with an altitude ranging from (300 to 550) m a.s.l. Annual rainfall is 575 mm and all the orchards are drip-irrigated. Cactus pear acreage is 200 ha and 80% of the orchards are younger than 8 years old.

In each of the three sites, ten different orchards were selected, with a similar age (9 to 15 years old), plant spacing and training system. In the San Cono area, plant spacing was 7 m × 5 m with trees trained to a globe shape; in the Santa Margherita Belice area, plant spacing was 6 m × 4 m, with trees trained to a vase shape; in the Roccapalumba area, plant spacing was 6 m × 5 m, with trees trained to a globe shape.

In the Santa Margherita Belice area, complementary irrigation was applied twice during the dry, summer season, (15 and 60) days after fruit set.

Six trees of Gialla and Rossa were selected in each of the orchards. Trees were managed to produce an out-of-season crop in October, through the removal of the spring flush at bloom time during the first week of June. Trees had a similar crop [(52 ± 10) kg of fruits·tree^{-1}], and no more than six fruits were left on each of the fruiting cladodes. All orchards received ordinary orchard management for pruning, fertilisation and irrigation.

In each site, air temperature was recorded from fruit set to fruit harvest.

At commercial harvest time, indicated by the peel colour breakage [1], fifteen fruits, chosen in five fertile, sunlit cladodes per tree, were harvested from each of the trees of the same orchard (75 fruits in each orchard and 750 fruits for each site).

All fruits were harvested from 12 to 25 October 2006.

After harvest, fruits were immediately analysed to determine fruit weight and shape, percent flesh, total soluble solid content, pH, total titratable acidity as oxalic acid, and seed content (viable and aborted seeds).

Fruits of each variety and production site were evaluated by sensory analysis. The panel was composed by 25 randomly chosen panellists (consumers) selected with no previous training.

Each panellist was asked to judge, in a blind, preference test, fruit appearance, firmness, taste, juiciness, flavour, sweetness and acidity.

Data were processed by two-way analysis of variance (Systat statistical package, SSCS© Inc.); Tukey's test was applied to indicate significant differences between means.

2.2. Within-tree variability factors

For studying within-tree variability, an experiment was carried out in 2006 on five 8-year-old trees of *Opuntia ficus-indica*, cv. Gialla, grown in a commercial orchard in Roccapalumba, 300 m a.s.l. Trees were globe-shaped, spaced 5 m × 6 m apart and drip-irrigated during the dry season. During the first week of June, the spring flush of flowers and cladodes was removed to induce a return bloom in July. Three weeks after full bloom, fertile cladodes were thinned to leave no more than nine fruits per cladode. All fertile cladodes were sampled. Fruits were harvested at commercial harvest time, indicated by the peel colour breakage [1]. Since *Opuntia ficus-indica* fruit ripening, at plant and cladode level, lasts up to three or four weeks, fruit harvest was distributed into three parts: October 16th, November 5th and December 2nd.

Table I.
Analysis of variance of quality parameters of *Opuntia ficus-indica* fruits, cultivars Gialla and Rossa, from three different growing sites in Sicily.

Factor studied	Weight	Total soluble solid content	Flesh percent	pH	Titratable acidity	Height / width
Site	**	**	Non-significant	Non-significant	Non-significant	*
Cultivar	**	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
Altitude	**	**	Non-significant	Non-significant	Non-significant	**
Site × cultivar	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant

*, ** Significant at $p < 0.05$ and $p < 0.01$, respectively (Tukey's test).

Table II.
Analysis of variance of seed content in *Opuntia ficus-indica* fruits, cultivars Gialla and Rossa, from three different growing sites in Sicily.

Factor studied	Total seeds	Viable seeds	Aborted seeds	Viable seeds
Site	**	**	**	**
Cultivar	*	Non-significant	**	**
Altitude	Non-significant	Non-significant	Non-significant	Non-significant
Site × cultivar	Non-significant	Non-significant	Non-significant	Non-significant

*, ** Significant at $p < 0.05$ and $p < 0.01$, respectively (Tukey's test).

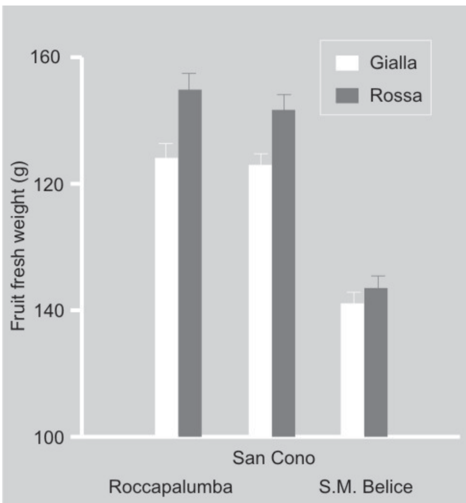

Figure 1.
Average fruit weight of *Opuntia ficus-indica* fruits, cultivars Gialla and Rossa, in three main sites in Sicily. Data are means of 10 orchards for each site (Roccapalumba, San Cono, Santa Margherita Belice) and 50 fruits per cultivar in each orchard. Bars indicate standard errors.

Photosynthetically Active Radiation was measured hourly from dawn to dusk, during five sunny days during the fruit development period (July 31st, August 15th, September 1st, September 15th and October 1st). Measurements were taken, in both vertical plane-surfaces of each of 100 fertile cladodes, at different plant exposures (North, East, South and West) and heights, with a LI-COR Li-189 quantum photometer (Li-Cor, Lincoln, NE, USA).

Fertile cladodes were sorted by crop load and position within the plant, in terms of height from the soil (0–1 m; 1.1–2.0 m; 2.1–3.0 m) and plant exposition (North, East, South and West).

Fruits were sampled from each cladode and, soon after harvest, they were analysed to determine fruit weight, percent flesh, total soluble solid content and total titratable acidity.

Cladode surface area, and fresh and dry weight were measured on fifteen fertile cladodes with different crop load, taken on each of the five trees. For each of these cladodes, fruit weight, total soluble solid content and total titratable acidity were measured.

Table III.
Seed content in *Opuntia ficus-indica* fruits, cultivars Gialla and Rossa, from three different growing sites in Sicily.

Growing site	Total seeds (*n*)		Viable seeds (*n*)		Aborted seeds (*n*)	
	mean ± standard error		means ± standard error		means ± standard error	
San Cono	374.7 a	6.9	174.4 b	3.9	200.3 a	6.1
Roccapalumba	374.2 a	6.6	202.4 a	4.7	171.8 b	4.7
Santa Margherita Belice	280.2 b	6.1	152.1 c	3.8	128.1 c	4.0

Different letters indicate significant differences within the column at $p = 0.05$ (Tukey's test).

Data were processed (Systat statistical package, SSCS© Inc.) by two-way analysis of variance; Tukey's test was applied to indicate significant differences between means.

3. Results

3.1. Fruit quality variability in relation to orchard location

Fruit weight, shape and total soluble solid content significantly changed with the environmental conditions, *i.e.*, site and altitude, while percent flesh, pH and total titratable acidity did not. Cultivars had a significant influence only on fruit weight and seed content (*tables I, II*).

Fruit weight was lowest where trees received only complementary irrigation and where the number of total and viable seeds was the lowest (*figure 1*, *tables I, III*). Cultivars affected fruit size (*table I*), except when fruit size was lowest (*figure 1*). Seed content, particularly viable and aborted seed number, changed with site but not with altitude (*table II*); Rossa fruits had a higher seed number (351 ± 6.7) than Gialla fruits (331.7 ± 5.5), with no significant differences in viable seed number but a significant difference in aborted ones (Rossa, 181.4 ± 5.7, *vs.* Gialla, 153.6 ± 3.9). Fruit weight increased with altitude, being 25% higher at the highest altitude than at the lowest ones (*figure 2*). Total soluble solid content did not change with cultivar, but it did with site (*figure 3*) and altitude (*figure 4*); the smallest fruits from Santa Margherita Belice also

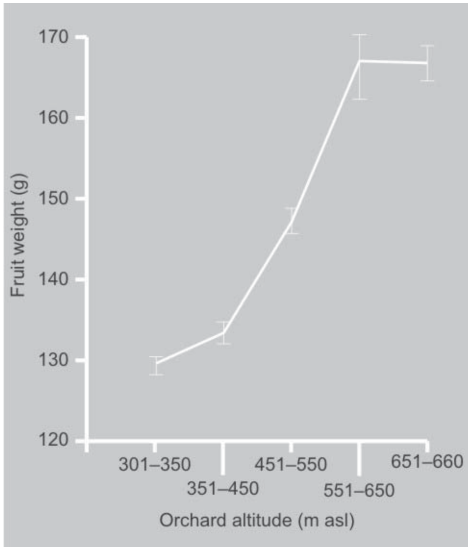

Figure 2.
Average weight of *Opuntia ficus-indica* fruits in relation to the altitude of the orchard site in Sicily. Data are means of 10 orchards for each site and 50 fruits per cultivar in each orchard. Bars indicate standard errors.

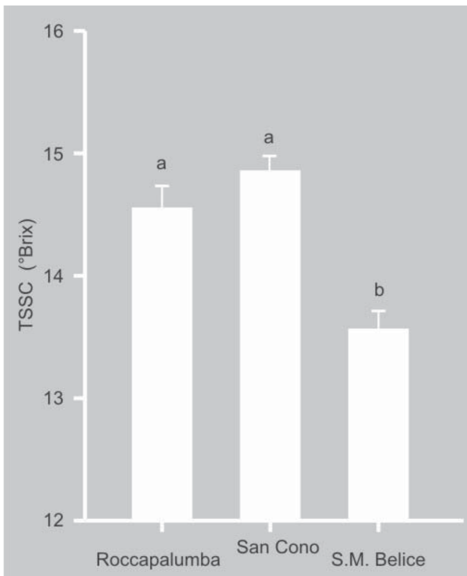

Figure 3.
Total soluble solid content (TSSC) of *Opuntia ficus-indica* fruits, cultivars Gialla and Rossa, in three main sites in Sicily. Data are means of 10 orchards for each site (Roccapalumba, San Cono, Santa Margherita Belice) and 50 fruits per cultivar in each orchard. Bars indicate standard errors.

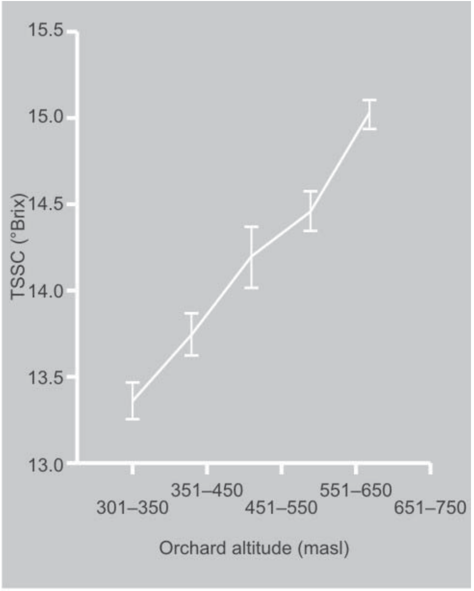

Figure 4.
Total soluble solid content (TSSC) in *Opuntia ficus-indica* fruits in relation to the altitude of the orchard site in Sicily. Data are means of 10 orchards for each site and 50 fruits per cultivar in each orchard. Bars indicate standard errors.

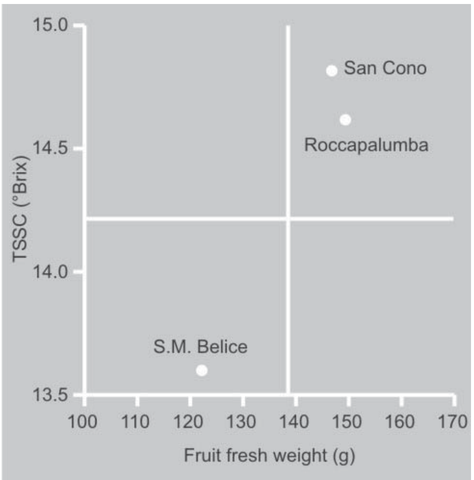

Figure 5.
Total soluble solid content (TSSC) and fresh weight of *Opuntia ficus-indica* fruits, cultivars Gialla and Rossa, in relation to the orchard site in Sicily. Data are means of 10 orchards for each site and 50 fruits per cultivar in each orchard.

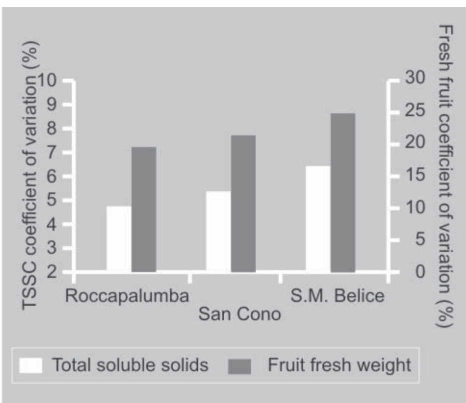

Figure 6.
Coefficient of variation of fruit weight and total soluble solid content (TSSC) in *Opuntia ficus-indica* fruits in each orchard site (Roccapalumba, San Cono, Santa Margherita Belice), in Sicily. Data are means of 10 orchards for each site and 50 fruits per cultivar in each orchard.

had the lowest total soluble solid content (*figure 3*), and total soluble solid content increased by altitude, although to a lower extent than fruit weight (15%). Fruits of both cultivars changed similarly with the environment, as shown by the absence of any (site × cultivar) interaction (*tables I, II*).

Where irrigation was poorly managed (Santa Margherita Belice) and pollination less effective, fruit size was lowest and so was total soluble solid content (*figure 5*), while the variability in both these parameters increased (*figure 6*).

Fruit weight showed a higher variability than total soluble solid content (*figure 6*). Orchard site had no significant influence on consumers' judgements except for fruit firmness, which was judged highest for Santa Margherita Belice fruits. Cactus pears from every site were perceived as low-acid, sweet and juicy fruits (*figure 7*). Panellists did not appreciate significant differences between Gialla and Rossa fruits (data not shown).

3.2. Within-tree variability factors

Fruit weight changed greatly within the tree (*table IV*), while total soluble solid content and percent flesh variability was much reduced (*table IV*). The range of variability was very similar in all the sampled trees (*table IV*) and increased with late harvest dates (from 50% for fruit weight and flesh firmness and 100% for total soluble solids), although fruit size, total soluble solid content and percent flesh did not change significantly with dates (data not shown). Fruits located in the upper canopy section and in the NE and SE expositions, where daily photosynthetically active radiation was higher than 20 $mol \cdot m^{-2} \cdot day^{-1}$, had the largest size, with no difference in total soluble solid content and percent flesh (*tables V, VI*). However, differences in fruit size did not exceed 15%. Fruit weight decreased with fruit number per tree (*figure 8*) and both fruit weight (*figure 9*) and total soluble solid content (*figure 10*) sharply decreased with more than six fruits per cladode. The average surface area and the dry weight of the fruiting cladodes were, respectively, (0.21 ± 0.003) m^2 and (123.6 ± 2.27) g. Fruit fresh weight and total soluble solid content were related neither to the surface area nor to the dry weight of the fruiting cladode in which fruits developed. However, individual fruit dry weight and the total soluble solid content, expressed in fresh weight per fruit, were related to the dry weight of the fruiting cladode (*figures 11, 12*). Cladode surface area was poorly related to fruit dry weight (r^2 = 0.33) and total soluble solid content (r^2 = 0.43). The "cladode excess dry weight" [10] at which the cladode became fruitful was 50 g; above this value it was not possible to relate cladode fruitfulness to its excess dry weight (*figure 13*).

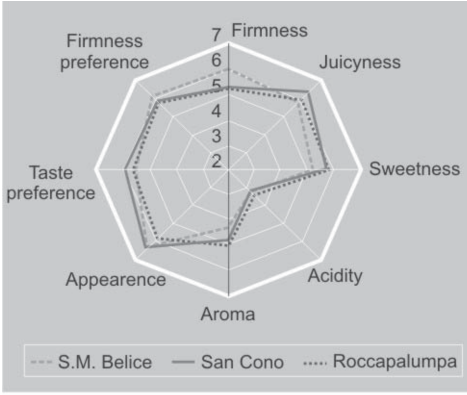

Figure 7.
Sensory profiles of *Opuntia ficus-indica* fruits in relation to the orchard site (Roccapalumba, San Cono, Santa Margherita Belice), in Sicily. Data comes from the evaluation of 50 fruits per cultivar in each orchard site.

4. Discussion

Crop value depends very much on crop variability in fruit size, which is the major factor for fruit price in Europe. In fact, differences between the highest priced fruits and the regular crop can be over 60% and this greatly reduces orchard profitability. In our experiment, fruit size showed a range of variability (coefficient of variation of fruit size within the different sites) between 7% and 25% and changed with cultivar, site and altitude, as well as tree and cladode crop load. It was confirmed that the threshold of 6–7 fruits per cladode must be taken into account to get export-sized fruits with adequate total soluble solid content [8], while moving from 220 fruits to 340 fruits per tree

Table IV.
Coefficient of variability (%) of fruit quality parameters for each of five trees of *Opuntia ficus-indica*, cv. Gialla.

Individual tree of *Opuntia ficus-indica*	Fruit weight	Total soluble solid content	Flesh percent
A	19.9	6.3	7.8
B	22.1	5.4	8.2
C	18.4	4.8	7.6
D	20.4	6.1	8.3
E	21.5	7.2	9.2

Table V.
Quality parameters for *Opuntia ficus-indica* fruits, cv. Gialla, in relation to canopy site and intercepted Photosynthetically Active Radiation (PAR).

Canopy site	Photosynthetically Active Radiation ($mol \cdot m^{-2} \cdot day^{-1}$)	Fruit weight (g)	Total soluble solid content (° Brix)	Flesh percent (%)
Bottom (0–1 m)	15	127.0 a	14.9 ns	55.1 ns
Middle (1–2 m)	18	139.5 b	15.0	56.3
Top (2–3 m)	22	146.6 c	15.7	56.1

In the same column, different letters indicate significant differences and ns = no significant differences at p = 0.05 (Tukey's test).

Table VI.
Quality parameters for *Opuntia ficus-indica* fruits, cv. Gialla, in relation to canopy orientation and intercepted Photosynthetically Active Radiation (PAR).

Canopy orientation	Photosynthetically Active Radiation ($mol \cdot m^{-2} \cdot day^{-1}$)	Fruit weight (g)	Total soluble solid content. (° Brix)	Flesh percent (%)
NE	24	142.9 a	14.8 ns	56.8 ns
SE	27	141.4 a	15.0	54.3
NW	17	131.8 b	14.9	55.8
SW	16	131.6 b	15.1	54.7

In the same column, different letters indicate significant differences and ns = no significant differences at $p = 0.05$ (Tukey's test).

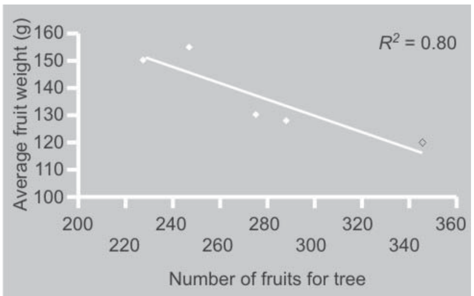

Figure 8.
Relationship between average fresh fruit weight and number of fruits per tree in five 8-year-old *Opuntia ficus-indica* trees, cultivar Gialla, grown in a commercial orchard, in Roccapalumba (Sicily, Italy).

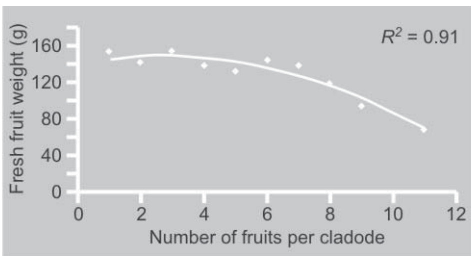

Figure 9.
Relationship between average fresh fruit weight and number of fruits per cladode in five 8-year-old *Opuntia ficus-indica* trees, cultivar Gialla, grown in a commercial orchard, in Roccapalumba (Sicily, Italy).

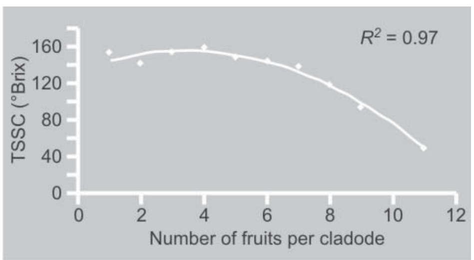

Figure 10.
Relationship between total soluble solid content (TSSC) and number of fruits per cladode in fruits of five 8-year-old *Opuntia ficus-indica* trees, cultivar Gialla, grown in a commercial orchard, in Roccapalumba (Sicily, Italy).

caused a 20% reduction of fruit size and tree crop load. If fruit thinning is crucial to get an export fruit size, the whole crop load plays a significant role in regulating the source-sink interactions, then regulating the fruit size at plant level. Our data clearly demonstrate that complementary basin irrigation is less efficient than drip irrigation in regulating fruit size and quality. In fact, the seasonal irrigation volumes did not differ very much, being around 60 mm in each of the sites, but the light and shallow Mediterranean red soils of Santa Margherita Belice determine the poor efficiency of the high volumes given twice during the season, due to fast water leaching. In these conditions, fruit quality decreases while its variability increases. Cultivars had no apparent influence on all the other fruit quality parameters, except the number of seeds, which was higher in Rossa fruits, that were also the biggest.

The CAM cycle of *Opuntia ficus-indica* is particularly efficient in a temperature range of 25 °C/15 °C (day/night) [15]. These conditions are uncommon during the hot and dry Mediterranean summers, when day/night temperatures may increase up to 35 °C/25 °C. During July and August, when flower bud development, bloom and the first 4–5 weeks of fruit growth occurred, average daily temperatures ranged from 31 °C/24 °C at 300 m a.s.l. to 26 °C/17 °C at 600–650 m a.s.l. These differences may explain the role of altitude in increasing fruit size and total soluble solid content. Moreover, fruits in cooler environments had a longer fruit ripening period, particularly a longer duration of the third stage of fruit growth (data not shown)

Cladode development in terms of surface area is not a good index of its capacity to give high fruit quality, while its position within the canopy is more important.

Indeed, the light environment is the most important source of variability in fruit growth and quality in many fruit trees [16]. In fact, fruit dry weight and total soluble solid content increased with cladode dry weight, which is closely related to cladode carbon uptake and, ultimately, to light availability [15]. The cladode excess dry weight reported in our experiment is 30% higher than the value indicated by Garcia de Cortazar and Nobel [10]. Differences in environmental conditions, plant age and planting densities may account for this discrepancy; however, also in that experiment, most of the fruiting cladodes had an excess dry weight ≥ 50 g.

Pruning is, therefore, important for adequate cladode dry weight accumulation, in order to couple its fruiting potential with good fruit quality.

The role of the cultivar in determining fruit quality did not change with site and, moreover, the sensory analysis was unable to discriminate for cultivar and environment. This must be considered when policies such as the *Protected Designation of Origin* (PDO) are used to develop the cactus pear industry.

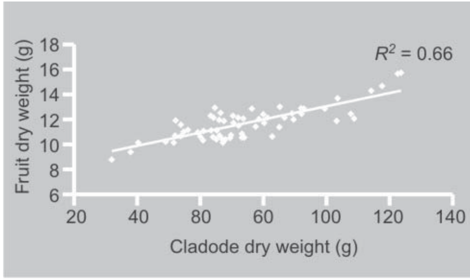

Figure 11.
Relationship between average fruit weight and calculated cladode dry weight (0.477 × length (cm) × width (cm) × thickness (r^2 = 0.93) [14] in five 8-year-old *Opuntia ficus-indica* trees, cultivar Gialla, grown in a commercial orchard, in Roccapalumba (Sicily, Italy).

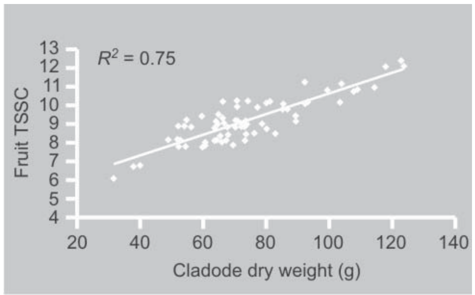

Figure 12.
Relationship between total soluble solid content (TSSC), expressed as g for fresh fruit weight, and calculated cladode dry weight (0.477 × length (cm) × width (cm) × thickness (r^2 = 0.93) [14], in five 8-year-old *Opuntia ficus-indica* trees, cultivar *Gialla,* grown in a commercial orchard, in Roccapalumba (Sicily - Italy).

Figure 13.
Cladode dry weight in excess of the minimum dry weight for its surface area vs. number of fruits on that cladode. Minimum dry weight was determined for 35 cladodes harvested in October 2006. The vertical line indicates the minimum excess dry weight of 50 g [10].

5. Conclusion

There is not much data on the variability in crop value in *Opuntia ficus-indica*, though there is evidence [5, 15] of differences in cropping performance related to site, planting system and orchard management. It is well known that physical attributes of cactus pears may change according to time of ripening and crop load; for instance, fruits ripening during the hot summer months have a lower size, a different shape, a lower flesh firmness and a higher sensitivity to post-harvest chill than fruits ripening under the cool temperatures prevailing during October and November [9, 5, 4]. Fruits ripening in winter also show a lower sugar content and flavour [6]. In this experiment, it has been demonstrated that the main sources of within-tree fruit quality are related to the characteristics of the fruiting cladode, in terms of fruit load, dry matter accumulation and position within the canopy, while the site effects are sources of variability in size and soluble solid content, but not consistent for organoleptic features. Consumers do appreciate differences in aroma and flavour between cactus pear varieties [5] but there is no scientific evidence of any consistent relationship between the variability in those parameters and the environmental or within-tree source factors. This makes it very difficult to set any standard of fruit quality related to its organoleptic features. In the future, the variability in aroma and flavour of cactus pear fruits should be investigated in relation to the fruit ripening stage at commercial harvest.

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Influencia de factores dentro del árbol y medioambientales en la calidad de los frutos de la higuera de chumbo (*Opuntia ficus-indica*) en Italia.

Resumen — Introducción. Se estudió la calidad de los frutos de la higuera de chumbo en los principales sitios de cultivo de *Opuntia ficus-indica* en Italia, con el fin de comprender las principales fuentes de variabilidad y de aumentar el valor de las cosechas. **Material y métodos**. Un primer análisis se llevó a cabo en 2006 en árboles adultos de *O. ficus-indica*, cvs. Gialla y Rossa, desarrollados en diez vergeles comerciales situados en tres localidades de los principales lugares de este cultivo en Italia. Se condujeron los árboles de modo a producir en octubre, fuera de temporada, mediante supresión de los brotes de primavera en el momento de la floración durante la primera semana de junio. Los árboles eran de producción equivalente [(52 ± 10) kg de frutos por planta], y no dejamos más de seis frutos por cladodio fructífero. Durante la cosecha comercial, indicada por el cambio de color de la piel, cosechamos 75 frutos por vergel y 750 frutos por cada lugar. Éstos se analizaron y evaluaron por un grupo de consumidores. Se llevó a cabo un segundo experimento en 2006 en higueras de chumbo, cv. Gialla, de 8 años de edad y cosechadas en vergel comercial. Se estudiaron factores propios del árbol, como la posición de los frutos en el dosel, el número de frutos por árbol y por cladodio, así como el peso seco de los cladodios. **Resultados y discusión**. El peso, la forma y el contenido total de sólidos solubles de los frutos cambiaron de manera significante en función de las condiciones medioambientales, es decir, el lugar y la altitud. Sin embargo no difirieron ni el índice de pulpa, ni el pH ni la acidez total del fruto. El cultivar sólo influyó significantemente el peso de los frutos y el contenido en semillas. El peso de los frutos varió mucho en un mismo árbol, mientras que la variabilidad del contenido total de azúcares sólidos y de la pulpa se redujo notablemente. El peso de frutos disminuyó con el aumento del número de frutos por árbol. Ambos rasgos: el peso de frutos y el contenido total en sólidos solubles, disminuyeron para los cladodios de más de seis frutos. La intercepción de la luz y el peso seco de cladodio fueron las principales fuentes de variabilidad del peso seco de los frutos y del contenido en azúcar. Sin embargo la superficie de los cladodios no tuvo ningún efecto en la calidad de los frutos. El papel del cultivar en la determinación de la calidad de los frutos no difirió entre un lugar y el otro. No obstante, el análisis sensorial no permitió discriminar ni cultivar ni el medioambiente.

Italia / *Opuntia ficus-indica* / ensayos de variedades / frutas / factores de rendimiento / características del sitio