

Comparison of morphological and chemical fruit traits from different pitaya genotypes (*Hylocereus* sp.) grown in Costa Rica

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Summary

Physico-chemical parameters of the fruits of five *Hylocereus* genotypes grown in their natural habitat in Costa Rica were determined and their morphological traits were assessed. Besides, overall dimensions, shape, weight, flesh fraction, skin thickness, seed content and juice yield were recorded. Chemical analyses comprised pH, total soluble solids, titratable acidity, proline and pectin content, formol number and density of the juices. In addition, the major sugars glucose, fructose and sucrose, as well as organic acids were quantified by HPLC. Moreover, skin and flesh firmness were assessed. Significant differences were observed between genotypes concerning fruit weight and dimensions, skin thickness, proportion of flesh and amount of seeds. Whereas lowest pH values were determined in the juices from 'San Ignacio', highest malic acid contents in 'Rosa' and maximal total soluble solids were found in juices from 'Nacional' fruits. Furthermore, differences between genotypes concerning density, pectin and glucose contents of the juices were noted.

Introduction

Vine cacti belonging to the genus *Hylocereus* are native to tropical regions of North, Central and South America. Plants are characterised by elongated three-ribbed stems climbing trees and rocks. The fruits are medium to large epigenous berries covered with large scales (NERD and MIZRAHI, 1997). Different species and genotypes within the genus differ in size, shape, taste, and colour. Pulp colour may range from white to various hues of red and purple (MIZRAHI and NERD, 1996; MIZRAHI et al., 1997). In contrast to the seeds of the more common cactus pear (*Opuntia* sp.), those from pitaya are small, soft and edible, thereby increasing the fruit's popularity for fresh consumption. Hence, several species within the genus *Hylocereus* have been recently developed as fruit crops and are successfully cultivated in tropical regions such as Central America, the Near and Far East (MIZRAHI and NERD, 1999; NERD et al., 2002).

H. undatus [(Haworth) Britton & Rose] (red skin, white pulp) has been widely cultivated, while others such as *H. polyrhizus* [(F.A.C. Weber) Britton & Rose] (red skin, red-violet pulp) and *H. costaricensis* [(F.A.C. Weber) Britton & Rose] (red skin, red pulp) are grown at smaller scale (LIEBSTER and LEVIN, 1999; MIZRAHI and NERD, 1999). The latter species is cultivated mainly in Nicaragua, and commercial plantations have been established from clones selected from the wild. Today, most of the production is transformed into pulp, which is highly appreciated by the food industry in the United States and Europe, especially as a natural colourant (NERD et al., 2002).

Fruit quality depends on a number of different parameters such as sugar content, total acidity, fruit texture, and particularly aroma (HUYSKENS-KEIL and SCHREINER, 2003). Investigations on *Hylocereus* fruits have been conducted in Israel (NERD et al., 1999) and Vietnam

(To et al., 2002), assessing total soluble solids (TSS), titratable acids (TA) and colour. More detailed data on the spectrum of non-volatile compounds in *H. polyrhizus* and *H. undatus* grown in Israel have been published more recently (STINTZING et al., 2003). However, extensive research on the quality characteristics of the different genotypes cultivated in their native environment of Central America was still missing. 'Lisa', 'Orejona', 'Rosa' and 'San Ignacio' are the common genotypes commercialised in Nicaragua, the Central American country with the highest pitaya production of about 3000 t on 420 ha (ANONYMOUS, 1994; VAILLANT et al., 2005). Considering the promising future of these fruits, the present work aimed at comparing morphological and fruit quality characteristics such as firmness together with selected chemical parameters of the juices from several *Hylocereus* genotypes commonly grown in Costa Rica and Nicaragua.

Materials and methods

Plant material

Three-year-old plants belonging to five *Hylocereus* genotypes locally known as 'Lisa', 'Nacional', 'Orejona', 'Rosa' and 'San Ignacio' were cultivated organically in Barranca, Puntarenas, Costa Rica (N9°57.566' W84°43.217') where an annually average temperature of 26.8°C and a total precipitation of 2057.7 mm prevailed. The sampled plants were originally brought from Nicaraguan plantations several years before, except for 'Nacional' which was formerly collected from the surroundings of the above mentioned pitaya plantation. Samples of each of the analysed genotypes were deposited at the Herbarium at the Universidad de Costa Rica (USJ), under the following accession numbers: 'Rosa' 88680, 'San Ignacio' 88681, 'Nacional' 88682, 'Lisa' 88683 and 'Orejona' 88684. Fruits of each genotype were harvested from July to August 2004. Five fruits of each genotype were collected from tagged plants when their peel colour started to change from green to purple. Fruits were subsequently stored at room temperature and analysed after full colour development, which was completed within four days.

Reagents and solvents

Reagents and solvents were purchased from Sigma International (St. Louis, MO, USA) and were of analytical or HPLC grade. Deionised water was used throughout.

Morphological characterisation, seed number and juice extraction

Flesh and skin weight, fruit size and skin thickness, were determined in six fruits of each genotype after full colour was reached. The general appearance of the fruits was documented by taking photos of the fruits. Juice of each separate fruit was obtained using a juice extractor (Oster Model 5720-08, France). The juice yields were determined and expressed as % of juice (g) of total fruit weight (g). The juice of each

fruit was analysed separately as a biological replicate. After juice extraction, the remaining pulp containing the seeds was washed and adjusted to a volume of 90 mL. 10 mL of HCl (37.5%) were added for acid hydrolysis of the mucilagenous material, and the samples stirred overnight. Subsequently, the seeds were washed with distilled water and dried. Four replicates of 500 seeds were counted manually and weighed and expressed as 1000-seed-weight. The number of seeds per fruit was determined based on the weight of 1000 seeds and the total seed weight of seeds per fruit.

Texture evaluation

Fruit firmness was determined at six different points on the equator of each fruit using a Texture Analyzer TA.XT Plus (Stable Micro Systems, Surrey, UK) with a 2 mm diameter stainless steel probe. The operating conditions were a pre-test speed of 2.0 mm s⁻¹, a test speed 2.00 mm s⁻¹ and a post-test speed of 10 mm s⁻¹, respectively. A penetration distance of 15 mm was applied in each case. The maximum force value (N) monitored during skin penetration was expressed as skin firmness, while the average value of the plateau registered after skin penetration was taken as flesh firmness.

Chemical characterisation

For titratable acidity (TA) assessment, 10 mL of juice were titrated with 0.1 N NaOH to pH 8.1 and expressed as g malic acid L⁻¹ (IFU, 1995). Total soluble solids (TSS) concentration in g/100g was determined using a refractometer (NAR-1T, Atago, Japan). Concentrations of sucrose, glucose and fructose were analysed applying a HPLC-system (Merck, Darmstadt, Germany) equipped with an analytical Aminex HPX-87H-column (300 x 7.8 mm i.d., Biorad, California, USA) with a particle size of 5 µm and an IR-Detector (LaChrom Elite L-2490, Tokio, Japan), according to the method of CHINNICI et al. (2005). Separation was achieved using isocratic elution at 30°C with a flow rate of 0.4 mL min⁻¹, applying 0.01 N *o*-phosphoric acid as eluent. Organic acid concentrations were determined using a modified HPLC-method described by CHINNICI et al. (2005) using the same Aminex column and 0.01 N *o*-phosphoric acid as mobile phase. Prior to analysis, 2 mL of 0.125 N NaOH were added to 10 mL juice for pH adjustment. Dehydroascorbic acid was then reduced with dithiothreitol (DTT) according to IWASE and ONO (1993), after addition of 0.4 mL 0.1% DTT to 2 mL and adjustment of the juice to pH 6.8. Due to co-elution of ascorbic and malic acids, the former was oxidised adding 0.4 mL of hydrogen peroxide (10%) to 2 mL of juice and the remaining malic acid quantified based on a five point calibration curve (R²>0.998). Based on the total peak area of ascorbic and malic acids alone, ascorbic acid quantification based on a five point calibration (R²>0.998) was possible (MOSSHAMMER et al., 2006). Further organic acids were directly assessed after 1:5 dilution of the juice. Density of the extracted juice was determined in triplicate by weighing 1 mL of juice in a 1 mL graduated flask at 20°C (triplicate). Formol numbers, proline and pectin concentrations were analysed according to IFU methods 30 (IFU, 1984), 49 (IFU, 1983) and 26 (IFU, 1995), respectively.

Statistical analysis

Analysis of variance was conducted using the Statistica for Windows (StatSoft, Tulsa, OK, USA) with the Tukey test to determine differences between means of each genotype, considering each of the five fruits as a biological replicate. Each analysis was carried out at least in duplicate for each fruit.

Results and discussion

Morphological traits

Fruit description. Differences in overall shape and scale form were observed between genotypes (Fig. 1): The fruits from 'Lisa' only exhibited few and small scales. 'Nacional' and 'Orejona' had broader scales at a higher number. 'Rosa' and 'San Ignacio' lost their scales during ripening, with only the base of the scale remaining. Notably, the scales of 'San Ignacio' fruits were thicker than those of the other genotypes at early stages, representing a useful feature for genotype differentiation.

Overall dimensions. The morphological traits determined for the different *Hylocereus* fruits are compiled in Tab. 1. Whereas, the maximal diameter was registered in 'Rosa' with 7.74 cm, 'Nacional' showed the smallest amounting to 4.54 cm. Maximum fruit length were found for 'San Ignacio' and 'Rosa' with 8.86 cm and 8.62 cm, respectively, while the smallest fruits were from 'Nacional' only reaching 5.64 cm. 'Nacional' and 'Rosa' exhibited a length:diameter ratio of almost one, representing the most round-shaped fruits. Hence, clear differences between genotypes were found for length, diameter and shape. NERD et al. (1999) reported final length and diameter values of *H. undatus* fruits to range between 8 and 9 cm, while those of *H. polyrhizus* were between 9 to 10 cm and 7 to 8 cm, respectively.

Fruit weight. BARBEAU (1990) reported total weights for *Hylocereus* fruits of 250 to 350 g, and suggested the impact of genotype and environmental conditions on fruit weight. In more recent studies, average weights of 400 to 482 g for *H. undatus* and of about 300 g for *H. polyrhizus* were reported at full colour (HOA et al., 2006; NERD et al., 1999). Investigations on *Hylocereus* fruits cultivated in Nicaragua indicated that 'Lisa' produces fruits with an approximate weight of 380 g, while 482 g and 533 g were described for 'Orejona' and 'Rosa', respectively (ANONYMOUS, 1994). From the data obtained in the present study, the differences between genotypes could be corroborated although lower total fruit weights were generally registered (Tab. 1) being maximal for 'Rosa' and 'Orejona' with 'Nacional' marking the minimum value.

For fresh fruit marketing size and colour are relevant. *Hylocereus* fruits exported from Israel are usually graded by the number of fruits per weight, i.e. 6, 8, 10, 12, 14 or 16 per 4 kg, respectively. In Vietnam, size grades are extra large (>500 g), large (380 to 500 g), regular (300 to 380 g), medium (260 to 300 g) and small (<260 g) (KAYS and PAULL, 2004). Accordingly, the fruits of the genotype 'Rosa' were assigned to the category large, 'San Ignacio' to regular, while the fruits of the other genotypes were considered small.

Flesh proportion and skin thickness. Both for fresh fruit marketing and processing, fruits with a high proportion of flesh are desirable. Concerning the flesh proportions, again differences between genotypes were found (Tab. 1). 'Lisa' reached the uppermost value with 74% fruit flesh, whereas the lowest value was marked by 'Nacional' with 55%. In an earlier study, flesh ratios of approximately 65 and 38% for *H. undatus* and *H. polyrhizus*, respectively, were reported (NERD et al., 1999). The results from the present work indicate that the genotypes assessed come close to *H. undatus*, the most widely commercialised pitaya fruit worldwide.

Skin firmness represents a crucial parameter for postharvest handling and has been reported to account for the variation in storage life of fruits from different varieties (CARRILLO-LÓPEZ et al., 2002). As shown in Fig. 2 and Tab. 1, skin firmness positively correlated with skin thickness scores being highest for 'Rosa' and 'San Ignacio' but lowest for 'Lisa' fruits.

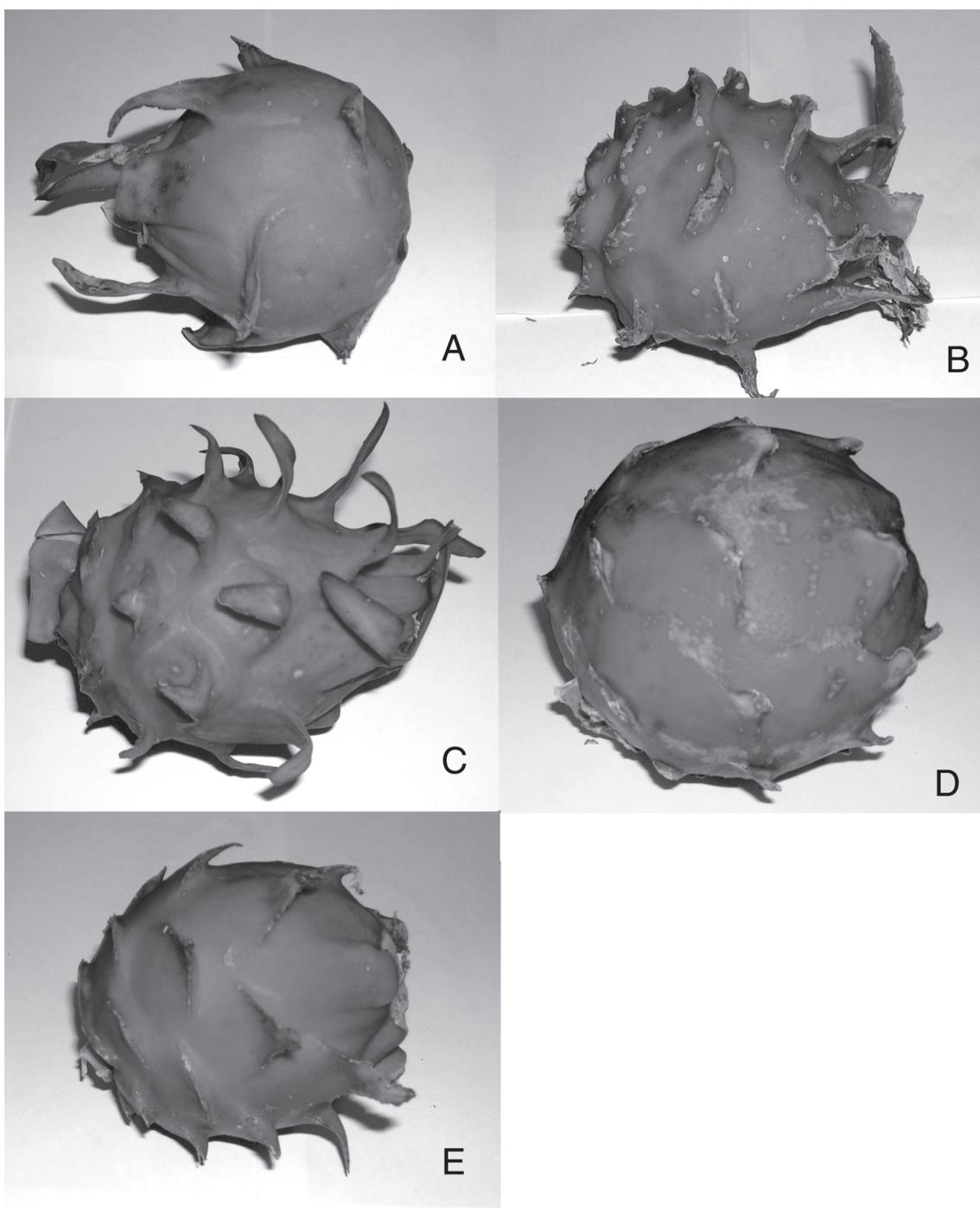


Fig. 1: Fruits from the genotypes 'Lisa' (A), 'Nacional' (B), 'Orejona' (C), 'Rosa' (D) and 'San Ignacio' (E) at full maturity

Seeds. For the production of fruit juices, the number of seeds is crucial since they have to be removed during processing. Whereas BARBERA et al. (1992) did not find differences between cactus pear (*Opuntia* sp.) cultivars, with values ranging between 302 and 326 seeds per fruit, genotypic variations were obvious in the *Hylocereus* genotypes evaluated in this work (Tab. 1). The highest amount of seeds was observed in 'Rosa' coming close to 5000 seeds per fruit, and the lowest in 'Lisa' and 'Orejona' with less than 3000. However, for objective comparison, total seed numbers were related to the particular fruit weights. While in the present investigation *Hylocereus* genotypes ranged between 13.41 and 30.27 in 'Rosa' and 'Nacional',

respectively (Tab. 1), FELKER et al. (2002) reported seed:whole fruit-ratios between 2.19 and 5.59 in *Opuntia* clones. Considering seed percentage in relation to flesh weight, values between 4.6% in 'Lisa' and 8.0% in 'Nacional' were registered (Tab. 1), whereas 5 to 10% have been reported for cactus pear (DURU and TURKER, 2005).

Moreover, the seed weight difference between genotypes with heavier seeds in 'Rosa' fruits compared to 'Nacional' (Tab. 1) was noteworthy. Interestingly, correlations of fruit weight and seed number were reported for *Opuntia ficus-indica* (BARBERA et al., 1994) and *Hylocereus* sp. (CASTILLO et al., 2003). In the present study, similar

Tab. 1: Morphological traits of fruits from different *Hylocereus* sp. genotypes at full ripeness (mean of five replicates \pm standard error).^a

Parameter	'Lisa'	'Nacional'	'Orejona'	'Rosa'	'San Ignacio'
Fruit diameter (cm)	6.52 \pm 0.15B	4.54 \pm 0.18C	6.46 \pm 0.15B	7.74 \pm 0.24A	6.76 \pm 0.17B
Fruit length (cm)	7.05 \pm 0.20B	5.64 \pm 0.22C	8.07 \pm 0.26AB	8.62 \pm 0.28A	8.86 \pm 0.36A
Fruit shape (length:diameter)	1.07 \pm 0.02A	1.23 \pm 0.02BC	1.23 \pm 0.02BC	1.11 \pm 0.03AB	1.30 \pm 0.03C
Fruit weight (g)	217.85 \pm 22.10BC	117.50 \pm 12.26C	229.13 \pm 12.81B	393.60 \pm 53.97A	308.25 \pm 36.21B
Flesh proportion (g/100g)	73.76 \pm 1.40A	54.67 \pm 2.52C	65.35 \pm 1.65B	59.13 \pm 1.78BC	60.68 \pm 1.30BC
Skin thickness (cm)	0.28 \pm 0.03C	0.42 \pm 0.04AB	0.32 \pm 0.04BC	0.55 \pm 0.06A	0.49 \pm 0.06AB
Total seed number	2763.61 \pm 458.67B	3359.15 \pm 51.04AB	2946.06 \pm 451.58B	4980.68 \pm 482.88A	4565.50 \pm 192.76AB
Total seed number / g total fruit weight	19.24 \pm 1.84AB	30.27 \pm 1.15A	15.14 \pm 1.23B	13.41 \pm 2.66B	20.15 \pm 2.25AB
Seeds/flesh (g/100g)	4.60 \pm 0.28B	8.01 \pm 0.42A	4.98 \pm 0.47B	5.04 \pm 0.57B	5.47 \pm 0.11AB
Seeds/whole fruit (g/100g)	3.28 \pm 0.15AB	4.57 \pm 0.12A	2.70 \pm 0.19B	3.22 \pm 0.37AB	3.47 \pm 0.10AB
1000-seed weight (mg)	1901.6 \pm 37.2AB	1510.0 \pm 16.8A	1901.6 \pm 73.4AB	2239.6 \pm 184.0B	1901.6 \pm 46.0AB

^a Significant differences within values in the same row are indicated by different letters ($P < 0.05$).

findings could not be noted. Data from other fruits indicate that the relationship between fruit size and seed content is highly variable being affected by genotype, crop load and fruit position within the canopy (LAWES et al., 1990).

Juice yield. Although differences concerning overall dimensions, flesh proportions and seed amounts were noted, juice yield did not vary significantly between genotypes ranging between 29% for 'Rosa' and 36% for 'Lisa' and 'Nacional'. In comparison, MOSSHAMMER et al. (2006) obtained juice yields of 37 to 47%, depending on enzymatic treatments and filtration technologies at pilot-plant production of cactus pear (*Opuntia ficus-indica*) juice.

Flesh and skin firmness of the fruits

Using a penetrometer for texture analyses, HOA et al. (2006) reported considerably higher skin firmness values ranging from 12.7 to 14.7 N for *H. undatus*, as opposed to those found for the Costa Rican genotypes in the present work with a different experimental setup. For cactus pear much lower skin firmness values between 1.8 and 3.3 N were reported at commercial maturity (SILOS-ESPINO et al., 2003). Whereas skin firmness is an important parameter for post-harvest handling, the texture of the flesh is a decisive trait for fresh fruit consumption (HARKER et al., 1997). Surprisingly, the latter parameter has not been considered in *Hylocereus* so far. While no distinction between genotypes could be established based on skin firmness, significant differences were found for fruit flesh firmness (Fig. 2), with 'Nacional' fruits exceeding the remaining genotypes.

Chemical quality parameters

Titrate acidity (TA) and pH. Chemical quality parameters analysed in juices from *Hylocereus* fruits are listed in Tab. 2. As reported by STINTZING and CARLE (2006) for *Hylocereus* fruits of different origin pH values range from 4.3 to 4.7. In the present work, even higher values of up to pH 5 were measured (Tab. 2) with 'San

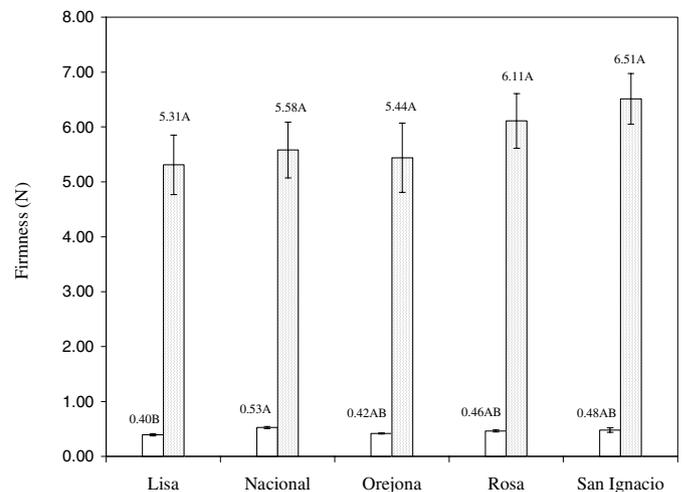


Fig. 2: Comparison of flesh (white columns) and skin (dotted columns) firmness of different Costa Rican genotypes at full maturity. Significant differences within values are indicated by different letters ($P < 0.05$).

Ignacio' marking the minimum value. In general, the pH values observed in *Hylocereus* fruits were higher compared to those of common fruit juices such as orange juice or apple juice ranging between 2.8 and 4.6 (A.I.J.N., 1996). No differences regarding TA were noted between genotypes. TA values of 3.4 g L⁻¹ reported by STINTZING et al. (2003) in *H. polyrhizus* are similar to the results observed for the different genotypes in the present work. In further investigations, TA values between 2.7 and 4.3 g L⁻¹ were reported for *H. undatus* (HOA et al., 2006; TO et al., 2002). For other tropical fruit juices TA values typically range between 5.8 to 15.4 g L⁻¹ for orange, 3.2 to 11.5 g L⁻¹ for pineapple and 25.6 to 50.0 g L⁻¹ for passion fruit (A.I.J.N., 1996), confirming that pitayas are fruits of low acidity (STINTZING and CARLE, 2006).

Total soluble solids (TSS). Considering TSS, 'Nacional' fruits showed the highest value, followed by 'Orejona', 'Lisa', 'San Ignacio' and finally 'Rosa'. In previous papers 9 to 15 and 8 to 11 g per 100g were found for *H. undatus* and *H. polyrhizus*, respectively (HOA et al., 2006; NERD et al., 1999; STINTZING et al., 2003; TO et al., 2003; VAILLANT et al., 2005). In other tropical fruit juices minimum TSS values are expected to reach 10% in orange juice, 8.5% in guava, 14% in mango, 11.2% in pineapple, 20% in bananas, and 12-17% in cactus pear fruits (A.I.J.N., 1996; HERNÁNDEZ-PÉREZ et al., 2005; CARRILLO-LÓPEZ et al., 2003; SILOS-ESPINO et al., 2003). According to HÜHN and SULC (2001) a TSS:TA ratio of 10:1 to 18:1 is necessary for sensory consumer acceptance. 'Rosa' and 'San Ignacio' came close to this requirement, while in all others sweetness was predominant (Tab. 2). As a consequence, the juices of most *Hylocereus* genotypes fruits would require acidification to balance their sugar-acid ratio.

Pectin. Minimum pectin contents of 650 mg kg⁻¹ were observed in the genotypes 'Lisa' and 'Orejona' (Tab. 2), while the maximum value was found in the genotype 'San Ignacio' amounting to 1360 mg kg⁻¹. Interestingly, these data correlated inversely with the respective juice yields (Tab. 1), corroborating the assumption by HERBACH et al. (2007), that mucilaginous material will considerably affect juice production. In comparison, typical pectin contents of pineapple, orange and passion fruit juices are 600, 700 and 1000 mg L⁻¹, respectively (A.I.J.N., 1996).

Density. With respect to density, juices extracted from fruits of the different genotypes could be grouped in two categories. Maximum values were measured in 'Nacional', 'Lisa' and 'Orejona', while the minimum was found in 'Rosa' and 'San Ignacio' (Tab. 2). Density values typical of other tropical fruit juices are 1.034 (guava), 1.083 (banana), 1.057 (mango) and 1.050 (maracuja) (A.I.J.N., 1996).

Formol number and proline. Since proline is the major amino acid of *Hylocereus* fruits (KUGLER et al., 2006), and the remaining amino compounds may be summarised by the formol value, both parameters were also determined (Tab. 2). Formol numbers of different tropical fruit juices are very variable ranging from 15 to 26 in orange, 8 to 20 in pineapple, and 20 to 50 in passion fruit juice (A.I.J.N., 1996). In the present study, differences observed between pitaya juices from the particular genotypes were insignificant and ranged between 8 and 11. Interestingly, although proline contents varied between 150 and 350 mg L⁻¹, differences between genotypes were again insignificant.

Proline contents of other tropical fruit juices are 8 to 50 mg L⁻¹ (pineapple juice), 150 to 1500 mg L⁻¹ (passion fruit juice) and 450 to 2090 mg L⁻¹ (orange juice) (A.I.J.N., 1996; WALLRAUCH and FAETHE, 1988).

Organic acid composition

The organic acid profiles (ascorbic, dehydroascorbic, citric, malic, lactic and oxalic acids) of juices from fruits of the evaluated genotypes are shown in Tab. 3. Whereas no differences were observed between genotypes with respect to ascorbic, dehydroascorbic, citric and oxalic acids, their malic and lactic acid concentrations varied significantly. Interestingly, titratable acidity (Tab. 2) stayed below the concentrations of the predominant malic acid (Tab. 3) which was ascribed to the buffering capacity of free amino acids (STINTZING et al., 2003).

Ascorbic acid. Contents of total vitamin C for the different genotypes are shown in Tab. 3, which were calculated as the sum of ascorbic and dehydroascorbic acids. Contrary to the results by STINTZING et al. (2003), ascorbic acid could be detected in all juices from the Costa Rican genotypes (Tab. 3). The pitaya genotypes studied in the present work showed ascorbic acid contents similar to other tropical juices, and dehydroascorbic acid considerably contributed to total vitamin C. Applying a non specific quantitative determination, NERD et al. (1999) found lower ascorbic acid concentrations than those determined by HPLC in the present work. According to VAILLANT et al. (2005) ascorbic and dehydroascorbic acid contents ranged from 0.12 to 0.17 g kg⁻¹ and 0.06 to 0.11 g kg⁻¹, respectively. VINCI et al. (1995) indicated that tropical fruits usually contain relatively high levels of ascorbic acid, varying between 0.2 and 0.9 g kg⁻¹, with few exceptions, such as avocado pear and feijoa (*Acca sellowiana* [O. Berg] Burret). Divergent findings may be explained by genotypic differences and culture conditions (KAFKAS et al., 2007). It is further assumed that specific enzymatic activities involved in ascorbic acid metabolism are the clue to the wide concentration ranges (DAVEY et al., 2000; VALPUESTA and BOTELLA, 2004).

Citric acid. Values ranged between 0.95 and 2.11 g L⁻¹, but significant genotype differences could not be corroborated (Tab. 3).

Malic acid. Malic acid was predominant in all genotypes, with maximum amounts in 'Rosa' and minimum contents in 'Nacional' (Tab. 3). In *Rosaceae* fruits, such as prunes and apples, a similar organic acid

Tab. 2: Chemical quality traits of juice from fruits of different *Hylocereus* sp. genotypes at full ripeness (mean of five replicates ± standard error).^a

Parameter	'Lisa'	'Nacional'	'Orejona'	'Rosa'	'San Ignacio'
pH	4.69±0.06A	4.98±0.06A	4.91±0.036A	4.96±0.04A	4.26±0.15B
Titratable acidity (TA) (g L ⁻¹)	3.15±0.07A	3.77±0.30A	3.41±0.25A	3.76 ±0.25A	6.85±2.53A
Total soluble solids (TSS) (g/100g)	9.70 ±0.67B	12.92 ±0.32A	10.25 ±0.40B	7.50 ±0.17C	9.00 ±0.41BC
TSS:TA	30.76±3.33	35.20±3.44	30.76±2.33	20.09±1.31	10.93±7.10
Pectin (mg g ⁻¹)	0.65±0.15B	1.13±0.20AB	0.64±0.06AB	1.18±0.17AB	1.36±0.12A
Density 20°C(g cm ⁻³)	1.042±0.002A	1.037±0.001A	1.044±0.002A	1.027±0.002B	1.025±0.002B
Formol number (mL 0.1M NaOH/100mL)	7.78 ±0.60A	9.02±1.28A	10.50±1.32A	9.32±0.36A	10.56±1.18°
Proline (mg L ⁻¹)	232.85±63.66A	175.69±56.39A	147.21±27.33A	347.44±136.56A	167.81±37.66A

^a Significant differences within values in the same row are indicated by different letters ($P<0.05$).

profile was observed with malic acid comprising 90% of the total organic acid contents (GLEW et al., 2005).

Lactic acid. Lactic acid may either be a genuine compound of fruits or an indicator of microbial spoilage. Therefore, lactic acid contents are limited to 0.5 g L⁻¹ for orange, mango, guava, banana and passion fruit juices (A.I.J.N., 1996). Although higher lactic acid contents were found in ‘Orejona’ compared to ‘Rosa’, pitaya fruits showed lactic acid values around 0.6 g L⁻¹. Consequently, lactic acid contents may be used to evaluate the microbiological status of *Hylocereus* juices.

Oxalic acid. Oxalic acid contents of *Hylocereus* fruits, which have so far not been considered, ranged from 0.19 to 0.42 g L⁻¹, showing insignificant differences between the genotypes analysed. Oxalate contents were found to range from 0.19 to 0.41 g kg⁻¹ in different cultivars of kiwifruit (PERERA et al., 1990) while lower values were observed in apples between 0 to 30 g kg⁻¹ (NOONAN and SAVAGE, 1999).

Major sugars

In agreement with NOMURA et al. (2005) analysing *H. undatus*, the predominant sugars in Costa Rican *Hylocereus* genotypes were glucose and fructose (Tab. 4). Glucose contents generally were in the range from 49 to 104 g L⁻¹, exceeding typical values reported for tropical juices of 20 to 50 g L⁻¹ for orange, 15 to 40 mg L⁻¹ for pineapple and 20 to 55 g L⁻¹ for passion fruit juice (A.I.J.N., 1996; HERRMANN, 2001). In contrast, fructose contents were in the range of other tropical fruit juices. The glucose/fructose ratio for pitaya juices in this investigation was between 3.0 and 5.2, without significant differences among

genotypes. Similar values of 2.5 and 2.9 have been previously reported for *H. undatus* and *H. polyrhizus*, respectively (STINTZING et al., 2003). In accordance with NOMURA et al. (2005) reporting that sucrose accounted for less than 3% of the total sugar content small amounts of sucrose were found using HPLC analysis in this work, but without differences between genotypes (Tab. 4). Noteworthy, STINTZING et al. (2003) could not detect sucrose in *Hylocereus* fruits using enzymatic analyses, and a high invertase activity in the flesh as earlier reported for *Hylocereus undatus* (WU and CHEN, 1997) was made responsible for this observation. The sole action of invertase activity is usually indicated by a glucose/fructose-ratio coming close to one as in the case of orange, pineapple and passion fruit juices (A.I.J.N., 1996; HERRMANN, 2001). Since the respective ratio was higher for pitaya, glucose is not exclusively resulting from invertase activity in *Hylocereus*.

Conclusions

For the first time a detailed investigation on the physico-chemical properties of *Hylocereus* fruits cultivated in Central America was performed. The fruits of the genotype ‘Nacional’ are not considered suitable for fresh fruit consumption due to their small size and skin thickness. Although no significant differences for juice yields were observed, the amount of seeds per fruit may also constitute a limiting parameter for fruit processing. Since pectin contents of ‘Lisa’ and ‘Orejona’ were minimal, they are considered most suitable for the production of clarified fruit juices. On the other hand, due to its harmonic acid-sugar ratio, ‘San Ignacio’ should be preferred for fresh fruit consumption.

Tab. 3: Organic acid contents [g L⁻¹] in juices from fruits of different *Hylocereus* sp. genotypes at full ripeness (mean of five replicates ± standard error).^a

Organic acid	‘Lisa’	‘Nacional’	‘Orejona’	‘Rosa’	‘San Ignacio’
Ascorbic acid	0.35±0.15A	0.23±0.10A	0.11±0.06A	0.19±0.12A	0.16±0.08A
Dehydroascorbic acid	0.23±0.21A	0.11±0.05A	0.15±0.04A	0.36±0.21A	0.16±0.11A
Total Vitamin C	0.58±0.23A	0.34±0.08A	0.26±0.04A	0.54±0.20A	0.32±0.12A
Citric acid	1.15±0.24A	1.06±0.20A	2.11±0.45A	0.95±0.25A	1.22±0.21A
Malic acid	6.96±0.47AB	6.08±0.27B	6.35±0.24AB	8.20±0.68A	6.21±1.09AB
Lactic acid	0.62±0.06AB	0.64±0.09AB	0.91±0.09A	0.48±0.05B	0.65±0.17AB
Oxalic acid	0.23±0.04A	0.21±0.04A	0.42±0.09A	0.19±0.05A	0.24±0.04A

^a Significant differences within values in the same row are indicated by different letters ($P < 0.05$).

Tab. 4: Sugar contents [g L⁻¹] in juices from fruits of different *Hylocereus* sp. genotypes at full ripeness (mean of five replicates ± standard error).^a

Parameter	‘Lisa’	‘Nacional’	‘Orejona’	‘Rosa’	‘San Ignacio’
Sucrose	0.41±0.18A	0.83±0.27A	0.34±0.22A	0.72±0.16A	0.46±0.21A
Glucose	103.95±15.56A	81.39±7.26AB	68.72±12.78AB	49.14±6.70B	61.75±9.67AB
Fructose	28.97±8.66A	21.10±4.80A	19.20±9.80A	24.40±6.21A	26.63±7.46 ^a
Glucose/Fructose	3.3±0.6A	5.2±1.0A	4.8±1.7A	3.1±0.7A	3.0±0.6 ^a

^a Significant differences within values in the same row are indicated by different letters ($P < 0.05$).

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References

- A.I.J.N. CODE OF PRACTICE FOR THE EVALUATION OF FRUIT AND VEGETABLE JUICES, 1996: Association of the Industry of Juices and Nectars from fruits and vegetables of the European Economic Community, Brussels, permanent update.
- ANONYMOUS, 1994: Tecnología para la Producción de Pitahaya. INRA-CEE.
- BARBEAU, G., 1990: La pitaya rouge, un nouveau fruit exotique. *Fruits* 45, 141-147.
- BARBERA, G., CARIMI, F., INGLESE, P., PANNO, M., 1992: Physical, morphological and chemical changes during fruit development and ripening in three cultivars of prickly pear, *Opuntia ficus-indica* (L.) Miller. *J. Hort. Sci.* 67, 307-312.
- BARBERA, G., INGLESE, P., LA MANTIA, T., 1994: Seed content and fruit characteristics in cactus pear (*Opuntia ficus-indica* Mill.). *Sci. Hort.* 58, 161-165.
- CARRILLO-LÓPEZ, A., CRUZ-HERNÁNDEZ, A., CÁRABEZ-TREJO, A., GUEVARA-LARA, F., PAREDES-LÓPEZ, O., 2002: Hydrolytic activity and ultra structural changes in fruit skins from two prickly pear (*Opuntia* sp.) varieties during storage. *J. Agric. Food Chem.* 50, 1681-1685.
- CARRILLO-LÓPEZ, A., CRUZ-HERNÁNDEZ, A., GUEVARA-LARA, F., PAREDES-LÓPEZ, O., 2003: Physico-chemical changes during ripening in storage of two varieties of prickly pear stored at 18°C. *J. Food Sci. Technol.* 40, 461-464.
- CASTILLO, R., LIVERA, M., BRECHU, A., MÁRQUEZ-GUZMÁN, J., 2003: Compatibilidad sexual entre dos tipos de *Hylocereus* (*Cactaceae*). *Rev. Biol. Trop.* 51, 699-706.
- CHINNICI, F., SPINABELLI, U., RIPONI, C., AMATI, A., 2005: Optimization of the determination of organic acids and sugars in fruit juices by ion-exclusion liquid chromatography. *J. Food Comp. Anal.* 18, 121-130.
- DAVEY, M.W., MONTAGU, M.V., INZÉ, D., SANMARTIN, M., KANELLIS, A., SMIRNOFF, N., BENZIE, I.J.J., STRAIN, J.J., FAVELL, D., 2000: Plant L-ascorbic acid: chemistry, function, metabolism, bioavailability and effects of processing. *J. Sci. Food Agric* 80, 825-860.
- DURU, B., TURKER, N., 2005: Changes in physical properties and chemical composition of cactus pear (*Opuntia ficus-indica*) during maturation. *J. Profess. Assoc. Cactus Develop.* 7, 22-33.
- FELKER, P., SOULIER, C., LEGUIZAMON, G., OCHOA, J., 2002: A comparison of the fruit parameters of 12 *Opuntia* clones grown in Argentina and the United States. *J. Arid Environ.* 52, 361-370.
- GLEW, R.H., AYAZ, F.A., MILLSON, M., HUANG, H.S., CHUANG, L.T., SANZ, C., GOLDING, J.B., 2005: Changes in sugars, acids and fatty acids in naturally parthenocarpic date plum persimmon (*Diospyrus lotus* L.) fruit during maturation and ripening. *Eur. Food Res. Technol.* 221, 113-118.
- HARKER, R., REDGWELL, R.J., HALLET, I.C., MURRAY, S.H., CARTER, G., 1997: Texture of fresh fruit. *Hort. Rev.* 20, 121-224.
- HERBACH, K.M., MAIER, C., STINTZING, F.C., CARLE, R., 2007: Effects of processing and storage on juice colour and betacyanin stability of purple pitaya (*Hylocereus polyrhizus*) juice. *Eur. Food Res. Technol.* 224, 649-658.
- HERRMANN, K., 2001: *Inhaltstoffe von Obst und Gemüse*. Ulmer Verlag, Stuttgart.
- HERNÁNDEZ-PÉREZ, T., CARRILLO-LÓPEZ, A., GUEVARA-LARA, F., CRUZ-HERNÁNDEZ, A., PAREDES-LÓPEZ, O., 2005: Biochemical and nutritional characterization of three prickly pear species with different ripening behaviour. *Plant Foods Human Nutr.* 60, 195-200.
- HOA, T.T., CLARK, C.J., WADDELL, B.C., WOOLF, A.B., 2006: Postharvest quality of Dragon fruit (*Hylocereus undatus*) following disinfecting hot air treatments. *Postharvest Biol. Technol.* 41, 62-69.
- HÜHN, T., SULC, D., 2001: Fertigstellung von Fruchtsäften. In: Schobinger, U. (Hrsg.), *Obst- und Gemüsesäfte, Handbuch der Lebensmitteltechnologie*, 440-444. Ulmer, Stuttgart.
- HUYSKENS-KEIL, S., SCHREINER, M., 2003: Quality of fruits and vegetables. *J. Appl. Bot.* 77, 147-151.
- INTERNATIONAL FEDERATION OF FRUIT JUICE PRODUCERS, 1983: Proline. IFU Method 49, Zug, Switzerland.
- INTERNATIONAL FEDERATION OF FRUIT JUICE PRODUCERS, 1984: Formol number. IFU Method 30, Bestimmung, Zug, Switzerland.
- INTERNATIONAL FEDERATION OF FRUIT JUICE PRODUCERS, 1995: Pectin. IFU Method 26, Zug, Switzerland.
- IWASE, H., ONO, I., 1993: Determination of ascorbic acid and dehydroascorbic acid in juices by high-performance liquid chromatography with electrochemical detection using L-cysteine as precolumn reductant. *J. Chromatogr. A* 654, 215-220.
- KAFKAS, E., KOŞAR, M., PAYDAŞ, S., KAFKAS, S., BAŞER, K.H.C., 2007: Quality characteristics of strawberry genotypes at different maturation stages. *Food Chem.* 100, 1229-1236.
- KAYS, S., PAULL, R.E., 2004: *Postharvest Biology*. Exon Press, Athens, Georgia.
- KUGLER, F., GRANEIS, S., SCHREITER, P.P.-Y., STINTZING, F.C., CARLE, R., 2006: Determination of free amino compounds in betalainic fruits and vegetables by gas chromatography with flame ionization and mass spectrometric detection. *J. Agric. Food Chem.* 54, 4311-4318.
- LAWES, G.S., WOOLEY, D.J., LAI, R., 1990: Seeds and other factors affecting fruit size, shoot growth, and return bloom of kiwifruit. *J. Am. Soc. Hort. Sci.* 109, 799-802.
- LIEBSTER, G., LEVIN H.G., 1999: *Warenkunde Obst und Gemüse*. Bd. 1: Obst. Hädecke Verlag, Weil der Stadt.
- MIZRAHI, Y., NERD, A., 1996: New crops as possible solution for the troubled Israeli export market. In: Janick, J., Whipkey, A. (eds.), *Trends in New Crops and New Uses*, 37-45. ASHS Press, Alexandria.
- MIZRAHI, Y., NERD, A., 1999: Climbing and columnar cacti: New arid land fruit crops. In: Janick, J. (eds.), *Perspectives on New Crops and New Uses*, 358-366. ASHS Press, Alexandria.
- MIZRAHI, Y., NERD, A., NOBEL, P.S., 1997: Cacti as crops. *Hort. Rev.* 18, 291-320.
- MOSSHAMMER, M.R., STINTZING, F.C., CARLE, R., 2006: Evaluation of different methods for the production of juice concentrates and fruit powders from cactus pear. *Inn. Food Sci. Emerg. Technol.* 7, 275-287.
- NERD, A., MIZRAHI, Y., 1997: Reproductive biology of cactus fruit crops. *Hort. Rev.* 18, 322-346.
- NERD, A., GUTMAN, F., MIZRAHI, Y., 1999: Ripening and postharvest behaviour of fruits of two *Hylocereus* species (*Cactaceae*). *Postharv. Biol. Technol.* 17, 39-45.
- NERD, A., TEL-ZUR, N., MIZRAHI, Y., 2002: Fruits of vine and columnar cacti. In: Nobel, P.S. (ed.), *Cacti: Biology and Uses*, 185-198. University of California Press, Davis, California.
- NOMURA, K., IDE, M., YONEMOTO, Y., 2005: Changes in sugars and acids in pitaya (*Hylocereus undatus*) fruit development. *J. Hort. Sci. Biotechnol.* 80, 711-715.
- NOONAN, S.C., SAVAGE, G.P., 1999: Oxalate content of foods and its effect on humans. *Asia Pacific J. Clin. Nutr.* 8, 64-74.
- PERERA, C.O., HALLET, I.C., NGUYEN, T.T., CHARLES, J.C., 1990: Calcium oxalate crystals: The irritant factor in kiwifruit. *J. Food Sci.* 55, 1066-1069, 1080.
- SILOS-ESPINO, H., FABIÁN-MORALES, L., OSUNA-CASTRO, J.A., VALVERDE, M.E., GUEVARA-LARA, F., PAREDES-LÓPEZ, O., 2003: Chemical and biochemical changes in prickly pears with different ripening behaviour. *Nahrung/Food* 47, 334-338.
- STINTZING, F.C., CARLE, R., 2006: Cactus fruits – more than colour. *Fruit Process.* 16, 166-171.
- STINTZING, F., SCHIEBER, A., CARLE, R., 2003: Evaluation of colour properties

- and chemical quality parameters of cactus juices. *Eur. Food Res. Technol.* 216, 303-311.
- TO, L.V., NGU, N., DUC, N.D., THANH HOUNG, H.T., 2002: Dragon fruit quality and storage life: effect of harvesting time, use of plant growth regulators and modified atmosphere packaging. *Acta Hort.* 575, 611-619.
- VAILLANT, F., PÉREZ, A., DÁVILA, I., DORNIER, M., REYNES, M., 2005: Colourant and antioxidant properties of red-purple pitahaya (*Hylocereus* sp.). *Fruits* 60, 3-12.
- VALPUESTA, V., BOTELLA, M.A., 2004: Biosynthesis of L-ascorbic acid in plants: new pathways for an old antioxidant. *Trends Plant Sci.* 9, 573-577.
- VINCI, G., BÓTRE, F., MELE, G., RUGGIERI, G., 1995: Ascorbic acid in exotic fruits: a liquid chromatographic investigation. *Food Chem.* 53, 211-214.
- WALLRAUCH, S., FAETHE, W., 1988: Amino Acids: Criteria for the evaluation of fruit juices in adulteration of fruit juices and beverages. *Food Sci. Technol.* 30, 27-48.
- WU, M.C., CHEN, C.S., 1997: Variation of sugar content in various parts of pitaya fruit. *Proc. Fla. State Hort. Soc.* 110, 225-227.

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