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Morphological characterization of the red dragon fruit - *Selenicereus undatus* (Haw.) D.R. Hunt - under growing conditions in the municipality of San Jerónimo (Antioquia, Colombia)

Caracterización morfológica de pitaya roja - *Selenicereus undatus* (Haw.) D.R. Hunt - en condiciones de cultivo en el municipio de San Jerónimo (Antioquia, Colombia)

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Jorge Andrés Betancur G.[1], Sandra Bibiana Muriel R.[1]* and Elena Paola González J.[1]

ABSTRACT

The red dragon fruit *Selenicereus undatus* is a native fruit from the Americas. Its growing appeal in the international market as an exotic fruit highlights the relevance of the crop for the local economies. In Colombia, the high diversity within the genus and species makes it difficult to have reliable materials for propagation as cultivars. This agronomic challenge requires more studies of the distribution and real diversity within the genus *Selenicereus* sp. Due to the information aforementioned, the fruit is harvested in small localities as an extraction production system. This project aimed to morphologically characterize the working collection of red dragon fruit under growing conditions in the Municipality of San Jerónimo. It contained 30 accessions from the departments of Antioquia, Córdoba, and Valle del Cauca. Twenty-one characters of cladode, flower, and fruit were quantified to assess the diversity, and a restricted cluster analysis was performed to understand the morphological richness of the materials. As a result, it was observed differences in terms of stems, such as distance between areolas and width of cladode. This was also observed in flowers, in which their total length, the width of petals, the presence of trichomes, the color of calyx and petals, and the color of the stigma were different. Also, differences were recorded in the fruit. Characteristics such as weight and color of its skin were assessed, resulting in fruit size medium to small. Regarding other properties, total soluble solids varied between 11.2 to 15.6 °Brix. 55% of the fruits have measurements that fit market requirements. Finally, three accessions match the requirements of weight and °Brix, to be used as possible genotypes by commercial growers; however, studies about agronomic management strategies that favor an increase in fruit weight must be done.

Keywords:
Cactaceae
Characterization
Diversity
Promising species
Selenicereus undatus

RESUMEN

La pitaya roja *Selenicereus undatus*, es una planta originaria de América, con potencial como fruta exótica, ya que es apreciada en el mercado internacional. En Colombia crece naturalmente en zonas cálidas y no se tiene claridad sobre las especies que existen, ya que este género presenta mucha hibridación intra e interespecífica, hace falta más estudios en este campo además de verificar los genotipos en otras zonas donde hay reportes de la especie. Su producción se hace de forma extractiva o en pequeñas áreas de cultivo. Este trabajo tuvo como objetivo la caracterización morfológica de la colección de trabajo de pitaya roja en condiciones de cultivo en el Municipio de San Jerónimo. El cultivo corresponde a 30 accesiones de los departamentos de Antioquia, Córdoba y el Valle del Cauca. Para ello, se evaluaron 21 caracteres de cladodio, flor y fruto. Se realizó un análisis de cluster restringido, donde se encontró que las accesiones difirieron en la distancia entre areolas y ancho de cladodio; en longitud total de las flores, ancho de pétalos, presencia de tricomas, color de cáliz y de pétalos, color y longitud del estigma; en peso del fruto y color de la cáscara. Los frutos presentan un tamaño mediano a pequeño. El contenido de solidos solubles totales varió entre 11.2 a 15.6 °Brix, siendo el 55% de los frutos los que presentaron los valores exigidos por el mercado. Por las variables peso y °Brix, tres accesiones cumplen con los requisitos para ser sembradas comercialmente, sin embargo es necesario evaluar una modificación en las labores de cultivo para tratar de aumentar el tamaño de los frutos.

Palabras clave:
Cactaceae
Caracterización
Diversidad
Especie promisoria
Selenicereus undatus

[1] Facultad de Ciencias Agrarias. Politécnico Colombiano Jaime Isaza Cadavid. Carrera 48 No. 7 – 151, CP 050022. Medellín, Antioquia, Colombia.
* Corresponding author: <sbmuriel@elpoli.edu.co>

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The genus *Hylocereus* belongs to the Cactaceae family, and recently was included in *Selenicereus* group (Korotkova *et al*., 2017); however, other authors suggest that it is important to evaluate morphological, ecological, and molecular traits to support the group position (Ruiz-Domínguez *et al*., 2019). In *Selenicereus*, there are native hemiepiphyte species from the American tropical regions considered valuable for their fruits. Among them, *S. undatus* (Haworth) Britton & Rose, and *S. megalanthus* (K. Schum. ex Vaupel) Moran are the most economically important and widely distributed species worldwide. When comparing both yellow and the red dragon fruit, the red one shows more favorable characteristics to be grown. The absence of fruit thorns and its intense red color make it very attractive and ornamental, besides its potential industrialization due to the high content of betalains pigments, considered an alternative to the use of artificial colors in food. In addition, it has been observed that these pigments have antioxidant properties (Esquivel and Araya Quesada, 2012). *S. undatus* is mainly known with the common names of dragon fruit, red pitaya, or red pitahaya (Esquivel, 2004).

Worldwide, it is considered that the biological diversity of the *Selenicereus* genus has been insufficiently studied. In grower countries, it is crucial to identify species and varieties because there are serious problems related to the lack of uniformity in many fruits characteristics, such as sweetness, size, shape, color, and bracts number. It is also important to determine their performance in handling and shelf life due to the morphological and genetic heterogeneity (Castillo-Martínez, 2006; Tel-Zur *et al*., 2010). This heterogeneity makes it difficult to increase the quality standards for the exportation market (Castillo-Martínez, 2006).

Nowadays, it is not easy to separate species and varieties of the dragon fruit due to the high intra and interspecific hybridization, which has been the cause of some taxonomical confusion (Tel-Zur *et al*., 2004).

In Nicaragua in 1990, some varieties of red dragon fruit were defined by Barbeau, and four years later, some genotypes were selected, becoming the most cultivated in the country. Several characterization studies were carried out, in which significant differences in the cladodes and fruits (color, shape, size, skin thickness) and the number of bracts were found (Maltez, 1994). In both Nicaragua and Mexico, the studied genotypes were mainly originated from family gardens. The red or purple dragon fruit, growing in Nicaragua, Costa Rica, and Guatemala, were identified as *S. costaricensis* and *S. polyrhizus* (Esquivel and Araya Quesada, 2012), but today are known as *S. monacanthus* (Tropicos, 2018).

In Mexico, 21 genotypes were evaluated and described using 47 characteristics. The analyzes allowed recognizing several groups of dragon fruits. The differences were related to cladodes characteristics (size of the concave angle, the height of the angle vertex, the height of the ripple, and the number of columns and lengths), and in flower (number, and length of the internal perianth segments) (Grimaldo-Juárez *et al*., 2007). A second study carried out in the same country, evaluated quantitative variables, finding that genotypes were different by their reproductive structure characteristics (Castillo-Martínez *et al*., 2005).

Similarly, in Taiwan, the morphological differences of four *Selenicereus* spp. clones were evaluated, showing variation in cladodes length and width, the distance of areolas, number, and length of spines, and the edge of the cladode. In the fruit characteristics, variations in shape and skin color, number of bracts, the width of the middle part bracts, length of the apex bract, the shape of the apical cavity, and flesh color were found (Tran and Yen, 2014).

In Colombia, the red dragon fruit (*S. undatus and Selenicereus spp.*) grow wild, mainly in the bs-T life zone in the Atlantic Coast, Tolima, and Antioquia (Mejía *et al*., 2013); although it is also possible to find it in other regions. The only known cultivation of *S. undatus* is in the municipality of Restrepo - Valle del Cauca, in the working collection of the Politécnico Colombiano Jaime Isaza Cadavid in San Jerónimo - Antioquia.

The accessions present in San Jerónimo were evaluated *in situ* and then were taken to the collection field, finding that the red dragon fruit had a solid soluble content desirable to the market, even though its size was small (Mejia *et al*., 2013).

The objective of this research was to make the morphological characterization and evaluate the fruit production of the red dragon fruit (*S. undatus*) accessions in the working collection in the municipality of San Jerónimo (Antioquia).

This working collection was previously evaluated by Mejía *et al.* (2013) in some agronomic characteristics but not in fruit production, which is important to identify the accessions that have the desired market characteristics.

MATERIALS AND METHODS

Location

The working collection formed by 30 accessions was established in an experimental field in the Research Station "Jhon Jairo González", of the Politécnico Colombiano Jaime Isaza Cadavid located in the municipality of San Jerónimo (Antioquia - Colombia) (6°26'37.57"N, 75°44'04.93"W, at 648 m.a.s.l.). The farm is located in the tropical dry forest (bs-T).

Characterization methodology

The descriptor used for vegetative characters was proposed by González Espino and Alvarado Ruíz (2004) and modified by Mejía *et al.* (2013). The flower characters were evaluated, according to Borja (2012). Additionally, characters related to production were also included. Twenty-one characters were evaluated: eight for flowers, seven for fruits, and six for cladodes. The cladodes characterization was made between February and March (2015). The characterization of flowers and fruits was made as they were coming out, between April and October of the same year. Every character was measure in three individuals per accession; five measurements were taken by plant, using the average value for the statistical analysis. Records of two fruit variables were taken in 2018 in order to evaluate the stability of market characteristics: weight and °Brix. These variables were compared with the results of 2015.

For each part of the plant, a cluster analysis was done separately because not all accessions formed reproductive structures. Thus, the description of the cladodes was made with 30 accessions, for flowers with 24 accessions, and for fruits with 27 accessions. The statistical procedure was initiated by a correlation between the variables to eliminate those that, in the researchers' opinion, could be measuring the same characteristics. The final list of characters included in the cluster analysis is recorded in Table 1.

Table 1. Descriptors of the red dragon fruit (*Selenicereus undatus*) to evaluate the accessions of the working collection "Jhon Jairo González"

Plant Organ	No.	Variable	Methods	Units
Cladode	1	Distance between areolas	Internal measurement between the areolas with the Vernier Caliper	Millimeters (mm)
	2	Length of the spines	Measurement with the Vernier caliper	Millimeters (mm)
	3	Cladode width	Measure of the middle part of the cladode with the Vernier caliper	Millimeters (mm)
	4	Thickness of the edge	Measurement with the Vernier caliper	Millimeters (mm)
	5	Spines number	Count of the number of spines	Units (Ud).
	6	Thorn length	Measured with the Vernier caliper	Millimeters (mm)
Flower	7	Average diameter of the flower	Distance in the middle part of the flower measured with the Vernier caliper	Millimeters (mm)
	8	Flower length	Measured from the insertion point to the end of the flower	Centimeters (cm)
	9	Basal diameter	Distance from the bottom of the flower	Millimeters (mm)
	10	Presence of trichomes	Observe if there is presence or not of trichomes	Presence / Absence
	11	Primary color of the calyx	Three categories: intermediate green, light green and pale green	
	12	Width of petals	Averaged Measurement of the widest part of 5 petals	Millimeters (mm)
	13	Primary color of the petals	Three categories: white, cream and another	
	14	Stigma length	Averaged Measurement of 5 stigmas.	Millimeters (mm)

Table 1 (continuation)

Plant Organ	No.	Variable	Methods	Units
Fruit	15	Fruit weight	Complete fruit weight	Grams (g)
	16	Ratio pulp weight/ fruit weight.	Calculation	Calculation D = weight / volume
	17	Pulp Weight	Weight of the pulp of the fruit	Grams (g)
	18	Bracts Length	Measurement of 5 bracts, which are averaged	Millimeter (mm)
	19	Brix Degrees	Taken of the Fruit Juice	°Brix
	20	Seed size	Measured with the vernier caliper	Millimeters (mm)
	21	Fruit Color	Five categories: pink, light red, dark red, yellow, another	The color is defined according to the Table of colors

It was used the restricted Ward method, of minimum variance within the conformed groups, in which the Euclidean distance is used. The PAST 3.0 program was used to perform this analysis. Subsequently, the groups formed were compared with mean and standard deviations to establish those variables that had greater weight in the group separation.

RESULTS AND DISCUSSION

Cladodes

The cloning analysis of the cladodes had 64% of explanation, with a Euclidean distance of 30 separated into three distinct groups (Figure 1). The first formed by eight individuals; the second one by 18 individuals, being the largest group; and the third one formed by four individuals. The variables influencing the group separation were separated between the areolas and the width of the cladodes. The Group III presented a medium distance among areola, greater than the other two groups (47.8 mm), with 30.3 and 32.3 mm, respectively (Table 2). Group I presented accessions with smaller cladode width than groups II and III. The other characteristics were similar among the groups.

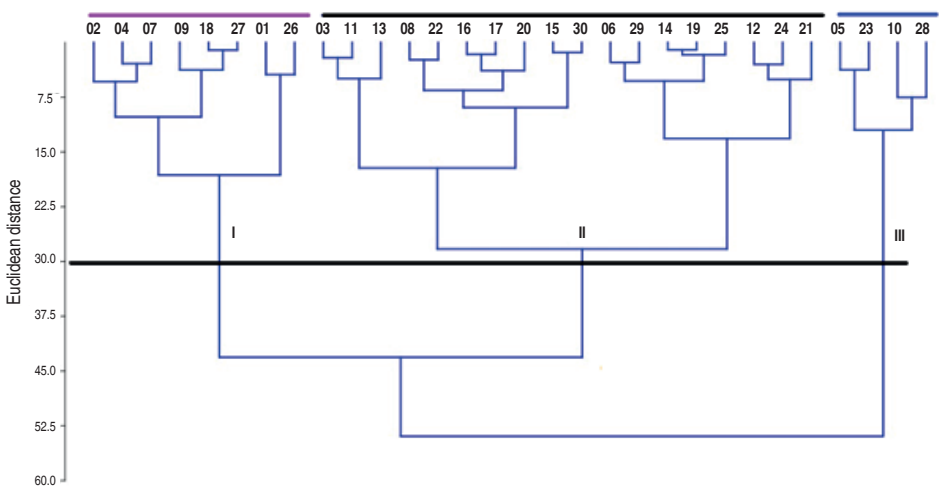

Figure 1. Cladodes dendrogram of the *Selenicereus undatus* working collection.

Table 2. Difference among the groups of Dragon fruits accessions, according to the cladodes, flowers and fruits characteristics.

	I	II	III
Cladode			
Distance areolas	30.3 (5.9)	32.3 (4.9)	47.8 (5.1)
Clade width	39.3 (2.6)	50.5 (4.6)	45.6 (4.6)
Thickness of the edge	4.9 (2.0)	4.6 (0.9)	4.6 (0.9)
Number of Thorns	5.2 (0.7)	4.9 (0.6)	4.8 (0.4)
Spine length	3.2 (0.9)	3.7 (0.8)	3.5 (0.6)
Flower			
Flower length	27.92 (2.0)	23.95 (0.8)	23.95 (0.8)
Petals width	26.79 (1.1)	19.03 (1.1)	32.64 (1.8)
Stigma length	18.21 (2.1)	13.83 (1.2)	17.31 (1.9)
Flower diameter	2.54 (0.7)	2.98 (1.0)	2.24 (0.3)
Flower basal Diameter	3.13 (0.3)	2.95 (0.2)	3.26 (0.3)
Presence of Trichomes	93%	100%	13%
Primary color of chalice	29% intermediate between green and light green	50% green 50% light green	50% light green
Primary color of petals	79% white	100% cream	63% white
Fruit			
Fruit weight	234.2 (20.3)	129.7 (28.1)	81.4 (15.0)
Relation: Weight pulp/weight fruit	0.6 (0.1)	0.5 (0.1)	0.5 (0.0)
Length of bracts	27.8 (6.8)	25.2 (5.1)	23.5 (4.7)
°Brix	12.6 (1.0)	13.2 (1.3)	13,5 (1.0)
Size of the seed	2.2 (0.2)	2.1 (0.1)	2.1 (0.1)
weight of 100 seeds	0.2 (0.0)	0.2 (0.0)	0.2 (0.0)
Color of fruit	40% pink 20% light red 20% dark red 20% between light red and dark red	31% pink 25% light red 6% dark red 19% between light red and dark red 19% between dark red and yellow	34% pink 17% dark red 32% between light red and dark red 17% between dark red and yellow

In Group III, the distance between areolas is similar to the reported in accessions from Mexico, whose distance was from 35 to 50 mm (Castillo-Martínez *et al*., 2005). The cladode width of the accessions from groups II and III was similar to the one found by Tran and Yen (2014), who reported values between 42 and 54.3 mm, and Castillo-Martínez *et al*. (2005) who recorded widths from 48 to 60 mm.

The spine length values correspond to those of Castillo-Martínez *et al*. (2005). Tran and Yen (2014) reported, from 3.7 to 4.4 mm, which match only with the group II but differs from Cálix de Dios (2005), who reported values higher than 5 to 6 mm.

The number of spines per areola (4.8 to 5.2) found in this study is higher than the recorded in other studies, as in Mexico from 3 to 4.7 (Castillo-Martínez *et al*., 2005), and in Taiwan from 2.5 to 4.5 mm (Tran and Yen, 2014).

Flowers

The flowers cluster analysis (Figure 2) had 58% of

explanation and showed three well-differentiated groups at a Euclidean distance of 15, the first group is formed by 14 individuals, the second is formed by two individuals, and the third is formed by eight individuals. The flowers of group II were smaller than those of groups I and III (Table 2), being that they showed lower values in the length of the flower, petals width, and stigma length. The other two groups did not differ in these characteristics.

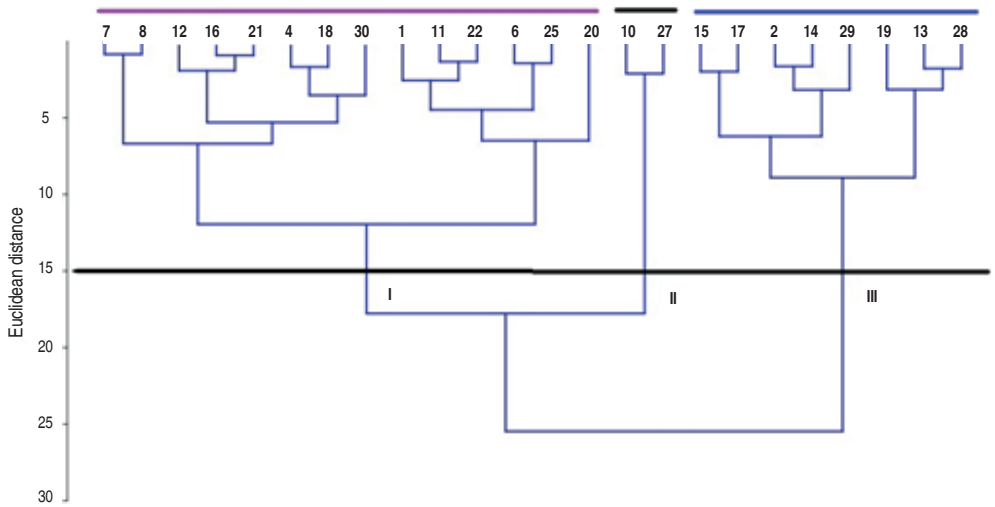

Figure 2. Flower dendrogram of the *Selenicereus undatus* working collection.

For the calyx color, in group I, 29% of the accessions had a green color, and 29% an intermediate color between green and light green. For group II, 50% of the accessions presented light green, and the 50% rested another color. For group III, 50% of the accessions were light green and 37.5% had a green color.

For the color of the petals, in groups I and III, the white color predominated (79% and 63%, respectively), coinciding with that reported by Tran and Yen (2014); however, the two accessions of the group II were cream color.

The accessions of groups I and III had the length of flowers similar to those registered in Mexico by Castillo-Martínez *et al.* (2005), but smaller than those recorded by Cálix de Dios (2005), who describes flowers from 30 to 37 cm in length. Tran and Yen (2014) had flowers between 28.6 and 34.1 cm. These results confirmed that the accessions of group II of the San Jerónimo collection have smaller flowers than those of the other studies.

Fruit

The cluster analysis of the fruit had 86% of explanation at a Euclidean distance of 100 separated three well-differentiated groups (Figure 3). The first formed by five individuals, the second group formed by 16 individuals, and the third was formed by six individuals. The variable that separated the groups corresponds to the fruit weight (Table 2), where the individuals of group I (18.5% of the accessions) presented the heaviest fruits between 232 and 262 g. Those of group II (59% of the accessions) presented fruits between 105 and 172 g, and those of group III (22% of the accessions) presented small fruits between 57 and 96 g. There were no differences in the other variables. The CODEX STAN 237 establishes nine categories (caliber) for the commercialization of the red/white dragon fruit (fruits from 110 g to greater than 701 g) (FAO, 2003). In this study, the fruits of group I correspond to fruits of C caliber (between 201 and 250 g) and D caliber (between 251 and 300 g), the fruits of group II correspond to fruits A caliber (between 110 and 150 g) and B (between 151 and 200 g). The fruits of group III did not reach weights accepted for commercialization. Therefore, it is confirmed that the fruits of the collection correspond to the small and medium categories.

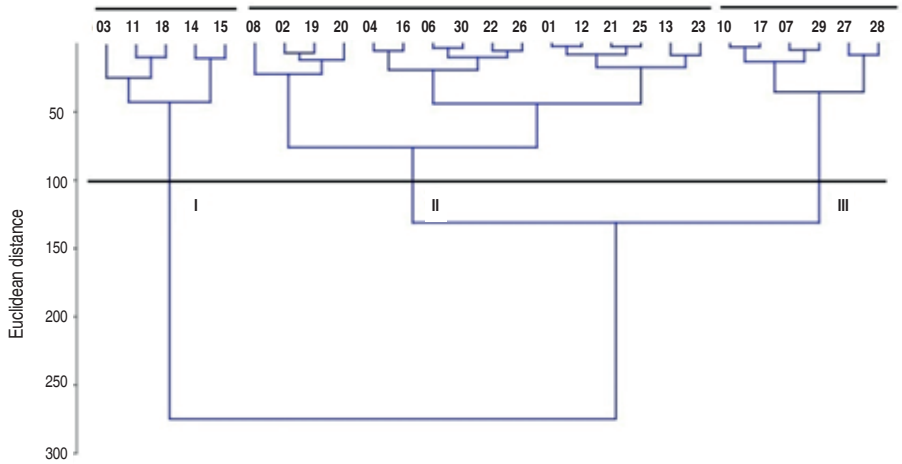

Figure 3. Fruits dendrogram of the *Selenicereus undatus* working collection.

The content of total soluble solids of the fruits, measured through the °Brix, is a measure of quality (Kleinhenz and Bumgarner, 2013). According to this characteristic, all accessions of the working collection are similar (Table 2). However, when comparing the accessions that produced fruits in 2015 with those that produced fruits in 2018, it was observed that most of the accessions increased the total soluble solids content (Figure 4). The °Brix can be affected by a set of factors, as genetic, climatic, soil, management, among others (Kleinhenz and Bumgarner, 2013). It is necessary to follow the climatic and management variables, which can vary in the place where the working collection is growing to determine how to increase the total soluble solids content, being this the most desired characteristic by consumers.

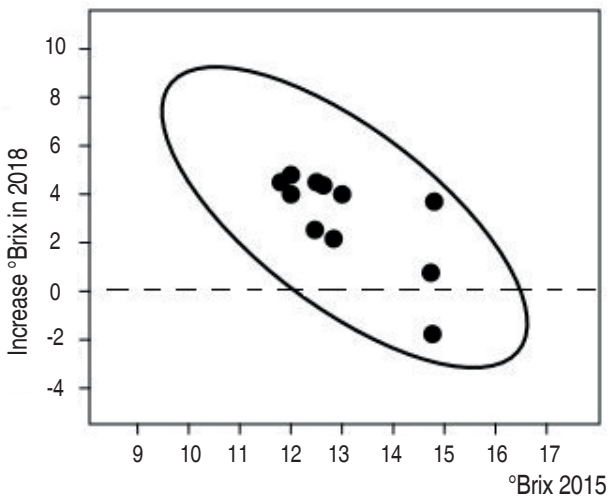

Figure 4. Comparison of fruits of *Selenicereus undatus* from the collection of years 2015 and 2018.

According to Mejía *et al*. (2013), a value of 18 °Brix was recorded for a fruit collected in the wild, and 45% of the fruits collected showed values accepted by the external market, between 13 and 15 °Brix (González Espino and Alvarado Ruíz, 2004). In this study, it fluctuated from 11.2 to 15.6 °Brix. 55% of the fruits had the values required by the external market, which also agreed with the results reported by Merten (2003), who indicated

that the total soluble solids of *S. undatus* at harvest fluctuated from 13 to 16 °Brix. They are also superior to those reported by Centurión Yah *et al*. (2008), who report value from 12.6 °Brix, but much lower than those reported by Nerd *et al*. (1999), who indicated values from 16 to 17 °Brix.

The five accessions which presented the highest weight values were numbers 03, 11, 18, 14, and 15, varying between 209 and 262 g. According to total soluble solids, the better accessions were 16, 13, 26, 28, and 07, with values varying between 14.8 and 15.7 °Brix. However, when both characteristics are joined, the best accession, were the numbers 14, 03, and 18, with weights between 223 and 262 g, and °Brix between 13 and 13.7. These three accessions are possible candidates to be grown as commercial varieties; however, it is important to introduce other aspects as sanity conditions, resistance to diseases, and others, which are important for this crop to achieve a good development on the field (Valencia-Botín *et al*., 2013).

CONCLUSIONS

The accessions of *S. undatus* in the working collection "Jhon Jairo González" have high variability in characteristics of cladode, flower, and fruit. Regarding weight and °Brix, there only were differences in the former one. The fruits of the working collection presented a medium to small size, and content of total soluble solids suitable for the market. The increasing in the fruit size should be evaluated, with management practices such as fertilization, periodic irrigation, and modification of the microclimate with moderate shade.

The plants of *Selenicereus* spp. are distributed wild in other departments of Colombia. It is recommended to increase the working collection with samples of other regions that have a more representative population of this species. It is also important to evaluate different climatic conditions to identify the most appropriate for this species and to identify the better genotype to be used on commercial crop production.

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