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Production performance of *Hylocereus polyrhizus* based on cladode size and position

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Abstract

The analysis of productive architecture of plants involves macroscopic observation of spatial distributions of different vegetative and reproductive organs. However, few studies have evaluated these aspects in dragon fruit plants for production purposes. The objective of this study was to evaluate vegetative, reproductive, and quality parameters of dragon fruit plants (*Hylocereus polyrhizus;* variety Cebra) based on the position and size of cladodes, considering morphological, production, and quality characteristics of the fruits. The experiment was conducted from September 2016 to May 2018, using a completely randomized design in a 3×4 factorial arrangement, consisted of three positions of cladode insertion in the plant (primary, secondary, and tertiary) and four different cladode sizes (≤ 20 cm; 21-40 cm; 41-60 cm, and 61-80 cm), with five replications and six cladodes per plot, totaling 360 evaluated cladodes. According to the results, vegetative and reproductive characteristics of dragon fruit plants variety Cebra were affected by the cladode position and size. Fruits developed on primary cladodes with sizes of 21 to 40 cm presented, in general, better-quality characteristics. All evaluated physical and physicochemical characteristics were affected by the cladode position and size, except for titratable acidity and soluble solids to titratable acidity ratio. Fruits developed on cladodes smaller than 20 cm had lower quality. Therefore, maintaining and promoting the growth of primary cladodes with sizes of 21 to 40 cm and removing those smaller than 20 cm is recommended.

Keywords: Cactaceae, exotic fruit growing, fructification, management

Introduction

Dragon fruit (*Hylocereus undatus* Britton & Rose) is a rustic fruit species of the Cactaceae family that has stood out not only for its highly attractive red-purple color, but mainly for its bioactive (Hor et al., 2012; Lee et al., 2014) and nutritional properties (Utpott et al., 2020) and high economic value (Wanitchang et al., 2010). It is native to Central America and its cultivation has been increasing in Brazil in the last years.

Dragon fruit, also known as pitaya or pitahaya, is extensively grown in Malaysia, Vietnam, Thailand, Taiwan, China, Israel, Australia, and South American countries, including Brazil (Hor et al., 2012; Muhammad et al., 2014). Its high contents of antioxidant compounds (Dembitsky et al., 2011; Madane et al., 2020; Tsai et al., 2019) have promoted this fruit to the status of a superfruit.

Studies on reproductive dynamics of cultivated plants, especially fruit-bearing ones, can minimize competition for assimilates among plant sinks. The position of the productive branch on the plant can also affect fruit production and quality, as the strength of the depends on the position of the inflorescence on the stem and the position of the fruit within the inflorescence (Martinazzo et al., 2015).

According to Maro et al. (2012), understanding phenology and reproductive dynamics of a fruit species is important, as information about sprouting, flowering, fruiting, and harvesting stages can contribute to stablishing proper cultural and phytosanitary practices for the crop.

Dragon fruit plants produce several new cladodes before the reproductive stage (Marques et al., 2011); however, the production is established on branches from previous cycles. Therefore, cladode management with selection of those that should be maintained on the plant is essential for regulating vigor and obtaining a satisfactory

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and high-quality production. It can be carried out by pruning, which is an important cultural management.

In this context, the objective of this study was to evaluate vegetative and reproductive parameters of dragon fruit plants (*Hylocereus polyrhizus*; variety Cebra) based on cladode position and size, considering vegetative, production, and quality characteristics of the fruits.

Material and Methods

The experiment was conducted from September 2016 to May 2018, evaluating two production periods in the experimental period, in an orchard at the Sector of Fruit production of the Department of Agriculture of the Federal University of Lavras (UFLA), Lavras, Minas Gerais (MG), Brazil (21°14'06"S, 45°00'00"W, and altitude of 919 m). The climate of region is Cwb, temperate rainy, according to the Köeppen classification.

Data on mean temperature, relative air humidity, and rainfall during the experimental period were recorded by an Automatic Weather Station of the UFLA at approximately 300 meters from the experimental area (**Figure 1**).

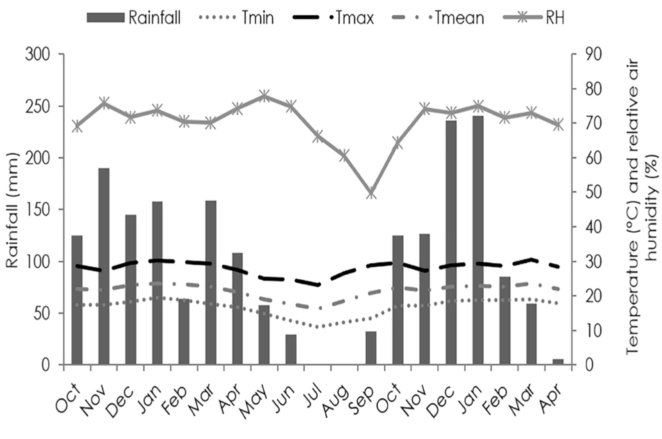

Figure 1. Climograph for the period from October 2016 to April 2018. Lavras, MG, Brazil

The evaluated dragon fruit plants (*Hylocereus undatus*) were two years old (after planting seedlings from root cuttings); they were managed focused on the most vigorous sprouting, in a single stem, which was composed of some cladodes up to the apex of the eucalyptus stake (1.80 m in height and 0.20 m diameter), to witch these cladodes were attached. Pruning of cladodes at the height of the stake was performed when they reached the top of the stake (apex) to break apical dominance in the plant. Thus, the plant was grown freely to form the crown, proceeding cleaning pruning only for removing suckers growing below the crown, on the main stem. New buds then emerged and formed the productive branches, which were selected for evaluation.

The plants were arranged with spacing of 3 m between rows and 2 m between plants. These plants had produced fruits in the previous year. Fertilizer applications and soil acidity correction were carried out according to results of the soil chemical analysis, which are shown in (**Table 1**). Fertilizer applications consisted of application of macronutrient-based products, annually supplying N (220 kg ha^{-1}), P_2O_5 (150 kg ha^{-1}), K_2O (250 kg ha^{-1}), Ca^{2+} (180 kg ha^{-1}), and Mg^{2+} (150 kg ha^{-1}), following the recommendations of Malavolta (2006) for perennial fruit tree species. Irrigation was performed using manual watering, applying 40 L of water per plant per week. Weed and disease control were carried out as needed.

A completely randomized experimental design was used, in a 3×4 factorial arrangement, with five replications and six cladodes per plot, totaling 360 evaluated cladodes. The first factor consisted of three positions of cladode insertion in the plant: primary cladode, developed from a bud on the cladode on the main structure, forming what is termed a single stem; secondary cladode, which develops from a bud on the primary cladode; and tertiary cladode, which develops from a bud on the secondary cladode. The second factor consisted of cladode sizes (≤ 20, 21-40 cm, 41-60, and 61-80 cm). Cladodes emerged during the vegetative stage (September to October) in the crown top of healthy plants in the 2014/2015 crop season were pre-selected and marked for evaluations. Cladodes that had already emitted reproductive structures during the previous crop season (2015/2016) were then selected for evaluations.

The following vegetative and reproductive parameters were periodically evaluated throughout the experiment: number of emerged cladodes (NEC) from the evaluated cladode, considering those with more than one cm; number of reproductive buds (NRB), by counting new buds (larger than one cm); number of abscissions of reproductive buds (NAB); number of fruits

Table 1. Chemical characteristics of the soil collected in the experimental area cultivated with dragon fruits. Lavras, MG, Brazil, 2018

Soil depth	Soil chemical characteristics									
	pH	P	K^+	Ca^{2+}	Mg^{2+}	Na^{2+}	Al^{3+}	$H+Al^{3+}$	OM	P-Rem
		mg dm^{-3}			cmolc dm^{-3}			cmol dm^{-3}	dag kg^{-1}	mg L^{-1}
0-20 cm	6.5	23.92	0.29	4.19	1.23	0.02	0.04	1.05	1.62	27.00
20-40 cm	6.0	13.82	0.19	3.29	0.73	0.01	0.07	2.27	1.52	38.53

pH = hydrogen potential in water in a soil to solution ratio of 1:2.5; OM = organic matter (oxidation with sodium dichromate, according to Walkley & Black, 1934).

(NF), by counting at 35 days after anthesis, evaluating all flower emergences over the crop seasons; fruit set percentage (FSP) by dividing the total number of fruits by the total number of flowers.

The fruits were manually harvested monthly from December to April in each production cycle, in the early hours of the day, when they were at the commercial ripening stage, which was identified by an intense-pink peel (Ortiz & Takahashi, 2015). The fruits were then placed in plastic boxes and evaluated for qualitative, physical, and physicochemical characteristics.

Ten fruits were selected per plot and evaluated for the following physical characteristics: fruit longitudinal diameter (FLD; mm) and fruit transverse diameter (FTD; mm), measured using a digital caliper; fruit diameter (FD; mm), corresponding to the FLD to FTD ratio; fruit weight (FW; g) and peel weight (PW; g), using a digital analytical balance; pulp firmness (FP), in Newton (N), using a fruit hardness tester (Lutron FR-5120).

The fruits were then cut and processed and the resulting pulp juice was immediately subjected to analyses of pH, soluble solids content (SS), and total titratable acidity (TA) and, then, the SS to TA ratio was calculated (AOAC, 2007). The pH analysis consisted of crushing and homogenizing fruit samples at a 1:4 ratio (10 g of pulp and 40 mL of distilled water) in a polytron and the resulting filtrate was analyzed using a benchtop digital pH meter (Mca-150). Soluble solids content (SS) was determined by direct reading on a benchtop refractometer (Abbe®) with a range of 0% to 65%; the sample was homogenized and three drops of the obtained juice were added to the refractometer lens; the result was expressed as Brix (°Brix). Total titratable acidity (TA) determination consisted of diluting 20 mL of juice in 80 mL of distilled water and titrating with 0.1 N NaOH solution, using three drops of 1% phenolphthalein to identify the endpoint; the reading was performed in triplicate and the results were expressed as grams of malic acid 100 g^{-1}.

The data were subjected to analysis of variance using the F test to identify significant effects, and the treatments were compared using the Tukey's test (P ≤ 0.05), with the data of NEC, NRB, NAB, and FSP transformed into √x+1. The means were compared using the statistical program Sisvar® (Ferreira, 2014).

Results and Discussion

The results of analysis of variance showed significant effects for the factors cladode position and cladode size for all evaluated variables, except for fruit set percentage (**Table 2**). Significant interaction between the factors was found for all evaluated variables (**Table 3**). Regarding the evaluated physicochemical characteristics, the interaction was significant for all variables, except for TA and SS to TA ratio (**Table 4**).

The number of emerged cladodes (NEC) was significantly affected only by cladode position (Table 2). Primary cladodes presented a higher number of emerged cladodes from their structure. The higher number of cladodes emerged near the main cladode may have

Table 2. Reproductive characteristics of dragon fruit plants as a function of cladode position and size

Source of variation	NEC	NRB	NAB	NF	FSP
	——	——	——	——	—%—
Cladode position (CP)	20.51**	11.55**	9.69**	5.04*	2.04^{ns}
Primary	1.76 a	2.50 b	2.38b	1.26b	27.7a
Secondary	1.36 b	3.01 a	2.84ab	1.38ab	39.5a
Tertiary	1.16 b	3.49 a	3.28a	1.55a	37.9a
LSD	0.23	0.49	0.51	0.21	15.3
Cladode size (CS)	0.66^{ns}	34.45**	31.61**	8.45**	0.48^{ns}
≤ 20 cm	1.36 a	1.83 c	1.74d	1.14c	30.5a
21-40 cm	1.41 a	2.61 b	2.46c	1.31bc	32.0a
41-60 cm	1.43 a	3.47 a	3.25b	1.53ab	34.7a
61-80 cm	1.52 a	4.09 a	3.88a	1.61a	38.4a
LSD	0.29	0.63	0.62	0.27	20.1
Interaction (CP×CS)	0.30^{ns}	0.62^{ns}	0.83^{ns}	0.94^{ns}	1.58^{ns}
CV (%)	21.32	21.69	22.62	20.05	57.30

NEC = number of emerged cladodes; NRB = number of reproductive buds; NAB = number of abscissions of reproductive buds; NF = number of fruits; FSP = fruit set percentage; CV = coefficient of variation; LSD = least significant difference; ns = not significant; * = significant at 5% probability (p < 0.05); ** = significant at 1% probability (p < 0.01) by the f test. Means followed by different letters in the columns are significantly different from each other by the Tukey's test.

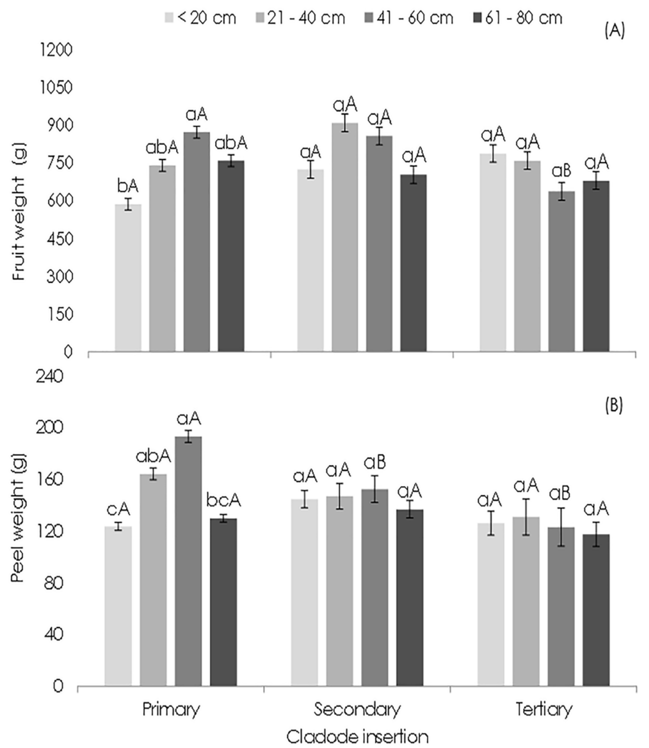

Figure 2. Fruit weight (A) and peel weight (B) of dragon fruits as a function of cladode position and size. Bars with the same lowercase (cladode size) or uppercase (cladode position) letters are not significantly different from each other. Symbols represent the standard error.

been due to pruning for promoting crown formation, favoring the induction of new vegetative buds originating directly from the stem and, subsequently, from primary branches.

Breaking apical dominance changes the hormonal balance, mainly between auxins and cytokinins, modifying the apical dominance in the plant and promoting the growth of lateral buds (Taiz et al., 2017). Auxin hormones are synthetized in the apical meristem of most angiosperms, acting as mediators of apical dominance and maintenance of lateral bud dormancy (Taiz et al., 2017). Therefore, the lower the auxin synthesis, the higher the emission of new buds due increases in availability of nutrients and synthesis of cytokinins to lateral buds (Schmidt et al., 2015).

Similar results were found for number of reproductive buds (NRB), number of abscissions of reproductive buds (NAB), and number of fruits (NF), as the cladodes that were more external (tertiary position) to the crown and with larger sizes (60 to 80 cm) presented higher means compared to the others. However, the evaluation of the distribution of vegetative and reproductive buds showed that they were inversely proportional and the number of reproductive buds is strongly connected to fruit production.

NRB and NF results found may be connected to a higher exposure of cladodes to direct sunlight, favoring an increased production of photoassimilates, as the vegetative and reproductive development stages are affected by photosynthesis (Ax et al., 2005); therefore, higher development rates are expected in crown positions where the photosynthetic activity is higher. Tertiary cladodes were more dependent on energy availability compared to those more internally within the plant crown, even in young plants with underdeveloped crowns, which are favored by light penetration. A higher availability of fruits located more externally in dragon fruit plants favors the thinning and harvesting managements, as the presence of modified structures (spines) hinders the access to fruits when they are inside the crown.

However, no correlation was found between reproductive buds and fruit set percentage (FSP). Thus, a decrease in flowering, considering the range of values found in the present study, did not decrease FSP, and decreases in emission of reproductive buds may have contributed to a lower spent of reserves, increasing fruit production. Furthermore, the number of emerged flowers may vary depending on climate conditions and cultural practices.

Considering the statistical breakdown of the factors (cladode position and size) and fruits developed on cladodes directly emerging from the main branch, higher fruit weights were found for cladodes with sizes between 41 and 60 cm, which did not statistically differ from cladodes with 21 to 40 and 61 to 80 cm. Similar trend was found for secondary cladodes and no difference in cladode size was found for tertiary cladodes (**Figure 3**).

Increases in fruit weight (FW) are directly connected to number of fruits due to competition for assimilates. A higher competition between fruits on some plant parts can hinder increases in fruit weight, resulting in smaller fruits. The highest weight found for fruits on

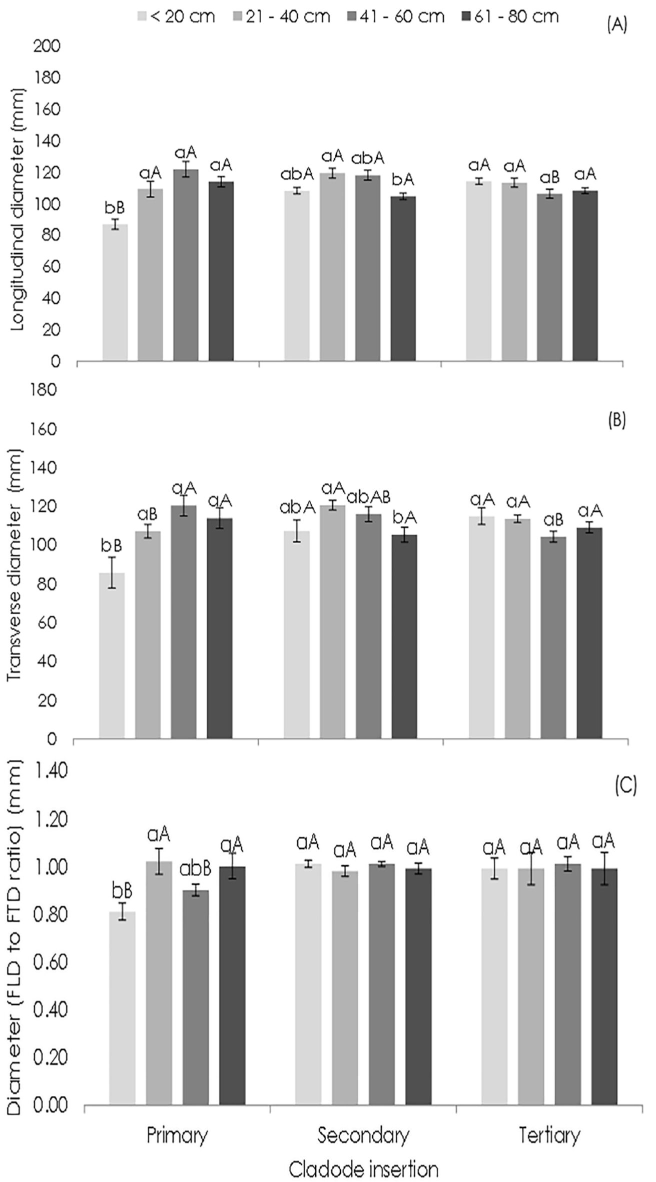

Figure 3. Fruit longitudinal diameter – FLD (A), fruit transverse diameter – FTD (B), and fruit diameter – FD (FLD to FTD ratio) (C) of dragon fruits as a function of cladode position and size. Bars with the same lowercase (cladode size) and uppercase (cladode position) letters are not significantly different from each other. Symbols represent the standard error.

secondary cladodes are connected to the number of fruits (NF) found (Table 2); although not statistically different, secondary cladodes had a lower mean NF (1.38 fruits) compared to tertiary cladodes (1.55 fruits), favoring increases in fruits on secondary cladodes.

According to Bertin et al. (2001), FW is the balance between photoassimilate supply by photosynthesis and the photoassimilate demand from all competing sinks, i.e., FW decreases as the number of sinks increases. They also reported that proximal fruits within each cluster reach higher weights than distal fruits due to the natural flowering sequence and higher number of cells in the ovary of proximal fruits at anthesis.

The results of fruit peel weight (PW) showed that primary cladodes with 41 to 60 cm produced fruits with higher PW mean (193.60 g) (Figure 2B). Similar trend was found for FW, i.e., higher FW were found for cladodes with sizes between 41 to 60 cm.

A significant interaction between the factors was found for fruit longitudinal (FLD) and transverse (FTD) diameters and fruit diameter (FD) (Table 3). The statistical breakdown of the factors (Figure 3) showed a similar pattern for these variables, as primary cladodes with smaller sizes (≤ 20 cm) resulted in lower mean FLD, FTD, and FD (87.02, 85.73, and 0.81 mm, respectively).

Table 3. Physical characteristics of dragon fruits as a function of cladode position and size

Source of variation	FW	PW	FLD	FTD	FD
	–g–	–g–	-mm-	-mm-	—
Cladode position (CP)	2.07 ^{ns}	8.64**	1.39 ^{ns}	2.18 ^{ns}	5.96**
LSD	100.75	17.08	6.61	6.56	0.05
Cladode size (CS)	2.33 ^{ns}	5.33**	6.16**	5.56**	2.49 ^{ns}
LSD	128.03	21.70	8.40	8.34	0.06
Interaction (CP×CS)	2.96*	2.96*	6.09**	7.43**	3.75**
CV (%)	17.56	15.83	7.84	7.82	7.08

FW = fruit weight; PW = peel weight; FLD = fruit longitudinal diameter; FTD = fruit transverse diameter; FD = fruit diameter from FLD to FTD ratio; CV = coefficient of variation; LDS = least significant difference; ns = not significant; * = significant at the 5% probability ($p < 0.05$); ** = significant at 1% probability ($p < 0.01$) by the f test.

These results can be explained by the lower space availability for the development of fruits grown on these cladodes, which are more internally within the plant crown, resulting in higher competition for space among fruits and even among cladodes. Dragon fruit plants have indeterminate growth habit, which may have negatively affected fruit development, and, consequently, FD and the natural fruit shape, as the FLD to FTD ratio was low. A FLD to FTD ratio close to 1.0 denotes more rounded fruits, which is an important factor for dragon fruits, as they are characterized by a subglobose shape (Le Bellec et al., 2006).

Considering the statistical breakdown of the factors for pulp firmness (PF), primary cladodes with sizes between 21 to 40 cm produced fruits with higher PF mean (9.75 N) (**Figure 4**A). According to Sams (1999), smaller fruits generally exhibit higher PF because a higher percentage of their volume is occupied by cell wall materials, which results in a higher density and resistance to penetration by the penetrometer plunger, as found in the present study.

Pulp firmness loss usually occurs due to softening caused by natural fruit ripening, which is a complex process involving various mechanisms (Chitarra & Chitarra, 2005). Furthermore, PF tends to decrease as the phenological stage advances, i.e., as the fruit ripens. A greater pulp cohesion is related to the chemical properties of cell walls, mainly pectin soluble fiber.

Changes in texture occur after the storage of

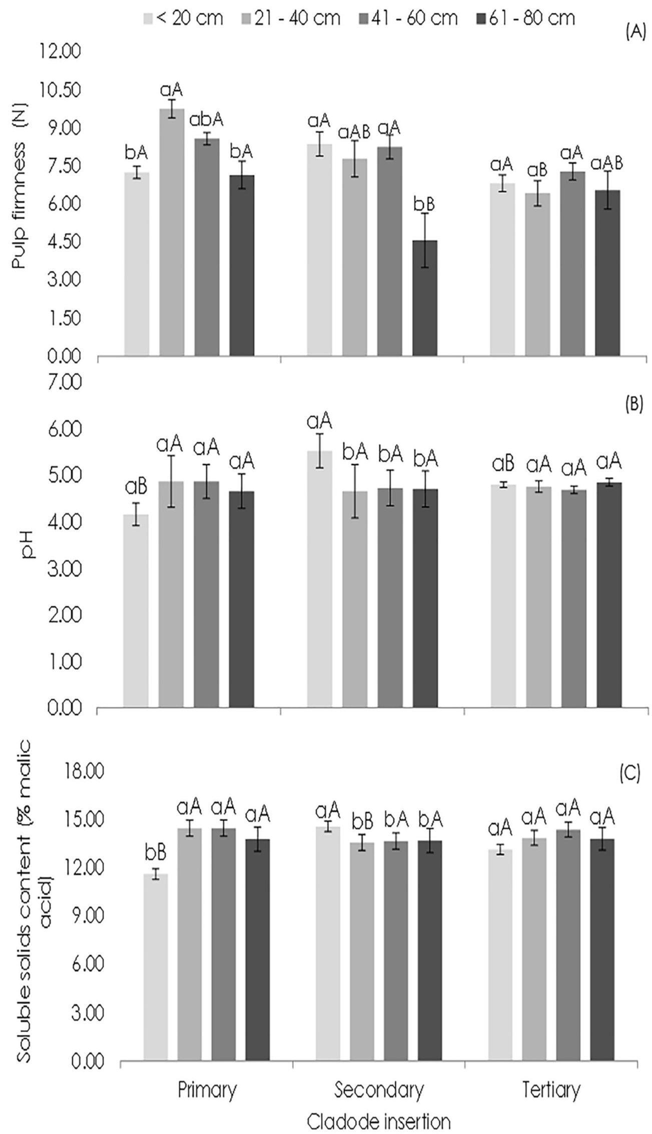

Figure 4. Pulp firmness (A), pH (B), and soluble solids content (C) of dragon fruit pulp as a function of cladode position and size. Bars with the same lowercase (cladode size) or uppercase (cladode position) letters are not significantly different from each other. Symbols represent the standard error.

fruits, when they are transported and marketed, which is shown by a progressive loss of pulp firmness and epidermis color due to degradation of chlorophyll and synthesis of other pigments (Chitarra & Chitarra, 2005; Pereira et al., 2013).

The results of pH (Figure 4B) and soluble solids contents (SS) (Figure 4C) showed similar dynamics for the statistical breakdown. The means presented little variation in the interactions between the factors (cladode position and size), except for cladodes smaller than 20 cm in the main branch, primary cladodes (4.16 and 11.61%, respectively for pH and SS). The occurrence of fruits with more acid pH and lower amounts of sugars may be connected to the position of the fruits on the plant, whereas increases in these variables are associated with production and partition of photoassimilates. Thus, these fruits may be affected by direct exposure to light, and this exposure affects their maturation in the latest weeks preceding the ideal harvest point (Bussi et al., 2011; Prakash et al., 2012).

The results found for SS indicated the quantity of sugars in the fruits; high SS are desirable for fruits intended to fresh consumption and processing (Fernandes et al., 2011).

Table 4. Physicochemical characteristics of dragon fruits as a function of cladode position and size

Source of variation	PF	pH	SS	TA	SS to TA ratio
	–N–	——	°Brix	%malic acid	______
Cladode position CP ("F")	5.45**	1.98 ns	0.27 ns	0.42 ns	1.40 ns
LSD	1.05	0.32	0.79	0.02	13.18
Cladode size CS ("F")	6.57**	0.12 ns	2.64 ns	2.41 ns	0.41 ns
LSD	1.33	0.41	1.01	0.03	16.75
Interaction (CP×CS)	3.20*	3.93**	5.16**	1.98 ns	1.58 ns
CV (%)	18.62	8.93	7.63	19.50	22.45

PF = pulp firmness; SS = soluble solids contents; TA = total titratable acidity; CV = coefficient of variation; LSD = least significant difference; ns = not significant; * = significant at 5% probability ($p < 0.05$); ** = significant at 1% probability ($p < 0.01$).

Regarding plant production and fruit development and quality in different species, studies have reported that, in general, a balance between vegetative and reproductive development stages is necessary to maximize fruit yield and quality (Pasa et al., 2011; Rufato et al., 2012; Randunz et al., 2014).

Conclusion

The results found under the evaluated experimental conditions showed that vegetative and reproductive characteristics of dragon fruit plants of the variety Cebra are affected by cladode position and size.

Fruits developed on primary cladodes with sizes of 21 to 40 cm generally presented better-quality characteristics. All evaluated physical and physicochemical characteristics were affected by cladode position and size, except for titratable acidity and soluble solids to titratable acidity ratio. Fruits developed on cladodes smaller than 20 cm had lower development and quality.

Maintaining and promoting the growth of primary cladodes with sizes of 21 to 40 cm and removing those smaller than 20 cm is recommended.

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