Commercial productivity and quality of pitaya as a function of number of fruits per cladode[1]

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ABSTRACT

Increasing orchard productivity is among the main objectives of pitaya producers. However, the commercial productivity may reduce due to reduction of fruit size as a function of the high amount per plant. This study evaluated the influence of the number of fruit per cladode in commercial productivity and in quality of fruits of two pitaya species at different harvest times. The experiment was carried out in a six-year-old orchard formed by the species *Selenicereus undatus* and *Hylocereus polyrhizus*. At each flowering time, the number of fruits set per cladode was counted and plants with two, four, five and six fruits per cladode were selected, and surplus fruits removed. The evaluations followed a split plot design over time, with the main plot as the number of fruit per cladode and the subplot as the harvest seasons: December, February and March, with four replicates and one plant per plot. Plants grown with two fruits per cladode presented the highest percentage of fruits with commercial size and commercial productivity. Both species showed fruits with commercial size in the first harvest of the cycle (December). *S. undatus* fruits classified as Class I and *H. polyrhizus* fruits classified as Extra and Class I showed the best quality.

Keywords: *Selenicereus undatus*, *Hylocereus polyrhizus*; fruit size; commercial yield.

INTRODUCTION

The quality of fruit is essential for commercialization. The quality standard of pitaya classifies the lots in three classes, which considers the variation of mass and defects (FAO, 2004; Asean Stan 42, 2015). However, the quality of fruit depends on intrinsic and extrinsic factors that affect the growth and production of plants.

Size is one of the most important quality variables, and in the case of pitaya, it is decisive for classification, because the largest size fruits are classified in the categories that achieve the best prices on the market (Then, 2013). However, information lacks on the number of fruit produced per plant related to commercial quality and productivity, which is important for the management of pitaya orchards.

In research studies, variation in productivity has been attributed to the uneven size of fruits, demonstrating that the number of fruits per plant is related to its composition, quality and productivity (Fernandes *et al.*, 2018; Rabelo *et al.*, 2020a; Rabelo *et al.*, 2020b; Alves *et al.*, 2021). According to these reports, the variations occur due to nutrient availability, so that the nutritional management of the orchard is one of the factors responsible for the commercial production of pitayas with quality.

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However, when the number of fruits affects commercial productivity, the best course of action is to adopt management practices to reduce the number of fruits in the plant (Cruz *et al.*, 2011); or increase the supply of pollen at the time of pollination (Silva *et al.*, 2011; Lone *et al.*, 2017), aiming to improve uniformity in size and increase yield.

Specifically for pitayas in Brazil, further studies are needed on management practices relating quality variables and commercial productivity. In this sense, this study evaluated the effect of the number of fruit per cladode on the commercial productivity and the quality of fruits of two pitaya species at different harvest times.

MATERIALS AND METHODS

The study was carried out in an orchard in Minas Gerais, Brazil, located at 18° 04' 15"S latitude and 43° 28' 15" W longitude, 726 m altitude. The climate of the region is Aw, classified as tropical high-altitude, with average annual temperature of 21.5 °C and average annual rainfall of 1,246 mm. In the period of evaluation, from January 2018 to April 2019, the accumulated rainfall was 503 mm. The monthly average of maximum temperature was 29.7 °C, average temperature was 26.5 °C, and minimum temperature was 23.2 °C (AccuWeather, 2019).

The soil in the experimental area is a Typic Haplorthox (Santos *et al.*, 2018), with 60% sand, 27% clay, and 13% silt. Fertilization management was according to the soil chemical analysis and the age of the plants, with three applications of 300 g of N, 300 g of K_2O, and 90 g of P_2O_5 per plant, during the flowering and fruiting period.

The orchard was formed by six-year-old *Selenicereus undatus* (Haw.) D.R.Hunt and *Hylocereus polyrhizus* (F.A.C. Weber) Britton & Rose spaced at 3.0 x 3.0 m, without management of artificial pollination. The training system consisted of "T" trellis of eucalyptus posts of 1.80 m high with a 1 m long cross arm. The plants were pruned for training of the main cladode and productive cladodes, ensuring light penetration to the stems and cleaning pruning to balance the numbers of cladodes and favor flowering, when necessary. *S. undatus* plants were kept with around 45 cladodes and in the *H. polyrhizus* with 130 cladodes per plant. Irrigation management was carried out during the period of low rainfall to maintain soil moisture for nutrient absorption at the time of fertilization, with 20 L per plant, weekly. The weed control was carried out within a radius of 40 cm from the stem by hand weeding, and the remainder of the area was mowed.

The experiment was arranged in randomized blocks, with a split plot design over time, with the main plot being the plants with different number of fruits per cladode, two, four, five and six, and, in the subplot, the harvest seasons, December 2018, February and March 2019, with four replicates and one plant per plot. The plants were selected from the count of the number of fruits formed per cladodes, one week after anthesis, when the fruits were around 6.5 mm in cross diameter. The number of fruit established per cladode was maintained in all cladodes of the plant, by thinning surplus fruits. This practice was applied at all flowering times, in the selected plants, in order to maintain the initial number established.

The fruit classification and calculation of productivity were performed at the harvests carried out from December 2018, February and March 2019, when the fruits presented red skin. In the laboratory, the number of fruits per plant, mean mass per fruit, and the longitudinal (mm) and cross (mm) diameters were evaluated. The fruits were separated and classified according to mass, following the standards of FAO (2004) and Asean Stan 42 (2015). The percentage of pitayas in each class was calculated by dividing the number of fruits produced in each commercial category by the total number of fruits produced and multiplied by 100, in order to determine the relationship between the number of fruits in each class and the total production in each treatment. The fruits in each class, were grouped in categories from A to I, or without classification, according to the mass, for later chemical evaluation.

The chemical characteristics were evaluated immediately after the classification, using representative samples of the fruits composed by four replicates, of each category, in each harvest season, determining the content of total soluble solids (ºBrix) and titratable acidity (% malic acid). The soluble solids content was measured using a digital refractometer with automatic temperature compensation, model PR-100 pallete (Atago Co Ltd., Japan). Titratable acidity was based on the neutralization of acids present in the fruit with a standardized alkali solution of 0.1 mol L^{-1} sodium hydroxide by titration (IAL, 2008). The ratio (SS / TA ratio) was calculated from the results of the titratable acidity (TA) and the soluble solids (SS) content.

Total production per plant was calculated by multiplying the mass of commercial class fruits, including fruits that were outside the commercial standard, by the total number of fruits harvested per plant and the total productivity from production per plant multiplied by the density of plants per hectare (1,111). The production and commercial productivity was calculated in the same way, but fruits that did not reach the minimum standard for commercialization, with mass below 135 g, were disregarded (FAO, 2004; Asean Stan 42, 2015).

The data were subjected to analysis of variance. The unfolding of the interaction was carried out to study the effect of the number of fruits per cladode in the different seasons, comparing the means with the Tukey test, with a 5% probability of error. The variables showing significant differences between the number of fruits per cladode subjected to regression analysis, considering a 5% probability of error. The analyses were performed using the Sisvar statistical software (Ferreira, 2011).

RESULTS AND DISCUSSION

According to commercial classification criteria, the highest percentage of pitayas was recorded in Class II, in categories D, C and B. Plants of *S. undatus* conducted with two fruits per cladodes had 51.8% of the fruits classified in these categories, whereas plants of *H. polyrhizus* conducted with two and four fruits per cladode had around 42% of the fruits classified in these categories. The lowest percentages were recorded in plants thinned to six fruits per cladode from 36.7% to 35.4% in both species, respectively (Table 1).

Table 1: Number of fruits per plant of the species *Selenicereus undatus* (1) and *Hylocereus polyrhizus* (2), conducted with two, four, five and six fruits per cladode, classified in different classes and categories according to the international standard

Class	Categories	Mass (g)	Fruits number per plant							
			two		four		five		six	
			1	2	1	2	1	2	1	2
			%							
Extra	A	> 701	0,7	0,4	0,0	0	0,0	0,0	0,0	0,0
	B	601 - 700	0,7	0,4	0,0	0	0,0	0,0	0,0	0,0
	C	501 - 600	1,9	0,7	4,4	0	0,0	0,7	1,2	0,0
Subtotal 1	-	-	3,3	1,5	4,4	0	0	0,7	1,2	0
I	D	401 - 500	3,7	2,9	4,4	1,1	1,1	1,7	4,8	0,0
	E	301 - 400	4,8	7,9	6,4	10,1	10,1	5,1	17,5	1,8
Subtotal 2	-	--	8,5	10,5	10,8	11,2	11,2	6,8	22,3	1,8
II	F	251 - 300	12,1	8,0	11,3	7,1	7,1	10,2	9,6	4,7
	G	201 - 250	18,4	12,3	15,7	12,0	12,0	12,2	8,4	12,6
	H	151 - 200	21,3	21,7	17,6	23,6	23,6	17,3	18,7	18,1
Subtotal 3	-	-	51,8	42,0	44,6	42,7	42,7	39,7	36,7	35,4
without standard	I	110 - 150	19,9	20,0	14,2	19,5	19,5	16,5	12,7	27,1
	SC*	< 110	16,5	26,0	26,0	26,6	26,6	36,3	27,1	35,7
Subtotal 4	-	-	36,4	46,0	40,2	46,1	46,1	52,8	39,8	62,8
Total number	-	-	272	280	204	295	267	270	166	277

Source: Adapted from FAO (2004); Asean Stan 42 (2015).
* SC = unrated fruit; Total = total of evaluated fruits, on mean.

The results demonstrate that there is a relationship between the number of fruits per cladode and per plant with the fruit mass. In this sense, conducting plants with two fruits per cladode can increase the production of pitaya in the commercial classes. In addition, farmers should adopt management practices that favor the production of larger fruit sizes such as thinning (Cruz *et al.*, 2011) or artificial pollination (Silva *et al*, 2011; Lone *et al.*, 2017). The results of thinning suggest that the number of fruits per plant should be reduced by around 41% in both species conducted with two fruits per cladode (Table 1). However, this percentage must be evaluated in the field, as well as the the number of productive cladodes per plant. In addition, to ensure efficiency of thinning, all flowering times or thinning seasons must be considered, as the species develops flowers and fruits simultaneously, with a short period between anthesis and fruit ripening (Marques *et al.*, 2011; Silva *et al.*, 2015), thus, there is high competition between sink for assimilates.

These results are important and demonstrate that *S undatus* plants presented a higher percentage of fruits meeting the marketing standards, including the Extra class, compared with *H. polyrhizus* (Table 1). The differences between the pitaya species may be related to genetic characteristics and the number of cladodes per plant, which influence the number of floral buds and pollination efficiency. The selected plants of *H. polyrhizus* had mean of 120 cladodes per plant, while *S. undatus* had mean of 50 cladodes, with different demand for photoassimilates and pollen, considering that the flower fertilization in this species depends on cross-pollination, whereas *S. undatus* can present self-pollination (Muniz *et al.*, 2019). In addition, the greater the number of floral buds, requires eficiency pollination to set fruits and to produce larger fruits.

Regarding the harvest season, it was observed in both species a lower number of fruits per plant in the first harvest of the cycle, in December 2018, resulting in fruits of greater mass and longitudinal and cross diameters, regardless of the number of fruits per cladode (Table 2). This increased mass may be due to the greater availability of photoassimilates, which may favor the increase in fruit mass because of the less competition between the sinks.

The greater number of fruits per plant and the smaller sizes observed in the harvests of February and March resulted from the greater amount of flowers in the plants in the second and third flowering times that occurred in January and February, respectively. At that time, the temperature and low precipitation in the crop site favored floral induction and natural pollination. The conditions were different from those prevailed in the flowering that occurred in November 2018 and contributed to reduce the fruiting index due to the lower availability of pollen and/or a decrease in the presence of pollinators (Silva *et al.*, 2011). This is because the temperature, light and absence of rain are the main climate elements responsible for flowering and natural pollination of pitaya (Marques *et al.*, 2011; Silva *et al.*, 2015, Muniz *et al.*, 2019).

These results are relevant for the management of orchards that do not manage artificial pollination, aiming to establish practices to avoid plant wearing out or increase the availability of photoassimilates, as it is essential that fruits reach mass for commercial classification. In addition, as new flowers bloom, the reserves seem to wear off and depending on the quantity of fruit that simultaneously grows in the plant, the competition between the sinks is greater, which explains the smaller sizes in the February and March harvests.

Regarding the total number of fruits, production per plant and total productivity, no differences were observed in function of the number of fruits per cladode, in the two species. *S. undatus* showed means of 58 fruits per plant, 10.5 kg per plant, and total productivity of 11.7 t ha^{-1}, while *H. polyrhizus* showed means of 70 fruits per plant, 10.9 kg per plant, and total productivity of 12.1 t ha $^{-1}$ (Table 3). These results show that a greater number of fruits per cladode does not result in greater productivity and, although *H. polyrhizus* produces a greater number of fruits per plant, the difference in productivity is not significant because of the lower mass of fruits, showing a relationship between the number of fruits per plant and the size of the fruits.

Considering only fruits that meet the commercial standard, the results show that the number of fruits per cladode influences production, with reduction in commercial number of fruits per plant from 43.9 to 29 and from 34 to 26, commercial production per plant from 11.6 kg to 6.2 kg and from 9.6 kg to 4.9 kg, and commercial productivity from 12.9 t ha^{-1} to 6.8 t ha-1 and from 10.7 t ha^{-1} to 5.4 t ha^{-1} for *S. undatus* and *H. polyrhizus*, respectively (Table 3). This is caused by the lower mean mass of fruits in plants conducted with six fruits per cladode. A relevant point observed was that the commercial productivity in plants conducted with two fruits per cladode (12.9 t ha^{-1} and 10.7 t ha^{-1}) is similar to the total productivity (11.7 t ha^{-1} and 12.1 t ha^{-1}), showing that fruit size uniformity, even with a smaller number of fruits per plant, compensates for commercial productivity.

In the analyses of fruit quality, in all harvest seasons, non-commercial fruits showed the lowest soluble solids concentrations and ratio and the highest acidity, for the two species (Tables 4 and 5). The exception was observed in fruits of *S. undatus* classified as extra A in the March harvest, which showed no difference from non-commercial fruits, with mean of 14.5° Brix. This result may be related to the maturation stage and the high demand for photoassimilates.

The pitayas of *S. undatus* ranked in class I presented the best results in the two categories (D and E) for soluble solids concentrations, varying between 16.8° Brix to 18.1° Brix, titratable acidity from 0.26% to 0.3%, and SS/TA ratio from 53.1 to 67.3 (Table 4). Fruits of *H. polyrhizus* in the Extra class and class I showed the best results for soluble solids concentrations with variation between 19.5° Brix to 22.3° Brix, the acidity between 0.19% and 0.29%, and the SS/TA ratio between 67.2 and 111.6 (Table 5).

Table 2: Number of fruits per plant, mass, transverse diameter and longitudinal diameter of the pitayas of *Selenicereus undatus* and *Hylocereus polyrhizus* conducted with two, four, five and six fruits per cladode, at different harvest times

Fruits number per plant

[2]NFC	*Selenicereus undatus*			*Hylocereus polyrhizus*		
	December	February	March	December	February	March
2	15 b	32a	21 b	19b	23 ab	28a
4	13 b	24a	17 ab	24b	22b	37a
5	18 b	21ab	25a	21b	21b	27a
6	10 b	22a	13ab	12b	19a	24a
Mean	14 b	24 a	19 b	13,8 c	21,2b	29,0a
CV(%)[1]		22,23			13,87	

Frutis mass (g)

NFC	December	February	March	December	February	March
2	383,19a	231,75b	199,75b	283,25 a	197,35 b	184,87 b
4	315,25a	182,25b	198,25b	270,87 a	185,11 b	173,95 b
5	225,85a	135,75b	154,75b	250,47 a	156,35 b	153,35 b
6	347,10a	135,75b	160,75b	230,81 a	166,71 b	148,35 b
Mean	317,8a	171,6b	178,9b	258,85a	176,37b	165,13b
CV(%)		16,78			7,87	

Transverse diameter (mm)

NFC	December	February	March	December	February	March
2	80,75a	71,25b	65,75b	76,37a	70,85b	64,75b
4	75,50a	65,00b	66,00b	72,15a	67,15b	63,97b
5	71,00a	58,50b	54,50b	70,73a	64,50 b	62,42a
6	81,25a	56,75b	59,50b	69,85a	65,27b	61,72b
Mean	77,12 a	62,87 b	61,43b	72,3a	66,4b	63,2 b
CV(%)		6,02			3,25	

Longitudinal diameter (mm)

NFC	December	February	March	December	February	March
2	88,10 a	79,25ab	74,25 b	74,97a	68,57b	65,22b
4	80,75a	70,75b	74,75 ab	70,35a	65,42b	64,10b
5	77,50a	65,10b	66,75 b	69,52a	66,65b	64,32b
6	89,50a	64,25c	73,25 b	68,55a	67,18b	63,72b
Mean	83,93a	69,81b	72,25b	70,8a	66,9 b	64,3 b
CV(%)		6,67			4,54	

Means followed by the same letters in the line, for each species, do not differ, by Tukey's test, at 5% probability.
[1]CV = coefficient of variation; [2]NFC = number of fruits per cladode.

The results observed for the fruits of the two species in all seasons, including the non-commercial fruits (Tables 4 and 5), show they are satisfactory for consumption, comparing the values considered acceptable of 12.2° Brix, titratable acidity less than 1%, and SS/TA ratio of 40 (To *et al.*, 2002; Wanitchang *et al.*, 2010; Ortiz & Takahashi, 2015). The low percentage of acids in pitayas imparts their mild flavor, which generally have a titratable acidity of less than 1% when ripe, being one of the variables used to assess the stage of fruit ripeness (Ortiz & Takahashi, 2015).

Table 3: Total number of fruits per plant, total production per plant, total productivity, number of commercial fruits, commercial production per plant and commercial productivity of *Selenicereus undatus* and *Hylocereus polyrhizus* species according to number of fruits per cladode

Variables	*S. undatus*			*H. polyrhizus*		
	Equation	R^2	Value	Equation	R^2	Value
Total number of fruits per plant	$\hat{Y} = 58,0^{ns}$	-	58,0	$\hat{Y} = 70,0^{ns}$	-	70,0
Total production per plant (kg plant^{-1})	$\hat{Y} = 10,5^{ns}$	-	10,5	$\hat{Y} = 10,9^{ns}$	-	10,9
Total productivity (t ha^{-1})	$\hat{Y} = 11,7^{ns}$	-	11,7	$\hat{Y} = 12,1^{ns}$	-	12,1
Number of commercial fruits	$\hat{Y} = 43,864 \pm 2,464x^{*}$	81,3	29,1	$\hat{Y} = 38,138 \pm 1,939x^{**}$	84,9	26,5
Commercial production per plant (kg plant^{-1})	$\hat{Y} = 11,64 \pm 0,912x^{**}$	96,6	6,2	$\hat{Y} = 9,66 \pm 0,797x^{**}$	88,5	4,9
Commercial productivity (t ha^{-1})	$\hat{Y} = 12,935 \pm 1,013x^{**}$	96,6	6,9	$\hat{Y} = 10,737 \pm 0,885x^{**}$	88,6	5,4

ns = not significant; * = significant, at 5%; ** = significant, at 1%.

Table 4: Content of soluble solids (SS), titratable acidity (TA) and SS / TA ratio of *Selenicereus undatus* fruits, in different categories of Extra, I and II classes e no commercial standard

Class		Soluble solids (° Brix)			Titratable acidity (% malic acid)			Ratio (SS/ TA)		
	Categories	December	February	March	December	February	March	December	February	March
Extra	A	15,2 c	15,8 b	14,5 c	0,31 a	0,30 ab	0,31 b	49,1 b	52,7 a	46,7 c
	B	16,1 b	16,8 ab	17,5 ab	0,32 a	0,30 ab	0,32 b	50,3 b	56,1 a	54,7 b
	C	17,5 a	17,3 a	17,1 ab	0,32 a	0,31 ab	0,26 c	54,7 b	55,8 a	65,7 a
I	D	17,1 a	16,8 ab	17,0 ab	0,26 b	0,30 ab	0,28 bc	65,7 a	56,1 a	60,7 a
	E	17,5 a	16,7 ab	18,1 a	0,26 b	0,29 b	0,29 bc	67,3 a	57,6 a	62,2 a
II	F	16,4 b	17,3 a	16,4 ab	0,26 b	0,29 b	0,28 bc	63,1 a	59,7 a	58,6 a
	G	16,8 ab	17,3 a	16,6 ab	0,26 b	0,30 ab	0,34 a	64,6 a	57,7 a	48,8 c
	H	15,1 c	17,2 a	16,5 ab	0,29 ab	0,32 a	0,32 a	52,1 b	53,7 a	51,1 b
No commercial standard	I	13,1 d	16,5 b	15,1 bc	0,31 a	0,34 a	0,34 a	42,2 c	48,7 b	44,1 d
	SC	13,4 d	14,3 c	15,1 bc	0,33 a	0,36 a	0,36 a	40,6 c	39,7 c	41,6 d
Mean	-	15,7 c	16,6 a	16,3 b	0,29 c	0,31 b	0,34 a	54,8 a	53,8 a	53,5 b
CV 1 (%)	-		1,33			5,36			3,19	
CV 2 (%)	-		3,18			6,79			6,84	

Means followed by the same lower case letters in the columns, do not differ by the Tukey test, at 5% probability.
CV1 (%) = coefficient of variation of the classes. CV2 (%). = coefficient of variation of the interaction between classes and harvest times; SC = unrated.

Table 5: Content of soluble solids (SS), titratable acidity (TA) and SS / TA ratio of *Hylocereus polyrhizus* fruits in different categories of Extra, I and II classes e no commercial standard

Class	Categories	Soluble solids (° Brix)			Titratable acidity (% malic acid)			Ratio (SS/TA)		
		December	February	March	December	February	March	December	February	March
Extra	A	19,9 a	20,5 b	19,9 b	0,19 d	0,21 c	0,19 d	104,7 a	97,7 ab	104, a
	B	21,3 a	22,3 a	21,3 a	0,20 d	0,21 c	0,21 d	106,8 a	106,5 a	101,6 a
	C	21,2 a	21,7 ab	21,2 a	0,19 d	0,21 c	0,21 d	111,6 a	103,3 a	101,0 a
I	D	21,2 a	22,1 a	21,2 a	0,22 c	0,21 c	0,22 d	96,4 b	105,2 a	96,4 a
	E	21,2 a	20,5 b	19,5 b	0,21 c	0,29 ab	0,29 b	104,3 a	70,7 bc	67,2 b
II	F	19,7 b	20,9 b	20,0 b	0,26 b	0,26 b	0,29 b	75,8 c	80,4 b	69,1 b
	G	19,8 b	20,5 b	18,2 c	0,30 a	0,30 a	0,26 c	66,1 c	68,3 c	70,1 b
	H	18,7 c	21,2 b	19,5 b	0,28 ab	0,30 a	0,31 a	66,8 c	70,7 bc	62,9 b
No commercial standard	I	17,6 d	17,5 c	16,5 e	0,31 a	0,32 a	0,32 a	56,8 d	54,7 d	51,6 c
	SC	16,5 e	17,5 c	17,5 d	0,31 a	0,32 a	0,30 a	53,2 d	54,7 d	58,3 c
Mean		19,7 b	20,5 a	19,4 b	0,25 a	0,26 a	0,26 a	83,6 a	81,2 a	77,7 b
CV 1 (%)			1,34			1,77			3,98	
CV 2 (%)			1,55			3,66			5,38	

Means followed by the same lower case letters in the columns, do not differ by the Tukey test, at 5% probability.
CV1 (%) = coefficient of variation of the classes. CV2 (%). = coefficient of variation of the interaction between classes and harvest times; SC = unrated.

Fruits with the lowest mass were those lowest in taste, indicating that, probably, the competition for photoassimilates depends on the sink force, which is responsible for the amount of photoassimilates that is partitioned to each fruit. Therefore, in absence of interference with the amount of fruit produced per plant, there is high competition between the sinks for the available photoassimilates.

CONCLUSIONS

Plants of the species *S. undatus* and *H. polyrhizus* conducted with two fruits per cladode presented the highest percentage of fruits that reach the commercial size and the highest commercial productivity.

Both pitaya species had most of the fruits meeting the commercial size in the first harvest of the cycle (December).

Pitayas of *S. undatus* classified as class I and *H. polyrhizus* classified as Extra and class I showed the best quality.

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