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SOIL LIMING AND NPK FERTILIZATION ON NUTRIENT EXPORT AND QUALITY OF PITAYA

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ABSTRACT

Nutrient export provides important information for fertilization decisions in pitaya production. Fertilization management can be planned considering the productivity reached by the orchard, aiming to maintain the fruit quality required by the consumer market. This study evaluated the nutrient export and quality of fruits *Selenicereus monacanthus* as a function of liming in the soil and NPK fertilization. The treatments were doses of NPK, arranged in a fractional factorial scheme 1/2(4×4×4), distributed in a randomized block design, with four blocks and two cultivation areas, with and without soil liming. The factors were doses of N: 13, 124, 235, and 347 kg ha^{-1}; P_2O_5: 9, 64, 120, and 231 kg ha^{-1}; and K_2O: 26, 138, 249, and 360 kg ha^{-1}. The quantity of nutrients exported per ton of *S. monacanthus* fruits were: K, 12.65 kg; N, 3.24 kg; Ca, 1.53 kg; P, 0.54 kg; Mg, 0.33 kg; Mn, 166.0 g; Fe, 12.67 g; and Zn, 3.49 g, with liming in the soil. The order of nutrients exported differs in the peel and pulp, being K>N>Ca>Mn>P>Mg>Fe>Zn in the peel and K>N>Ca>P>Mg>Mn>Fe>Zn in the

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pulp. Liming increases the quantity of nutrients exported to fruits, mainly Ca, P and Mg in the peel. K_2O fertilization in pitaya orchards improves fruit quality. Liming and NPK fertilization should be carried out in pitaya cultivation to adjust nutrient contents in the soil in order to replace the nutrients exported by fruit harvests.

Keywords: *Selenicereus monacanthus*, dragon fruit, Physical-chemical characteristics, mineral composition, productivity.

INTRODUCTION

The quantity of nutrients removed from the orchards by fruit harvests is an indication of the need for fertilization to replenish nutrients. In perennial fruit species, such as pitaya (*Selenicereus monacanthus* (Lem.) D.R.Hunt), proper management practices, such as correction of soil acidity and periodic maintenance of nutrient and organic matter contents, ensure the nutritional balance of plants and influence fruit production and quality.

Determining the quantity of nutrients exported by the fruits provide information for fertilization management, aiming to replenish the mineral nutrients in the soil to increase the cultivated area and productivity of pitaya with commercial quality. High productivity of pitaya orchards requires a greater quantity of nutrients in the soil due to the greater exportation of fruits (Rabelo et al., 2020b). Therefore, producers need to provide the appropriate quantity of nutrients, considering the export of nutrients by fruits to obtain satisfactory results in terms of production and quality of pitaya (Silva et al., 2022).

Nutrient export by pitaya depends on soil type, availability of nutrients to the plants through correction, and fertilization and demand of the species (growth and production). In addition, the functions of nutrients in establishing flavor, color, size, resistance to pests and diseases, and conservation during post-harvest storage of fruits must be considered. In pitaya orchards, fertilization management is one of the main factors that directly interfere with fruit quality (Duarte et al., 2017; Fernandes et al., 2018; Rabelo et al., 2020a; Alves et al., 2021). Studies related to liming and mineral fertilization are relevant, but there are still many challenges due to the complexity of research under field conditions (Fernandes et al., 2018; Rabelo et al., 2020a; Reis et al., 2020; Alves et al., 2021).

Potassium is regarded as the most critical nutrient for pitaya production, being mostly accumulated in the aerial part of the plant (Moreira et al., 2016; Lima et al., 2019), and also considered the most exported by fruits (Rabelo et al., 2020b). This macronutrient strongly influences the quality of pitaya, since it contributes to enhancing flavor and making the fruits sweeter, which is an important factor for consumer acceptance (Rabelo et al., 2020a). The export order of nutrients, mainly N, P, Ca and Mg, has been variable in shoots and fruits (Moreira et al., 2016; Lima et al., 2019; Rabelo et al., 2020b). Therefore, liming and fertilization management is important to know the order exported to produce high-quality fruits.

Crop management practices are aimed to achieve high productivity, without affecting fruit quality standard and consumer acceptance. Accordingly, proper fertilizer use and management are key aspects of crop production to ensure high production and fruit quality.

Evaluating nutrient export for fruit production in pitaya orchards can contribute to a better planning of liming and fertilization management aimed at replenishing nutrients in the soil. Given that pitaya is a perennial species, in addition to soil analysis for fertility adjustment, maintenance fertilization of the orchards must be carried out considering nutrient exports from fruit harvests, with values estimated based on the expected harvest. Therefore, the objective of this was to evaluate the nutrient export and quality of fruits *S. monacanthus* as a function of liming in the soil and NPK fertilization.

MATERIALS AND METHODS

The experiments were carried out in an orchard of *S. monacanthus* (synonym: *Hylocereus polyrhizus* (F.A.C.Weber) Britton and Rose) (Fig. 1), located at 18°04′43″S, 43°27′28″W and 728 m altitude, in the municipality of Couto de Magalhães de Minas, state of Minas Gerais, Brazil. The local climate is classified as Aw, according to the Köppen-Geiger classification, which is characterized by a dry winter and rainy summer. The average annual temperature is 21.3 °C and the average annual precipitation is 1,183 mm.

The soil of the experimental areas is classified as Latossolo Vermelho-Amarelo Distrófico (Santos et al., 2018). Soil fertilization management was carried out based on the chemical analysis of two cultivation areas. In the area without liming, the soil had the following chemical characteristics at

Fig. 1. *Selenicereus monacanthus* plant and fruit evaluated in the experiments.

the time of seedling planting: pH 5.50 (water), P 2.01 mg dm^{-3} (Mehlich-1 extractor), K 19.59 mg dm^{-3}, Ca + Mg 1.15 $cmol_c$ dm^{-3} and base saturation 30%. In the liming area, the following attributes were evaluated in the soil at planting time: pH 6.52 (water), P 3.52 mg dm^{-3} (Mehlich-1 extractor), K 60.94 mg dm^{-3}, Ca + Mg 3.11 $cmol_c$ dm^{-3} and base saturation 65%. Liming was carried out with dolomitic limestone, with PRNT 80%, at a depth of 0.2 m in the total area and, in the holes, 70 days before planting, seeking to increase base saturation to 70% (Reis et al., 2020).

In the experiments with and without liming, the treatments were the doses of NPK that were arranged in a fractional factorial scheme 1/2(4×4×4) (Conagin et al., 1997), distributed in a randomized block design with four blocks and one plant per experimental plot. The factors were N doses: 13, 124, 235 and 347 kg ha^{-1}; of P_2O_5: 9, 64, 120 and 231 kg ha^{-1} and of K_2O: 26, 138, 249 and 360 kg ha^{-1}. These doses were based on the results published by Rabelo et al. (2020b) and Alves et al. (2021), which were presented in the recommendation of Silva et al. (2022).

In both experiments, doses of P_2O_5 were applied in the planting holes of 0.5×0.5 m in size, according to the disposition of the fractional factorial scheme, also applying 5 L of bovine manure and 50 g of FTE BR12 (9% Zn, 2,1% Mn, 1,8% B, 0,8% Cu, 0,1% Mo). The source of bovine manure is important to favor seedling growth and provided 13 kg ha^{-1} of N, 9 kg ha^{-1} of P_2O_5 and 26 kg ha^{-1} of K_2O. Planting was carried out at a density of 1,111 plants per hectare, in September 2019.

Production fertilizations with NPK were carried out in the first and second production cycles (2020/2021 and 2021/2022 harvests). P_2O_5 was applied at pre-flowering stage and the doses of N and K_2O were split into three applications, the first being carried out at pre-flowering and the others at 60 and 120 days after the first application, respectively. After the last mineral fertilization in each cycle, 5 L of bovine manure were applied per plant. The quantity of nutrients provided by the organic source were considered in the calculation of NPK doses. The sources were urea (46% N), simple superphosphate (19% P_2O_5, 18% Ca, 20% S) and potassium chloride (58% K_2O). The fertilizers were applied superficially to the soil, in the projection of the canopy of the plants.

Pollination management was carried out in both production cycles to ensure the fruiting of *S. monacanthus* plants (species that presents self-incompatibility) and to facilitate the production of commercial-sized fruits. Manual cross-pollination was carried out with pollen grains of the species *Selenicereus undatus* (Guimarães et al., 2022), in all flowering flows of the plants, which occurs from November to March, in the place of cultivation of the experiments.

Pitayas were harvested when the entire surface of the peel was red in color and the scales were still green. After that, the diameters were measured. In representative samples, the content of soluble solids (SS, °Brix), the titratable acidity (TA, %), the SS/TA ratio, the pH of the pulp, the thickness (mm) of the peel and the moisture (%) of the peel and pulp were evaluated, according to the norms of the Instituto Adolfo Lutz (Zenebon et al., 2008).

Nutrient contents were determined from 0.5 g of dry matter of peel and pulp, added to 10 mL of HNO_3, for digestion (Silva, 2009). After digestion, distilled water was added to the obtained extracts up to a volume of 50 mL. Ca, Mg, Fe, Mn and Zn contents were determined in an air-acetylene flame atomic absorption spectrometer, P by spectrophotometry and K by flame photometry (Silva, 2009). The N content was determined in an elemental analyzer, according to Astm D5373-21 (2021), Test Method A.

Nutrient export was calculated per ton of fruit based on the nutrient content and dry matter of the peel and pulp of the fruit, considering the dose of N that provided 90% of the maximum productivity in the first production cycle.

The data obtained were submitted to analysis of variance and regression studies. The equations were adjusted according to N, P_2O_5 and K_2O doses. Based on the equations adjusted for productivity, the doses of N, P_2O_5 and K_2O necessary to obtain 90% of the maximum productivity, considered as being of maximum economic efficiency, were estimated (Malavolta, 2006). Nutrient export was estimated by substituting the doses of N, P_2O_5 and K_2O associated with maximum economic efficiency productivity in the equations.

RESULTS

The quantity of nutrients exported per ton of peel and pulp showed differences depending on the N doses applied to the soil, in both experiments, with and without liming (Table 1). There was an increase in the export of P and K as a function of the doses of P_2O_5 and K_2O.

The order of nutrient export in liming cultivation differed, contributing to the greater nutrient export, mainly Ca, P and Mg in the peel. With liming, the order evaluated was K>N>Ca>Mn>P>Mg>Fe>Zn in the peel, and K>N>Ca>P>Mg>Mn>Fe>Zn in the pulp; in the cultivation without liming, Ca, P and Mg in the peel follow Mn, K>N>Mn>Ca>P>Mg>Fe>Zn, and K>N>Ca>P>Mg>Mn>Fe>Zn in the pulp (Table 1).

The difference in relation to liming management resulted in the following quantity of nutrients exported per ton of fruit (peel and pulp): 12.65 kg of K, 3.24 kg of N, 1.53 kg of Ca, 0.54 kg of P, 0.33 kg of Mg, 166.02 g of Mn, 12.67 g of Fe and 3.49 g of Zn; while, in the experiment without liming, there were 12.48 kg of K, 3.1 kg of N, 0.64 kg of Ca, 0.47 kg of P, 0.35 kg of Mg, 209.85 g of Mn, 15.06 g of Fe and 4.40 g of Zn (Table 1). In the cultivation with and without liming, the quantity exported per ton of fruit (peel and pulp), due to increasing applications of P_2O_5 and K_2O, was higher compared to the quantity exported as a result of fertilization with N, with 0.59 kg and 0.45 kg of P and 14.09 kg and 14.03 kg of K.

In the present study, in addition to fertilization management, there was an increase in nutrient exports with liming and productivity management (Table 2). The difference is related to the increased availability of these nutrients in the soil.

Regarding the physicochemical characteristics of the fruits, no differences were observed as a function of the N doses applied to the soil, in the experiments with and without liming, in the two production cycles (Table 3). In cultivation with liming, the soluble solids content increased in fruits due to potassium fertilization. The results observed as a function of the increase in K_2O fertilization provided an increase in the soluble solids content from 14.6 °Brix to 19.1 °Brix and 17.1 °Brix to 19.7 °Brix in the first and second production cycles, respectively (Table 3).

Pulp and peel moisture ranged from 85.62% to 89.06%, pulp pH from 4.84 to 5.03, and peel thickness from 2.29 to 2.77 mm, in the cultivation without and with liming (Table 3) and in both production cycles.

DISCUSSION

With respect to soil type, the order of nutrient export to the cladodes of pitaya species cultivated in Latossolo Vermelho-Amarelo Distrófico and liming to increase base saturation to 60%, the order was K>N>Ca>S>Mg>P (Moreira et al., 2016), while in Argissolo Vermelho-Amarelo Eutrófico and liming to increase base saturation to 70%, the order was K>Ca>N>P>Mg>S (Lima et al., 2019). For fruits, different results were obtained in a study carried out by Rabelo et al. (2020b), in Latossolo Vermelho-Amarelo Distrófico with liming to increase the base saturation to 60%, in which Ca and Mg follow P and other macronutrients: K>N>P>Ca>Mg>Mn>Fe>Cu>Zn>B. Differences in the export order reflect soil characteristics and fertility, which vary according to the climate of the different growing regions and management practices, and serve as justifications for the variations reported in the cited studies.

The difference related to liming management highlights the importance of correcting soil acidity. Without liming, there is less Ca exportation and an increase in the export of micronutrients such as Mn. Generally, in acid soils, Mn contents tend to increase in dry matter due to the increase in the solubility and availability of this nutrient when the soil pH is low, between 5.0 and 5.5 (Malavolta, 2006), which justifies the difference in the export order

Table 1. Quantity ($\hat{Y}$) of exported nutrients (g) per ton of fruit as a function of N doses (x) applied to the soil, in the cultivation without and with liming, and regression equations, coefficient of determination (R^2), coefficient of variation (CV), maximum exported quantity of P and K as a function of P_2O_5 and K_2O doses.

Nutrient	Without liming	R^2	90% (g t^{-1})	CV (%)	With liming	R^2	90% (g t^{-1})	CV (%)
				Peel				
N	$\hat{Y} = 546.25 + 3.2351x - 0.0061x^{2**}$	94.21	932.98	12.65	$\hat{Y} = 666.17 + 1.1006x^{*}$	93.07	999.65	24.90
P	$\hat{Y} = 145.69^{ns}$	-	-	22.59	$\hat{Y} = 149.04^{ns}$	-	-	19.06
K	$\hat{Y} = 7{,}586.90^{ns}$	-	-	16.81	$\hat{Y} = 7{,}672.83^{ns}$	-	-	19.71
Ca	$\hat{Y} = 106.44 + 0.279x^{*}$	92.83	157.22	17.76	$\hat{Y} = 443.27^{ns}$	-	-	36.32
Mg	$\hat{Y} = 133.61 - 0.3217x + 0.0006x^{2*}$	96.11	94.94	16.28	$\hat{Y} = 191.16 - 0.8636x + 0.0021x^{2**}$	94.16	122.29	23.25
Fe	$\hat{Y} = 7.8843 - 0.0305x + 0.00008x^{2*}$	92.59	4.98	42.41	$\hat{Y} = 5.84^{ns}$	-	-	36.24
Mn	$\hat{Y} = 28.426 + 1.374x - 0.0021x^{2*}$	98.83	208.93	30.04	$\hat{Y} = 41.681 + 0.374x^{*}$	98.24	155.02	36.84
Zn	$\hat{Y} = 1.2268 + 0.0082x - 0.00002x^{2*}$	88.76	2.06	25.78	$\hat{Y} = 1.53^{ns}$	-	-	32.12
				Pulp				
N	$\hat{Y} = 2{,}169.31^{ns}$	-	-	21.99	$\hat{Y} = 2{,}241.11^{ns}$	-	-	30.84
P	$\hat{Y} = 254.82 + 0.5958x - 0.0011x^{2*}$	91.04	326.82	12.01	$\hat{Y} = 224.93 + 2.0123x - 0.0048x^{2**}$	95.57	393.97	26.41
K	$\hat{Y} = 4{,}888.72^{ns}$	-	-	11.11	$\hat{Y} = 4250.5 + 10.169x - 0.0256x^{2*}$	98.88	4,981.40	14.92
Ca	$\hat{Y} = 685.16 - 2.4297x + 0.0071x^{2*}$	64.42	478.14	35.91	$\hat{Y} = 1{,}091.09^{ns}$	-	-	7.95
Mg	$\hat{Y} = 254.48^{ns}$	-	-	10.53	$\hat{Y} = 205.72^{ns}$	-	-	21.57
Fe	$\hat{Y} = 10.08^{ns}$	-	-	33.57	$\hat{Y} = 6.83^{ns}$	-	-	33.32
Mn	$\hat{Y} = 4.3856 + 0.0359x^{*}$	94.64	10.92	33.94	$\hat{Y} = 3.3017 + 0.0254x^{*}$	95.87	11.0	37.91
Zn	$\hat{Y} = 2.34^{ns}$	-	-	14.87	$\hat{Y} = 1.96^{ns}$	-	-	21.15
Productivity (kg ha^{-1})	$\hat{Y} = 2153.5 + 65.14x - 0.1162x^{2*}$	99.72	10,154.36^{P}	39.74	$\hat{Y} = 2564.3 + 27.272x^{*}$	84.75	10,824.92^{P}	32.47
N^D (kg ha^{-1})	182	-	-	-	303	-	-	-
				Doses of P_2O_5 (kg ha^{-1})				
P peel	$\hat{Y} = 112.6 + 0.313x^{*}$	98.17	184.90^{M}	22.59	$\hat{Y} = 113.48 + 0.3364x^{*}$	92.89	191.19^{M}	19.06
P pulp	$\hat{Y} = 311.25^{ns}$	-	-	12.01	$\hat{Y} = 303.11 + 1.5802x - 0.0063x^{2*}$	94.44	402.20^{M}	26.41
				Doses of K_2O (kg ha^{-1})				
K peel	$\hat{Y} = 4077.4 + 31.729x - 0.0497x^{2*}$	99.92	9,141.43^{M}	16.81	$\hat{Y} = 4927.3 + 29.394x - 0.0556x^{2*}$	96.56	8,812.22^{M}	19.71
K pulp	$\hat{Y} = 4{,}888.72^{ns}$	-	-	11.11	$\hat{Y} = 3824 + 10.955x - 0.0206x^{2*}$	82.58	5,280.46^{M}	14.92

N^D, dose of N corresponding to 90% of the maximum productivity. ^{P} 90% of maximum productivity. ^{M} maximum value. ^{ns} not significant. *, **, significant, at 5% and 1% probability, by the t-test. Doses of P_2O_5: 9, 64, 120 and 231 kg ha^{-1} and K_2O: 26, 138, 249 and 360 kg ha^{-1}. Planting density: 1,111 plants per hectare.

Table 2. Quantity of nutrients exported (kg) as a function of the estimated productivity of plants that did not receive mineral fertilization and corresponding to the productivity of maximum economic efficiency, in cultivations without and with liming, in the first and second production cycles of *S. monacanthus*.

	Productivity (Mg ha^{-1})	N	P	K	Ca	Mg
		kg				
First production cycle with liming						
	2.92[1]	9.46	1.58	36.94	4.47	0.96
	10.82[2]	35.06	5.84	136.87	16.55	3.57
Second production cycle with liming						
	6.29[1]	20.38	2.96	79.57	9.62	2.08
	16.13[2]	52.26	7.58	204.04	24.68	5.32
First production cycle without liming						
	2.98[1]	9.24	1.40	37.19	1.91	1.04
	10.15[2]	31.47	4.77	126.67	6.50	3.55
Second production cycle without liming						
	3.38[1]	10.48	1.59	42.18	2.16	1.18
	16.08[2]	49.85	7.56	200.68	10.29	5.63

[1] Without mineral fertilization. [2] dose of N corresponding to 90% of the maximum productivity. Planting density: 1,111 plants per hectare.

in the cultivation without liming.

Despite the differences in export order, K has been identified as the most exported nutrient (Moreira et al., 2016; Lima et al., 2019; Rabelo et al., 2020b), as observed in the present study, in both cultivations (with and without liming), with emphasis on the peel. Rabelo et al. (2020a) have indicated that the greater quantity exported indicates that adequate K fertilization is fundamental for the production of fruits with a higher nutrient composition, mainly K, which is essential for quality. According to the authors, K is the macronutrient that mostly contributes to improving the quality of pitaya, and thus its deficiency results in reduced growth, production and quality, mainly in the sugar content of the fruits. This occurs because K is fundamental in metabolic processes, such as the synthesis of proteins and sugars, being responsible for transporting sugars and carbohydrates produced by photosynthesis to fruits (Malavolta, 2006). In addition, the results observed in the present study expand the technological use of the peel in the industry, since in addition to being used as a thickening agent and natural dye (Pantoja et al., 2022), it is a source of nutrients, mainly K.

Considering that most tropical soils are characterized by low contents of K, which is the main nutrient accumulated in the aerial part and exported to the fruits, potassium fertilization and annual replacement at the end of each production cycle are required, since a high amount of K is removed at harvest from the orchard as observed in the present study, with 136.87 kg and 204.04 kg in the first and second production cycles, respectively (Table 2).

N appears as the second most exported nutrient. Low N availability limits plant growth, influencing dry matter production of cladodes and roots, emission of new cladodes, length of cladodes formed, productivity and fruit size (Almeida et al., 2014; Alves et al., 2021).

The fact that Ca was the third most exported nutrient in cultivation with liming highlights the importance of correcting the soil with limestone to increase Ca contents in the soil and availability for plants, mainly because the redistribution of Ca from cladodes to fruits is low, due to its reduced mobility in the phloem of the plants (Malavolta, 2006). For the production of pitaya, Ca is fundamental to avoid the cracks that can occur in the fruits, affecting their quality and making them unsuitable for commercialization. Ca is involved in cell wall formation, increasing resistance to pests and diseases (Silva et al., 2022). Liming is the most recommended management practice for supplying Ca and Mg in pitaya cultivation (Silva et al., 2022), aiming to replace the quantity exported by harvests, in addition to improving other soil attributes (Reis et al., 2020). In addition, it is possible to apply fertilizers with sources of Ca and Mg, in situations that demand a quick supply.

P was the fourth most exported nutrient

Table 3. Physical-chemical characteristics of *S. monacanthus* fruits as a function of N doses applied to the soil in cultivations without and with liming, and maximum value of soluble solids as a function of K_2O doses, in the first and second production cycles.

Variable	Without liming	With liming
	Doses of N (kg ha^{-1}) - first production cycle	
Longitudinal diameter (mm)	$\hat{Y} = 94.30^{ns}$	$\hat{Y} = 89.38^{ns}$
Transverse diameter (mm)	$\hat{Y} = 91.12^{ns}$	$\hat{Y} = 87.67^{ns}$
Soluble solids (SS, °Brix)	$\hat{Y} = 16.38^{ns}$	$\hat{Y} = 16.84^{ns}$
Titratable acidity (TA, %)	$\hat{Y} = 0.15^{ns}$	$\hat{Y} = 0.17^{ns}$
SS/TA	$\hat{Y} = 111.13^{ns}$	$\hat{Y} = 101.71^{ns}$
Pulp pH	$\hat{Y} = 5.03^{ns}$	$\hat{Y} = 4.92^{ns}$
Thickness peel (mm)	$\hat{Y} = 2.29^{ns}$	$\hat{Y} = 2.31^{ns}$
Pulp moisture (%)	$\hat{Y} = 85.62^{ns}$	$\hat{Y} = 85.76^{ns}$
Peel moisture (%)	$\hat{Y} = 88.78^{ns}$	$\hat{Y} = 89.06^{ns}$
	Doses of N (kg ha^{-1}) - second production cycle	
Longitudinal diameter (mm)	$\hat{Y} = 102.26^{ns}$	$\hat{Y} = 100.85^{ns}$
Transverse diameter (mm)	$\hat{Y} = 100.01^{ns}$	$\hat{Y} = 99.93^{ns}$
Soluble solids (SS, °Brix)	$\hat{Y} = 18.08^{ns}$	$\hat{Y} = 18.40^{ns}$
Titratable acidity (TA, %)	$\hat{Y} = 0.32^{ns}$	$\hat{Y} = 0.33^{ns}$
SS/TA	$\hat{Y} = 60.43^{ns}$	$\hat{Y} = 58.45^{ns}$
Pulp pH	$\hat{Y} = 4.95^{ns}$	$\hat{Y} = 4.84^{ns}$
Thickness peel (mm)	$\hat{Y} = 2.59^{ns}$	$\hat{Y} = 2.77^{ns}$
	Doses of K_2O (kg ha^{-1})	
Soluble solids (°Brix)[1]	$\hat{Y} = 16.38^{ns}$	$\hat{Y} = 14.251 + 0.0134x^*$ $R^2 = 91.79$ $\hat{Y} = 19.08^M$
Soluble solids (°Brix)[2]	$\hat{Y} = 18.08^{ns}$	$\hat{Y} = 16.941 + 0.0076x^*$ $R^2 = 95.22$ $\hat{Y} = 19.68^M$

[1] First production cycle. [2] second production cycle. ^{M} maximum value. R^2, determination coefficient. ^{ns} not significant. * different, at 5% probability, by the t-test. Doses of N: 13, 124, 235 and 347 kg ha^{-1} and K_2O: 26, 138, 249 and 360 kg ha^{-1}.

for the pulp and the fifth for the peel, ranking among the last most exported macronutrients. This happens because P is one of the primary macronutrients least required by plants in quantitative terms (Malavolta, 2006). However, Brazilian soils normally have low P contents and, therefore, fertilization that provides this nutrient is essential for plants.

Uniformity in fruit size in relation to diameters (transverse and longitudinal) and mass can be related to the management of hand pollination, which was a common management practice for all plants, regardless of fertilization and liming. The increase in the quantity of pollen grains that reach the flower stigma contributes to the uniformity of fruit size because it influences the number of fertilized ovules (Guimarães et al., 2022). This occurs because the seeds formed secrete hormones, such as auxins, which promote ovary development, leading to larger fruits (Weiss et al., 1994).

The increase in the soluble solid content contributes to the improvement of fruit quality. Araújo et al. (2022) have described that the soluble solid content is a variable that serves as an indicator of fruit sweetness, which has been evaluated to define the appropriate harvest stage and ensure consumer acceptance. According to the authors, it is one of the most important quality characteristics because it is related to flavor, corresponding mainly to the sugar content, in addition to other compounds in fruits.

An increase in soluble solid content is desirable because values above 12 °Brix provide greater acceptance for natural consumption (Wanitchang et al., 2010). In addition, fruits destined for the industry that have more soluble sugars reduce the processing cost due to the waiver or reduction of sugar incorporation (Sato et al., 2014). Soluble solids are associated with the quantity of sugar in the fruit and, therefore, it is a characteristic related to acceptance for consumption (Rabelo et al., 2020a).

Fernandes et al. (2018) and Rabelo et al. (2020a) have reported on the improvement in fruit quality of the *S. monacanthus* and *S. undatus* species as a result of potassium fertilization. Their findings coincide with those of the present study as total soluble solids (16.82 to 22.1 °Brix) were higher than the minimum content (12 °Brix) considered for market acceptance (Wanitchang et al., 2010). The authors highlight the importance of fertilization with K_2O for the production of pitaya with high contents of soluble solids, which is essential for maintaining quality after harvest. This is important in pitaya because contents of total soluble solids commonly vary after harvesting, which can significantly reduce as a function of temperature during storage (Brunini and Cardoso, 2011; Duarte et al., 2017). The reduction in soluble solid content during storage under room temperature conditions (without refrigeration) occurs due to the use of sugars in the respiratory process (Osorio et al., 2013). Therefore, it is essential to harvest the fruits at the appropriate maturation stage to favor a high soluble solid content, in addition to managing potassium fertilization and adequate storage.

Differences in cultivation with liming are also important for the preservation of fruits after harvesting because most of the composition of pitaya is water and moisture content of the fruit determines the care with storage and use of adequate packaging, influencing processing, quality and nutritional composition (Cruz and Moreira, 2022). Water content solubilizes important compounds, such as vitamins, minerals, sugars and acids, favoring the development of microorganisms in a way that safety and shelf life are compromised (Bobbio and Bobbio, 2001). Pitaya tends to have low acidity, requiring special post-harvest care to avoid fruit loss since foods with a pH greater than 4.5 are subject to microbial multiplication (Sato et al., 2014).

The results of the present study show that, in addition to soil analysis, fertilization management in pitaya orchards needs to consider the exports of K>N>P by fruit harvests for maintenance fertilizations, with adjustments based on the expected harvest in each season. Liming and NPK fertilization are important for the maintenance of pitaya orchards in order to replenish nutrients in the soil. Proper management contributes to ensuring that all the fruits meet the commercialization standard, allowing the orchard to reach high productivity with the production of commercial quality fruits.

CONCLUSIONS

Nutrient export per ton of *S. monacanthus* fruits was as follows: K, 12.65 kg; N, 3.24 kg; Ca, 1.53 kg; P, 0.54 kg; Mg, 0.33 kg; Mn, 166.0 g; Fe, 12.67 g and Zn, 3.49 g, with liming in the soil.

The order of nutrients exported by pitaya differed in the peel and pulp, being K>N>Ca>Mn>P>Mg>Fe>Zn in the peel and K>N>Ca>P>Mg>Mn>Fe>Zn in the pulp.

Liming increases the quantity of nutrients exported to fruits, mainly Ca, P and Mg in the peel.

K_2O fertilization in pitaya orchards improves fruit quality.

Liming and NPK fertilization should be applied in pitaya cultivation to adjust nutrient contents in the soil in order to replace the nutrients exported by fruit harvests.

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Authors' contributions

Bibliographic review: D.A. Alves, M.C.M. Cruz, E.B. Silva. Development of the methodology: D.A. Alves, M.C.M. Cruz, E.B. Silva, J.E. Lima, N.C. Santos, C.G. Sena, V.A.P. Lima, C.M. Abreu. Discussion of the results: D.A. Alves, M.C.M. Cruz, E.B. Silva. Review and approval of the final version: D.A. Alves, M.C.M. Cruz, E.B. Silva, J.E. Lima, N.C. Santos, C.G. Sena, V.A.P. Lima, C.M. Abreu.

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