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Fertilization strategies to reduce the formation of stenospermocarpic mango fruits in the semiarid region

Camila Israela Freire Silva Carvalho[1], Ítalo Herbert Lucena Cavalcante[1], Augusto Miguel Nascimento Lima[1]*, Roberto Lustosa Silva[2], Kátia Araújo da Silva[1], Marcos Sales Rodrigues[1]

[1] Universidade Federal do Vale do São Francisco, Petrolina-PE, Brazil.
[2] Universidade Federal de Viçosa, Viçosa-MG, Brazil.
*Corresponding author. E-mail address: augusto.lima@univasf.edu.br

Abstract: The mango cultivation has shown considerable losses, due to the intense occurrence of physiological disorders in its fruits, and stenospermocarpy is the main disorder under tropical semiarid conditions. So, the experiment was carried out to evaluate the potential loss of yield of mango cv. Palmer by stenospermocarpy, its relation with the nutritional state of the plant and yield as a function of fertilization strategies. The study was conducted in two experimental areas in the Brazilian semiarid. There is evidence that the leaf contents of phosphorus (P), iron (Fe) and zinc (Zn) influenced the development of stenospermocarpy fruits, associated with high temperature and low relative humidity in the flowering period of the crop. The incidence of fruits affected by stenospermocarpy reaches 90%, with an estimated yield loss of 28.81 Mg ha^{-1} for the mango cv. Palmer.

Index Terms: *Mangifera indica* L.,Mineral nutrition, Physiological disorder, Yield.

Estratégias de fertilização para reduzir a formação de frutos estenoespermo-cárpicos de manga na região semiárida

Resumo: A cultura da manga tem apresentado perdas consideráveis, devido à intensa ocorrência de desordens fisiológicas em seus frutos, sendo a estenoespermocarpia a principal desordem nas condições do semiárido tropical. Assim, o experimento foi realizado para avaliar o potencial de perda de produtividade da manga cv. Palmer por estenoespermocarpia, sua relação com o estado nutricional da planta e sua produtividade em função das estratégias de fertilização. O estudo foi realizado em duas áreas experimentais no semiárido brasileiro. Há evidências de que os teores foliares de fósforo (P), ferro (Fe) e zinco (Zn) influenciaram o desenvolvimento

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dos frutos estenoespermocárpicos, associados à alta temperatura e baixa umidade relativa, no período de floração da cultura. A incidência de frutos afetados pela estenoespermocarpia chegou a 90%, com perda de produtividade estimada de 28,81 Mg ha^{-1} para a manga cv. Palmer.

Termos para indexação: *Mangifera indica* L., Nutrição mineral, Desordem fisiológica, Produtividade.

Introduction

Mango is a tropical climate crop of great economic and social importance, involving annually a large turnover in the domestic and foreign markets, especially in the region of the São Francisco Valley located in the Brazilian semiarid region, which accounts for 34% of the cultivation area, 49% of the national production and more than 85% of Brazilian exports of mango (CARVALHO et al., 2019).

'Palmer' mango stands out for being a late variety, with physicochemical characteristics appreciated by the domestic and foreign markets, and has excellent conservation capacity, being able to remain with satisfactory quality for up to 28 days under low temperature (12.8 °C) and controlled atmosphere (1 to 10% oxygen) (TEIXEIRA; DURIGAN, 2011). However, in the field, the cultivar has shown considerable losses, due to the intense occurrence of physiological disorders in its fruits, and stenospermocarpy is the main disorder under tropical semiarid conditions, responsible for the formation of fruits with reduced size and differentiated shape, popularly referred to in Portuguese as "manguita" or "castanha" (BARBOSA et al., 2016).

Stenospermocarpy is common in some plant species in which there is the formation of seedless fruits due to embryonic abortion after fertilization of the ovule (HUANG et al., 2010). In 'Palmer' mango, fruits affected by this physiological disorder have no commercial value, negatively affecting the economic profitability of the crop. This unwanted phenomenon may be associated with several causes, but under tropical semiarid conditions there is no consensus in the scientific literature. It is known that in some mango cultivars, the occurrence of stenospermocarpic is related to exposure to low temperatures (SUKHVIBUL et al., 2000) and also to high temperatures (NÚNEZ-ELISEA; DAVENPORT, 1983) in the period of pollination and early fruit formation.

In the 'Palmer' cultivar, there is evidence that this physiological disorder is associated with boron (B) nutrition (BARBOSA et al., 2016), because this nutrient is important in pollination, fruit formation, and absorption and use of calcium (Ca) by plants (SARAN; KUMAR, 2011). Additionally, the use of nutrients, such as B and Ca, associated with amino acids during the flowering of the crop, has favored the yield and retention of mango fruits (KHATTAB et al., 2016).

This study hypothesizes that the correct fertilization strategies with Ca, B, amino acids, and algae extract can reduce the formation of stenospermocarpic fruits and increase mango yield cultivated in the semiarid region of Brazil. This, the present study aimed to evaluate the potential loss of yield of mango cv. Palmer due to stenospermocarpy, its relationship with plant nutritional status and yield as a function of fertilization strategies.

Materials and methods

The experiment was carried out in commercial orchards of mango of the cultivar Palmer, located in the municipality of Petrolina, Pernambuco state, Brazil, with the geographic coordinates 9°23'39" S latitude and 40°30'35" W longitude, with a mean altitude of 380 m. The first experimental area corresponds to a mango orchard with flowering period in the second half of 2016 composed of 3-year-old plants, and the second area corresponds to a mango orchard with flowering period in the first half of 2017 composed of 5-year-old plants, both referring to the first season of production. The planting spacings used were 8.0 m x 3.0 m and 8.0 m x 5.0 m for the first and second experimental areas, respectively, being irrigated by a localized drip system.

According to Köppen's classification, the climate of the region is semiarid tropical, Bswh', with precipitation below 500 mm concentrated in three to four months of the year. During the initial two months of the experiment in each area, referring to the flowering period, the maximum temperature, minimum temperature, maximum relative humidity, and minimum relative humidity ranged from 31.3 ºC to 38.8 ºC, 20.4 ºC to 26.0 ºC, 55.8% to 89.0% and 10.3% to 39.8% in the first area, respectively, and from 29.2 ºC to 36.5 ºC, 20.5 ºC to 24.9 ºC, 62.9% to 93.0% and 17.3% to 52.8% in the second area, respectively, recorded in an automatic weather station installed on the Agrarian Sciences Campus of the Federal University of the São Francisco Valley (UNIVASF).

Soil chemical analyses were performed according to the methodology proposed by Teixeira et al. (2017). Physical analyses consisted of texture, determined by the pipette method, and bulk density (BD), by the volumetric ring method (CLAESSEN, 1997). The chemical and physical characteristics of the soil are presented in Table 1.

Table 1. Chemical and physical characteristics of the soil in the 0.0-0.2 and 0.2-0.4 m layers before setting up the experiment

Attributes	2nd half/2016		1st half/2017	
	0.0-0.2 m	0.2-0.4 m	0.0-0.2 m	0.2-0.4 m
pH (water)	6.46	5.72	7.62	7.32
ECse (dS m^{-1})	0.31	0.25	1.34	0.86
Ca^{2+} (cmol$_c$ dm^{-3})	2.28	1.77	3.33	1.98
Mg^{2+} (cmol$_c$ dm^{-3})	3.64	3.51	3.72	3.45
Al^{3+} (cmol$_c$ dm^{-3})	0.16	0.09	0.00	0.00
K^{+} (cmol$_c$ dm^{-3})	0.14	0.21	0.36	0.13
Na^{+} (cmol$_c$ dm^{-3})	0.04	0.04	1.01	0.53
P (mg dm^{-3})	75.20	46.06	162.19	53.36
B (mg dm^{-3})	0.29	0.32	0.54	0.42
H+Al (cmol$_c$ dm^{-3})	2.00	2.43	0.71	1.24
$CEC_{pH7.0}$ (cmol$_c$ dm^{-3})	8.10	7.96	9.13	7.33

(to be continued)

Table 1. Continuation

Attributes	2nd half/2016		1st half/2017	
	0.0-0.2 m	0.2-0.4 m	0.0-0.2 m	0.2-0.4 m
SB (cmol$_c$ dm^{-3})	6.10	5.53	8.42	6.09
V (%)	75.31	69.47	92.22	83.08
OM (dag kg^{-1})	0.66	0.67	2.38	1.14
Mn^{2+} (mg dm^{-3})	20.00	19.43	61.59	21.71
Zn^{2+} (mg dm^{-3})	34.82	4.79	37.52	8.13
Fe^{2+} (mg dm^{-3})	20.34	18.53	24.33	27.89
BD (g cm^{-3})	1.48	1.57	1.28	1.55
Sand (dag kg^{-1})	88.27	85.24	90.00	89.56
Silt (dag kg^{-1})	4.57	5.10	3.53	2.44
Clay (dag kg^{-1})	7.17	9.67	6.47	8.00

ECse: electrical conductivity of saturation extract; Ca^{2+}, Mg^{2+}, Al: 1 mol·L^{-1} KCl extractant; P, K^+, Na^+, Mn^{2+}, Zn^{2+}, Fe^{2+}: Mehlich-1 extractant; H+Al: potential acidity, 0.5 mol·L^{-1} calcium acetate extractant; CEC: cation exchange capacity; SB: sum of bases; V (%): base saturation; OM: organic matter; BD: bulk density.

For initial characterization of the nutritional status of the orchard (Table 2), leaf samples were collected before setting up the experiment (pre-flowering), in all quadrants of the plant, at a median height in the crown, in the penultimate segment of the branches (GENÚ; PINTO, 2002). Then, the chemical elements of the samples were extracted by the dry digestion method and nitrogen was determined by the Kjeldahl method in sulfuric mineralization extracts, following the recommendations of Teixeira et al. (2017).

Table 2. Leaf contents of macro and micronutrients in mango cv. Palmer before setting up the experiment and reference values[1/] for the mango crop. Petrolina, Pernambuco state

		2nd half/2016	1st half/2017	1/Quaggio (1996)
N	g kg^{-1}	4.62	4.06	12-14
P		0.78	0.75	0.8-1.6
Ca		24.96	18.49	20-35
Mg		1.98	2.58	2.5-5
K		3.60	2.85	5-10
B	mg kg^{-1}	56.71	55.03	50-100
Fe		36.31	28.48	50-200
Mn		197.90	222.31	50-100
Zn		13,99	12,43	20-40

The plants were subjected to the cultural practices recommended for mango crop under the regional conditions of cultivation, following the technical standards of Integrated Mango Production, defined by Lopes et al. (2003). Floral induction management in the orchards was carried out with a set of practices involving pruning, use of plant regulator (Paclobutrazol-PBZ), reduction of irrigation depth, maturation of the branch, and induction of bud break. Production fertilizations were carried out based on soil analysis and crop demand.

The experiment was set up in randomized blocks, with five treatments and four replicates with four plants each, and the usable area was composed of the two central plants. The treatments were: T1 = without fertilization (absolute control); T2 = foliar application of water-soluble Ca and B + L-α-amino acids; T3 = two fertigation events with 50 g per plant of H_3BO_3 + five sprays with H_3BO_3 [first two (0.3%) and others (0.2%)], as recommended by Barbosa et al. (2016); T4 = foliar application of water-soluble Ca and B + free amino acids + algae extract, and T5 = foliar application of water-soluble Ca and B + L amino acids glycine and betaine.

The commercial products used are classified as foliar fertilizers and have the following compositions: Kamab-26®= 10% Ca, 0.1% B, 2% Mg, 5% K, 10% N, 0.35% free amino acids; Energy = 8% Ca and 2% B; Alga + = 8% total organic carbon (TOC), 10% N, 1% Mn, 0.5% Zn, amino acids, algae extract, humic substances and lignosulfonate; Glibor-Ca = 8.6% Ca, 3% B, 12.1% MEA complexing agent; Sprintalga = 10% total N, 5% organic N, 1.2% nitric N, 1.3% ammoniacal N, 2.5% amidic N, 15% Mo and 1.8% TOC. The amounts of Ca and B applied per plant in the treatments were: T2 = 51.84 and 0.52 g; T3 = 0 and 114.92 g; T4 = 29.95 and 7.49 g; T5 = 34.67 and 12.1 g, respectively.

The fertilizations of treatments T2 to T5 were split into three applications, performed in pre-flowering, early flowering and full flowering. In T3, in addition to the aforementioned applications, two fertigation events [50 g per plant of H_3BO_3] and two additional foliar applications were performed, as recommended by Barbosa et al. (2016). The treatments were defined considering the demands and physiological changes that occur during flowering and retention (set) of mango fruits, according to Genú and Pinto (2002) and Ramírez and Davenport (2010).

After the occurrence of physiological fall, fruits that showed the stenospermocarpy physiological disorder were removed from the plants and counted to determine the number of fruits with disorder per plant. The physiological disorder is characterized by small fruits, without seeds and with differentiated shape (Figure 1).

Figure 1 External (**a**) and internal (**b**) aspects of mango fruits cv. 'Palmer' affected by the stenospermocarpy physiological disorder

In order to determine the nutritional status of the plants in the phase immediately after flowering, aiming at evaluating the effect of the applied treatments, leaf sampling was performed to determine the contents of B, K, P, Ca, Mg, Fe, Mn, Zn and N, following the recommendations of Teixeira et al. (2017).

Additionally, leaf contents of nutrients were used to calculate the Deviation from Optimum Percentage (DOP) proposed by Montanés et al. (1995), which allows evaluating the nutritional status of the plant as a percentage of the content of a given nutrient in the sample of interest relative to the standard (critical level). The DOP index is obtained through the following equation: DOP = [(C x 100)/Cref] – 100 , where C is the nutrient content in the leaf and Cref is the critical level established in the literature. The critical level used were: N (13 g kg^{-1}), P (1,2 g kg^{-1}), K (7,5 g kg^{-1}), Ca (27,5 g kg^{-1}), Mg (3,75 g kg^{-1}), B (75 mg kg^{-1}), Zn (30 mg kg^{-1}), Fe (125 mg kg^{-1}) and Mn (75 mg kg^{-1}) (GUAGGIO, 1996). The higher the absolute value of the index, the greater the severity of the deficiency (-) or excess (+).

To determine yield, harvest was carried out prioritizing the fruits at maturity stage II, usually used for export, characterized by yellow cream color in the pulp (PBMH, 2004). Harvest was carried out manually in March and August 2017, in the mango orchards of the second half (2016) and first half (2017), respectively, for quantification of: fruit mass (g); number of fruits per plant; yield, by multiplying fruit production per plant by the number of plants per hectare (Mg ha^{-1}); and percentage of fruits with physiological disorder as a function of the total number of fruits (number of fruits with physiological disorder per plant x 100/total number of fruits harvested).

The data obtained were subjected to analysis of variance to diagnose the significant effects between treatment means and, for the variables that showed statistical difference, Tukey test was applied at $p< 0.01$ and $p> 0.05$ probability levels. Additionally, a simple correlation analysis was performed between leaf contents of nutrients, percentage of stenospermocarpic fruits and yield. All analyses were performed in the ASSISTAT statistical program (SILVA; AZEVEDO, 2009).

Results and Discussion

There were effects of the treatments on the leaf contents of P, K and B in the mango orchard of the second half of 2016 and a significant difference ($p< 0.01$) between the treatments for the leaf contents of P, B and Fe in the mango orchard of the first half of 2017 (Table 3).

Table 3. Leaf contents of macro and micronutrients in mango cv. Palmer in different production periods (2nd half of 2016 and 1st half of 2017) as a function of fertilization strategies. Petrolina-PE

Source of Variation	N	P	K	Ca	Mg	B	Zn	Fe	Mn
	g kg^{-1}					mg kg^{-1}			
					2nd Half of 2016				
$F_{treatment}$	2.30 ns	15.67 **	8.95 **	1.38 ns	3.35 ns	14.89 **	0.52 ns	0.62 ns	0.48ns
T1	1.97	0.09 d	3.90 a	28.08	1.82	60.22 b	9.69	33.71	228.47
T2	2.81	0.10 cd	1.64 b	25.26	1.18	58.19 b	9.10	32.02	219.42
T3	2.80	0.12 bc	1.01 b	26.55	1.78	186.52 a	6.87	38.87	220.59
T4	2.90	0.15 a	1.98 b	23.17	1.36	55.03 b	9.73	47.51	201.10
T5	2.82	0.14 ab	5.45 a	22.73	2.01	63.16 b	9.48	50.14	243.73
LSD	1.15	0.03	1.91	8.68	0.85	66.66	7.52	28.97	100.25
CV (%)	19.16	11.45	30.26	15.29	23.12	34.93	37.17	33.63	19.97

(to be continued)

Table 3. Continuation

Source of Variation	N	P	K	Ca	Mg	B	Zn	Fe	Mn
	------------------------ g kg^{-1} ------------------------------					-------------------- mg kg^{-1} --------------------			
1st Half of 2017									
$F_{treatment}$	0.22^{ns}	0.01 **	0.20^{ns}	0.16^{ns}	0.06^{ns}	0.002**	0.05^{ns}	0.004**	0.73^{ns}
T1	2.50	0.17 b	8.17	11.27	2.07	49.38 b	17.06	49.58 a	249.68
T2	2.42	0.22 ab	9.87	9.62	1.59	42.84 b	14.26	30.06 b	223.66
T3	2.69	0.25 ab	8.87	7.74	1.53	228.96 a	10.53	30.85 b	237.46
T4	2.83	0.28 a	5.54	6.82	1.22	44.89 b	15.64	17.51 b	239.46
T5	2.41	0.30 a	4.71	7.94	1.49	49.84 b	8.68	22.45 b	192.00
LSD	0.65	0.09	7.15	5.64	0.80	37.41	8.78	15.93	140.85
CV (%)	11.23	16.23	40.73	28.85	22.48	19.95	29.43	23.49	27.35

^{ns}: not significant; * and **: significant at p< 0.05 and p <0.01 probability levels, respectively. T1 = without fertilization; T2 = foliar application of water-soluble calcium and boron + L-α-amino acids; T3 = two fertilizations with 50 g per plant of H_3BO_3 + five sprays with H_3BO_3 [first two (0.3%) and others (0.2%)]; T4 = foliar application of water-soluble calcium and boron + free amino acids + algae extract; T5 = foliar application of water-soluble calcium and boron + L amino acids glycine and betaine. Means followed by the same letter in the column do not differ from each other by Tukey test at p > 0.05 and p > 0.01 probability levels.

Leaf P content was significantly influenced by the treatments in the two mango areas evaluated, and the highest values were obtained with foliar application of water-soluble calcium and boron + free amino acids + algae extract (T4) and foliar application of water-soluble calcium and boron + L amino acids glycine and betaine (T5), when compared to T1 (absolute control) (Table 3). In the mango area of the second half of 2016, treatments 4 and 5 led to 67 and 56% higher leaf P contents, respectively, compared to the control (T1). In the mango area of the first half of 2017, treatments 4 and 5 resulted in 64.7 and 76.5% higher leaf P contents, respectively, compared to the control (T1). The leaf P contents of the present study (0.09 to 0.30 g kg^{-1}) are below the range considered adequate for mango crop (0.8 to 1.6 g kg^{-1}) (QUAGGIO, 1996).

The use of amino acids associated with fertilizers exerts an effect of chelation with mineral nutrients, forming organic chelates, optimizing their absorption and transport to the interior of the plant (TAIZ et al., 2017). In addition, Lobo et al. (2019) evaluated the effect of biostimulants on the nutritional status and fruit production of 'Kent' mango in the Brazilian semiarid region and verified that algae extract favors nutritional status and increases plant production.

The foliar application of water-soluble Ca and B + L amino acids glycine and betaine (T5) resulted in the highest leaf K content compared to treatments T2, T3 and T4 in the second half of 2016, with a 439.6% superiority in comparison to plants fertilized with boric acid (T3) (Table 3). The leaf K contents for all treatments, except T5, are below that considered adequate for mango crop (5 to 10 g kg^{-1}) (QUAGGIO, 1996) in the orchard of the second half of 2016. For the first half of 2017, the leaf K content in the T5 treatment was below that considered adequate for mango crop. Carneiro et al. (2017), in a study conducted in the Sub-middle São Francisco Valley with the mango cv. Tommy Atkins, observed adequate leaf K contents, of 6.97 and 7.10 g kg^{-1}, with application of different K sources, namely potassium chloride and potassium sulfate, respectively. According to Gupta et al. (2016), K together with B plays an important role in increasing physiological activities in mango, besides being important for the functioning of the cell membrane and transport of assimilates and nutrients.

For the leaf B content, average increments of 215 and 390% were observed in the mango orchards of the second half of 2016 and first half of 2017, respectively, under fertilization with boric acid (T3) compared to the other treatments, which did not differ from one another (Table 3). This is due to the greater utilization of the nutrient by the mango tree, in addition to the greater supply of this nutrient in the treatment with boric acid (T3). Except for the T3 treatment, which was above the adequate level, the leaf B contents in the other treatments were within the range considered adequate for the mango crop (50 to 100 mg kg^{-1}) in the second half of 2016 and below the adequate level in the first half of 2017 (QUAGGIO, 1996).

It is worth pointing that, although the leaf B content in T3 was above the limit considered adequate for mango crop, no symptoms of B toxicity were observed in the plants. A similar result was found by Barbosa et al. (2016), who found high leaf B contents with boric acid management in mango plants and no symptoms of toxicity. This is possibly due to the lack of reference tables developed in regions with edaphoclimatic characteristics, crop management and expected yield similar to those found in the São Francisco Valley.

The Zn and Fe contents in the mango orchards for the second half of 2016 and first half of 2017 were generally below the range considered adequate for mango (20 to 40 and 50 to 200 mg kg^{-1}, respectively), while Mn contents were above the adequate level (50 to 100 mg kg^{-1}) (QUAGGIO, 1996) (Table 3). Although micronutrients are required in smaller amounts by plants, their effects are as important as those of macronutrients. Thus, their deficiency or excess may affect the nutritional balance of the plant (TAIZ et al., 2017).

Based on the values of the Deviation from Optimum Percentage (DOP) index, which consists of evaluating the content of each nutrient relative to the optimum value (median of the sufficiency range) (SILVA et al., 2012), it was possible to diagnose imbalance of the nutrients evaluated compared to their critical level, and in the descending order of limitation due to deficiency, the following nutrients stand out: P (-90.00), N (-79.54) and Zn (-70.09) in the orchard of the second half of 2016 and N (-80.23), P (-79.67) and Fe (-75.93) in the orchard of the first half of 2017 (Table 4).

Table 4. Deviation from the Optimum Percentage (DOP) of leaf nutrient contents of mango cv. Palmer as a function of fertilization strategies. Petrolina-PE

Source of Variation	DOP_N	DOP_P	DOP_K	DOP_{Ca}	DOP_{Mg}	DOP_B	DOP_{Zn}	DOP_{Fe}	DOP_{Mn}
	2nd Half of 2016								
T1	-84.85	-92.50	-48.00	2.11	-51.47	-19.71	-67.70	-73.03	204.63
T2	-78.38	-91.67	-78.13	-8.15	-68.53	-22.41	-69.67	-74.38	192.56
T3	-78.46	-90.00	-86.53	-3.45	-52.53	148.69	-77.10	-68.90	194.12
T4	-77.69	-87.50	-73.60	-15.75	-63.73	-26.63	-67.57	-61.99	168.13
T5	-78.31	-88.33	-35.47	-17.35	-46.40	-15.79	-68.40	-59.89	224.97
Mean	-79.54	-90.00	-64.35	-8.52	-56.53	12.83	-70.09	-67.64	196.88
	1st Half of 2017								
T1	-80.77	-85.83	8.93	-59.02	-44.80	-34.16	-43.13	-60.34	232.91
T2	-81.38	-81.67	31.60	-65.02	-57.60	-42.88	-52.47	-75.95	198.21
T3	-79.31	-79.17	18.27	-71.85	-59.20	205.28	-64.90	-75.32	216.61
T4	-78.23	-76.67	-26.13	-75.20	-67.47	-40.15	-47.87	-85.99	219.28
T5	-81.46	-75.00	-37.20	-71.13	-60.27	-33.55	-71.07	-82.04	156.00
Mean	-80.23	-79.67	-0.91	-68.44	-57.87	10.91	-55.89	-75.93	204.60

T1 = without fertilization; T2 = foliar application of water-soluble calcium and boron + L-α-amino acids; T3 = two fertilizations with 50 g per plant of H_3BO_3 + five sprays with H_3BO_3 [first two (0.3%) and others (0.2%)]; T4 = foliar application of water-soluble calcium and boron + free amino acids + algae extract; T5 = foliar application of water-soluble calcium and boron + L amino acids glycine and betaine.

The number of stenospermocarpic fruits was not influenced by the treatments in the second half of 2016 and first half of 2017 (Figure 2a). However, the mango orchard of the second half of 2016 had, on average, 103.2 stenospermocarpic fruits per plant, which corresponds to an average loss of 87.3% of fruits per plant. Thus, there was an estimated reduction in yield of 28.81 Mg ha^{-1}, considering the average fruit mass of 670 g (average fruit mass obtained from the fruits at harvest). In the first half of 2017, there was a lower number of stenospermocarpic fruits per plant, an average of 3.8 fruits per plant, corresponding to 7% fruit loss per plant. Thus, a significant effect of stenospermocarpy on mango yield is noted, when considering the national average yield (16 Mg ha^{-1}) and the average yield of the Sub-middle São Francisco Valley (20 Mg ha^{-1}) (IBGE 2016).

Possibly, the higher temperatures and lower relative humidity, reaching 38.8 °C and 10.3%, respectively, contributed to the high

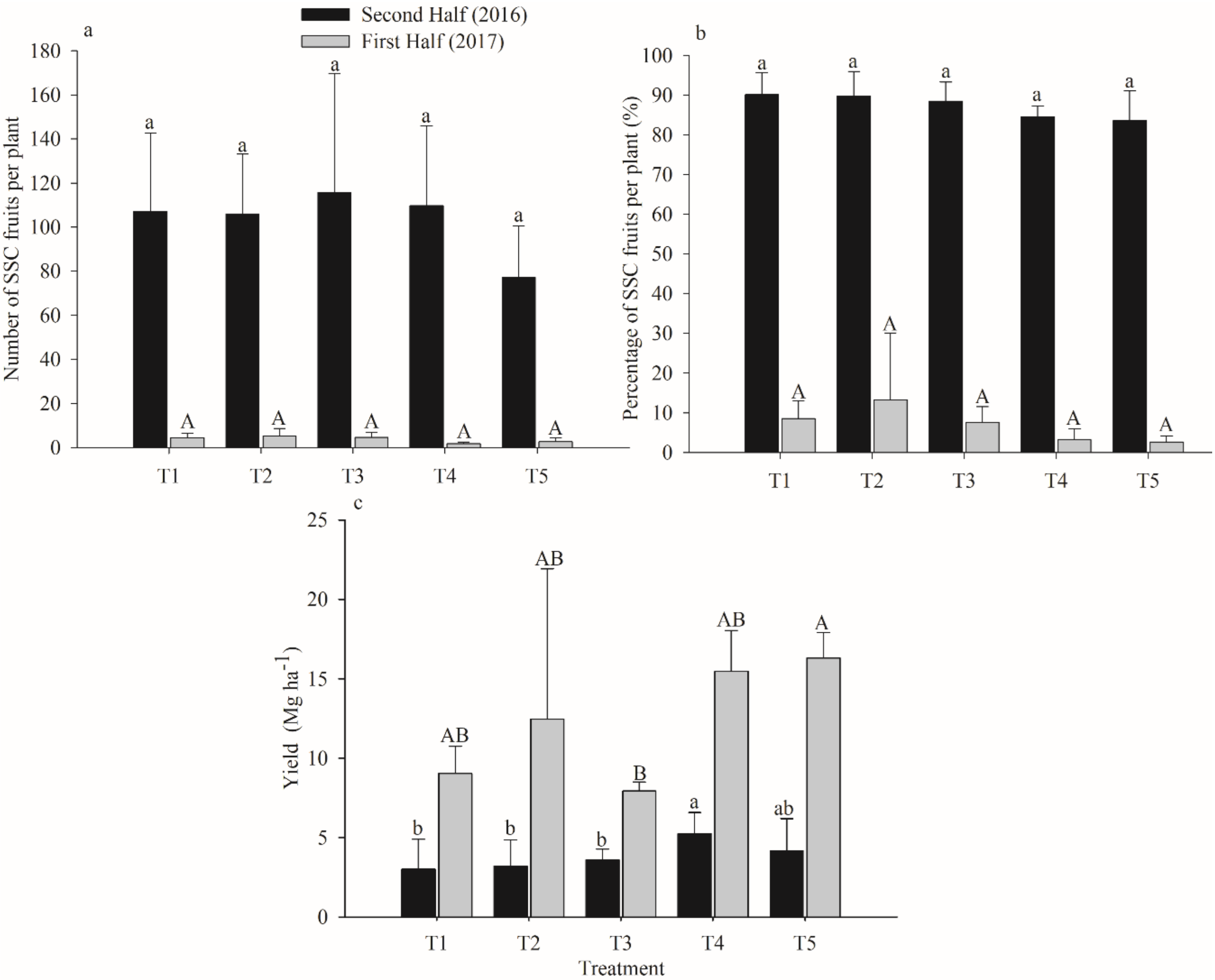

Figure 2 Number of stenospermocarpic (SSC) fruits per plant [1st and 2nd half: CV= 31.22 and 58.39%; LSD= 72.62 and 4.95, respectively] (**a**) percentage of SSC fruits per plant [1st and 2nd half: CV= 6.77 and 107%; LSD= 13.37 and 16.95, respectively] (**b**), and yield [1st and 2nd half: CV= 23.34 and 36.63%; LSD= 1.76 and 8.63, respectively] (**c**) of the mango cv. Palmer in the second half of 2016 and first half of 2017 as a function of fertilization strategies.

T1 = without fertilization; T2 = foliar application of water-soluble calcium and boron + L-α-amino acids; T3 = two fertilizations with 50 g per plant of H_3BO_3 + five sprays with H_3BO_3 [first two (0.3%) and others (0.2%)]; T4 = foliar application of water-soluble calcium and boron + free amino acids + algae extract; T5 = foliar application of water-soluble calcium and boron + L amino acids glycine and betaine. Bars with the same letter do not differ from each other by Tukey test (p < 0.01), for the same period. The bars represent the average standard deviation.

occurrence of stenospermocarpic fruits in plants that had their flowering period in the second half of 2016. On the other hand, for plants that had their flowering period in the first half of 2017, which showed the lowest number of fruits affected by stenospermocarpy, the maximum temperature and minimum relative humidity recorded were 36.5 °C and 17.3%, respectively.

When the flowering period and initial development of fruits of 'Palmer' mango coincide with times of higher temperatures, the consequence has frequently been the development of stenospermocarpic fruits (SANTIAGO et al., 2020). This phenomenon is characterized by the formation of seedless fruits due to seed degeneration or embryonic abortion after ovule fertilization (REVERS et al., 2006). According to Huang et al. (2010), ovule fertilization is dependent on pollen grain germination and pollen tube development, so low pollen grain germination rates can affect the normal development of the fruit due to degradation of the ovule before the pollen tube reaches the ovary.

Sukhvibul et al. (2000) observed that the ideal temperature range for pollen germination and in vitro pollen tube growth of four mango cultivars (Kensington, Nam Dok Mai, Irwin and Sensation) in Australia ranged from 15 to 25 °C and from 20 and 25 °C, respectively. They also observed that high temperature (30 °C) reduced pollen grain germination and pollen tube growth in all cultivars. Moreover, the duration of exposure to a limit temperature seemed to have more influence than the exposure to a constant temperature. In this context, Ayerza and Coates (2004) report that the olive crop, cv. Manzanillo, when cultivated under hot conditions, has low production due to the occurrence of seedless fruits, which may be associated with slow pollen development, resulting in little or no fertilization.

For mango, the optimum temperature is around 24-27 °C (DAVENPORT, 2009), but the crop can withstand higher temperatures. However, its growth ceases with a temperature equal to or greater than 42 ºC, and the phase of anthesis (floral opening), pollination and fertilization is the most critical period, with high sensitivity to stressful weather conditions, such as rain, humidity, temperature, light, wind and water supply (STHAPIT et al., 2012). These authors state that such conditions can reduce pollination, pollen grain germination, pollen tube growth and cause embryonic abortion, resulting in physiological disorders such as stenospermocarpy.

The percentage of stenospermocarpic fruits per plant also did not differ between the treatments applied in the two mango areas evaluated (Figure 2b). In the second half of 2016, the percentage of stenospermocarpic fruits per plant ranged from 83.5 to 90.1%, being much higher than the values observed in the first half of 2017, which ranged from 2.6 to 13.2%. Lobo and Sidhu (2017) also mention other physiological disorders in mango that are related to low yield and economic losses of orchards such as black tip, fruit fall, mango malformation, lenticel discoloration, and 'soft nose'. Generally, these physiological disorders can reach about 50% of the fruits and, when they do not make them unmarketable, they reduce their quality, negatively affecting the export growth of the fruit, since there is a demand for quality fruits by the importing market (SHIVASHANKAR, 2014).

The treatments caused effect on mango yield in the two periods evaluated; in the second half of 2016, the foliar application of water-soluble calcium and boron + free amino acids + algae extract (T4) promoted higher yield (5.25 Mg ha^{-1}), not differing from the foliar application of water-soluble calcium and boron + L amino acids glycine and betaine (T5) and from the management with boric acid (T3), with averages of 4.16 Mg·ha-1 and 3.59 Mg·ha-1, respectively (Figure 2c), whereas in the first half of 2017, the T5 promoted higher yield (16.30 Mg ha^{-1}), not differing from the other treatments, except T3, which led to lower yield (7.93 Mg ha^{-1}). Thus, fertilization with micronutrients associated with algae extracts and amino acids contributed to increasing mango yield. According to Fernandes and Silva (2011), the use of algae extracts promotes greater resistance to stress in plants and favors their growth and fruiting, mainly due to the considerable concentrations of auxins, gibberellins and cytokinins. Additionally, foliar fertilization with amino acid-based products can be a good alternative to increase production, since it optimizes the use and absorption of nutrients by plants (MARQUES et al., 2016).

Although there was a difference in mango yield as a function of the treatments applied, the average values obtained in the second half of 2016 (3.01 to 5.25 Mg ha^{-1}) and first half of 2017 (7.93 to 16.30 Mg ha^{-1}) were below the average of the São Francisco Valley region (20 Mg ha^{-1}). In the second half of 2016, the low yield of mango was mainly due to the occurrence of the high number of stenospermocarpic fruits (Figure 2a). In addition, the spacings used of 8 x 5 m in the area of the second half of 2016 and 8 x 3 m in the area of the first half of 2017 result in low plant densities (250 plants ha^{-1} and 416.66 plants ha^{-1}, respectively), which possibly limited the production potential of mango. Corroborating these results, in a study conducted in India, Rajbhar et al. (2016) found yield 10 times higher in orchard with high density (1111 plants ha^{-1}) compared to that with low planting density (100 plants ha^{-1}).

Barbosa et al. (2016) reported the phenomenon of stenospermocarpy in fruits of mango cv. Palmer in a study conducted in the Submiddle São Francisco Valley region, Brazil. In their results, they observed that plants cultivated with the fertilization used by the producer [fertigation with 50 g per plant of H_3BO_3 (control treatment)] had on average 239 mangoes per plant affected by stenospermocarpy. For the other treatments of management with H_3BO_3 (fertigation and foliar fertilization), the average number of stenospermocarpic fruits per plant decreased to approximately seven. In the above-mentioned study, a comparison of yield between the treatments showed that the treatment with the highest number of stenospermocarpic fruits (239 mangoes per plant) had the lowest yield (15.6 Mg ha^{-1}), about 133% lower than the highest yield obtained (35.62 Mg ha^{-1}).

Considering the high occurrence of fruits affected by stenospermocarpy in the second half of 2016, a simple correlation analysis was applied between leaf contents of macro and micronutrients, percentage of stenospermocarpic fruits, and yield. The simple correlation analysis showed that the percentage of stenospermocarpic fruits was negatively correlated with the leaf contents of P (-0.45), Zn (-0.49), and Fe (-0.56) and with crop yield (-0.64). However, there was no correlation between the percentage of stenospermocarpic fruits and leaf B content in the present study, diverging from the results found by Barbosa et al. (2016), who attributed the production of fruits affected by the physiological disorder (stenospermocarpy) in the mango cv. Palmer in the São Francisco Valley to the deficiency of this nutrient.

Possibly, the divergence between these results is associated with the edaphoclimatic conditions and management adopted, which are important factors for the good development of plants. Considering the appropriate balance of saturation of Ca (50 to 65%), Mg (10 to 20%) and K (3 to 5%) of CEC at pH 7.0 (ALBRECHT; SMITH, 1941), it was observed that the soil base saturation indices of the experimental areas in the present study, before setting up the experiment, were outside the range considered adequate for the mango crop, ranging from 22.0 to 36.5%, 40.1 to 47%, and 1.7 to 4% for Ca, Mg and K, respectively. Conversely, Barbosa et al. (2016) observed that the saturation indices of Ca, Mg and K were 63, 17.5 and 4.7%, respectively, being within the limits considered adequate for the mango crop.

The low leaf contents of P, Zn and Fe may also have contributed to the occurrence of stenospermocarpy. Although B was not correlated with the percentage of stenospermocarpic fruits in the present study, it has a synergistic interaction with P and Zn, which may indicate an indirect influence on the results.

Sinha et al. (2003), in a study conducted with mustard in India, observed synergistic interaction between the nutrients P and B, concluding that the low P content in the plant can interfere with B metabolism, accentuating the effects of deficiency of this nutrient, which can possibly compromise flowering and contribute to the development of stenospermocarpy.

In a study conducted with cotton in the municipality of Aquidauana-MS, Araújo and Silva (2012) found a synergistic relationship between B and Zn, noting that the content and quantity of B in the plant, as well as its transport efficiency and use occurred as a function of the supply and contents of Zn, and the transport efficiency of Zn was influenced by the concentration of B. Thus, it is also believed that the low leaf Zn content in the present study may have inhibited the potential effects of B on the control of stenospermocarpy. According to Politi et al. (2013), Fe is among the micronutrients that are generally deficient in mango orchards in the semiarid region of the northeast, and its deficiency can cause nutritional imbalance and affect the production potential and quality of fruits, given its importance in the constitution of enzymes and participation in the photosynthetic process.

For mango yield, a negative correlation was observed only with the percentage of stenospermocarpic fruits, highlighting the importance of this physiological disorder for the mango cv. Palmer and the significant impact it can have on the final yield of mango orchards in the São Francisco Valley region, Brazil.

Conclusions

There is evidence that low leaf phosphorus, iron and zinc contents contributed to the development of stenospermocarpic fruits , associated with the conditions of high temperature and low relative humidity in the flowering period of the crop;

Foliar fertilization with water-soluble calcium and boron + free amino acids + algae extract (Treatment 4) and foliar application of water-soluble calcium and boron + L amino acids glycine and betaine (Treatment 5) increase the yield of mango cv. Palmer in the two periods of production.

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