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Flowering and production of Palmer mango trees under organic compound and paclobutrazol application

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Abstract

The objective of this work was to evaluate the effects of applications of humified organic compound rates combined with paclobutrazol (PBZ) rates on the flowering, production, and fruit quality of Palmer mango trees grown in two production seasons (Seasons 1 and 2). Two experiments were conducted in different production seasons and areas in Matias Cardoso, MG, Brazil. A randomized block experimental design with four replications was used, in a 4×2+1 factorial arrangement, consisted of 4 humidified organic compound rates (10, 15, 20, and 25 mL plant^{-1}), 2 PBZ rates (0.7 and 0.85 g per meter of canopy diameter), and a control (application of PBZ at 0.85 g per meter of canopy diameter). Vegetative, physiological, reproductive, production, and post-harvest fruit quality characteristics were evaluated. The data were subjected to analysis of variance and regression or mean tests. The treatments had significant effects on some characteristics in Season 1. Plants treated with the organic compound combined with PBZ had higher chlorophyll contents than those in the control. The increase in the organic compound rate linearly increased the total number of flowers and number of male flowers per axillary panicle, but decreased soluble solids content. The application of the lowest PBZ rate resulted in higher soluble solids content and titratable acidity in mango fruits. The treatments did not affect the evaluated characteristics in Season 2. The application of humidified organic compound combined with paclobutrazol showed no benefits for the management of floral induction in Palmer mango trees.
Keywords: floral induction, humic substances, *Mangifera denotes* L., plant growth regulator, soluble solids content

Introduction

The use of plant growth regulators is one of the main strategies for floral induction in mango trees throughout the year, which promotes staged production, mainly in semiarid regions. Paclobutrazol (PBZ) is the most used plant growth regulator, inhibiting gibberellin biosynthesis and halting vegetative growth. Studies have reported that PBZ application to soils in mango orchards reduces branch growth and induces flowering, which denotes its effectiveness in reducing or regulating vegetative growth (Oliveira et al., 2015; Garcia de Niz et al., 2014).

However, one of the main challenges of using PBZ is its low mobility in the soil, which prevents its complete absorption by plants. Moreover, its continuous use, mainly at high rates, may lead to soil contamination, as well as contamination of surface and underground water sources (Souza et al., 2017).

The use of humic substances, such as fulvic and humic acids, ensures a higher absorption efficiency by enhancing transport to the roots, mainly due to their ability to complex ions and molecules (Chen et al., 2004). Humic substances induce H+-ATPase activity, providing energy to secondary ion transporters, promoting nutrient absorption, and activating ion metabolism and the transport of different substances (Canellas et al., 2015). They also stimulate protein synthesis, photosynthesis, enzymatic activity, solubilization of macro and micronutrients, and microbial activity, and promote similar effects to those of auxins (Seyed Bagheri, 2010).

The complexing effect between humic substances and PBZ is due to the hydrophobic and hydrophilic interactions that occur between them, increasing the adsorption of the PBZ molecule (Milfont et al., 2008). Thus, a greater amount of PBZ remains available to the plant for a longer time, as it is translocated together with humic

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substances, especially fulvic acids, which have lower molecular weights and, therefore, move more easily in the soil close to root zones (Nardi et al., 2007).

Thus, the search for organic molecules that can enhance the transport of PBZ to plant root systems is necessary to obtain better responses of mango production characteristics. The application of lower PBZ rates, combined with application of humic substances, is an alternative for mitigating negative impacts on plants and reducing residues that remain in the soil, decreasing risks to the environment.

In this context, the objective of this work was to evaluate the effects of applications of humified organic compound rates combined with paclobutrazol (PBZ) rates on the flowering, production, and fruit quality of Palmer mango trees grown in two production seasons

Material and Methods

The experiments were conducted in two commercial mango (cultivar Palmer) orchards in the area C2 of the Irrigated Perimeter of the Jaíba Project, in Matias Cardoso, MG, Brazil. The first experiment was conducted from July 2018 to April 2019 (Season 1) on the Rio Doce farm (15°06'30.3"S and 43°51'30.9"W), where the mango orchard was implemented in July 2014, with spacing of 4.4 × 2 m (1,136 plants ha^{-1}). The second experiment (Season 2) was conducted from October 2018 to July 2019 (Season 2) on the Rio Novo farm (15°06'17.6"S and 43°48'59.8"W), where the orchard was implemented in July 2011, with spacing of 6.6 × 4 m (378 plants ha^{-1}). The distance between the two rural properties is 8 km.

The soils of the orchards were classified as Quartzipsamments (Neossolos Quartzarenicos; Santos et al., 2018) of sandy texture. The physical and chemical attributes of the soils of the orchards are shown in **Table 1**. The plants were at the vegetative development stage at the time of implementation of both experiments. Both areas had been subjected to paclobutrazol (PBZ) application in previous years. The cultural practices used in the areas are described in **Table 2**

. Cultural practices (soil preparation, fertilization, irrigation, and pest and disease control) were the same in both areas, except fertilizer application for branch maturation in Season 1, which were more frequent because harvest in Season 1 is carried out in the first half of the year, when there is more intense rainfall. The number of fertilizer applications is lower in orchards with harvests in the second half of the year, when there is less rainfall, as in the case of the experiment in Season 2.

The first experiment (Season 1) was implemented in July, characterized by lower temperatures and no rainfall, whereas the second experiment (Season 2) was implemented in October, characterized by higher temperatures and the beginning of the rainy season (**Figure 1**).

The two areas had plants at the vegetative development stage at the time of the experiment implementation. The same management practices were used for floral induction in both areas, as described by Lima et al. (2016), with adaptations (Table 2). The experiments were conducted in a randomized complete block design with four replications, in a 4×2+1 factorial arrangement consisted of applications of four humified organic compound rates (10, 15, 20, and 25 mL plant^{-1}), two paclobutrazol (PBZ) rates (0.7 and 0.85 g per meter of canopy diameter), and a control (application of PBZ at 0.85 g per meter of canopy diameter, which is the commonly used rate by Palmer mango growers).

The humified organic compound rates were determined based on the manufacturer's technical recommendation and rates commonly used in field when applying other sources of liquid organic matter. The recommended rate is 20 mL plant^{-1}; therefore, two lower rates and one higher rate were also tested in the experiments.

The recommended PBZ rate for mango orchards

Table 1. Physical and chemical attributes of soils in the Rio Doce and Rio Novo farms, Matias Cardoso, MG, Brazil.

	Layer(cm)	pH[1]	pH[2]	OM[3]	OC[4]	P	K	S	P	K	S	H+Al	CEC[5]
				dag kg^{-1}	%	—— mg dm^{-3} —			—— cmol$_c$ dm^{-3} ——				
P4-Rio Doce	0-20	6.1	5.4	1.2	0.7	54.2	193.4	2	0.8	0.5	<0.1	1.4	3.2
P4-Rio Doce	0-40	5.7	4.8	1.0	0.6	24.8	134.6	5	0.9	0.4	0.3	1.4	3
P5-Rio Novo	0-20	6.4	5.6	0.6	0.3	171.3	290	7	2.2	0.9	<0.1	1.3	5.1
P5-Rio Novo	0-40	6.5	4.4	0.3	0.2	15.6	210	11.5	0.9	0.4	0.5	2.6	4.4
		BS[6]	AS[7]	Ca/Mg	Ca/K	Mg/K	B	Zn	Fe	Mn	Cu		
		——— % ——				——— mg dm^{-3}———							
P4-Rio Doce	0-20	56	0	1.6	1.6	1	0.4	1	45.4	22.6	0.2		
P4-Rio Doce	0-40	54	15	2.3	2.6	1.2	0.6	0.3	46	10.9	<0.1		
P5-Rio Novo	0-20	75	0	2.4	3	1.2	2.7	26.6	50.5	80.2	2.6		
P5-Rio Novo	0-40	41	21	2.3	1.7	0.7	2.1	1.6	26.9	36.4	1		

P4 = Parcel 4; P5 = Parcel 5; 1 = pH in water; 2 = pH in calcium chloride; 3 = organic matter; 4 = organic carbon 5 = cation exchange capacity at pH 7.0; 6 = base saturation; 7 = aluminum saturation;

Table 2. Cultural practices carried out in mango orchards in two rural properties (Rio Doce Farm and Rio Novo Farm) in Matias Cardoso, MG, Brazil

Practices	Management
Post-harvest pruning	Removal of part of the vegetative and reproductive branches of the plants for an appropriate production.
Application of paclobutrazol (PBZ)	PBZ was applied to the soil 45 to 60 days after pruning, when at least two vegetative flushing had occurred. PBZ inhibits gibberellin biosynthesis, reduces vegetative growth, and promotes floral induction.
Gradual reduction of the irrigation water depth	Normal irrigation was maintained up to 30 days after PBZ application. The irrigation depth was then gradually reduced to 75% between 30 and 50 days, to 50% between 50 and 60 days, and stopped for 15 days. Subsequently, the dormancy breaking process started (at 90 days) with nitrate application, when 70% of the plants showed panicle emission with approximately 5 to 7 cm, the application of normal irrigation depths was then resumed.
Foliar application of potassium, sulfur, and ethephon	Approximately 5 weekly foliar applications of potassium sulfate, sulfur, and a low ethephon (Ethrel®) rate were carried out to promote branch maturation, starting 45 days after PBZ application.
Topping and calcium nitrate applications	Topping (pruning for uniform maturation of branches for flowering) was performed 90 days after PBZ application. Application of calcium nitrate at a concentration of 2% started two days after topping, with four weekly applications for dormancy breaking and floral induction.

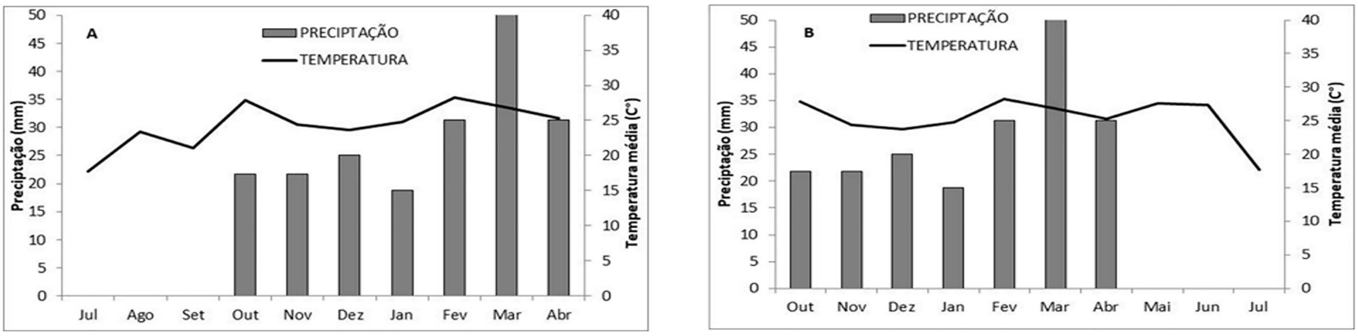

Figure 1. Monthly mean air temperature and rainfall from July 18, 2018 to April 17, 2019 (Season 1) (A) and from October 22, 2018 to July 19, 2019 (Season 2) (B) recorded by weather stations at the Rio Doce (A) and Rio Novo (B) farms, Matias Cardoso, MG, Brazil.

is generally 1 g per meter of canopy diameter. Lower PBZ rates were tested in the experiments to assess whether the results of the analyzed variables would be favorable, contributing to a reduction in the PBZ application rate and, consequently, decreasing impacts on plants and soil contamination. The canopy diameter was measured for each plant just before PBZ application to determine the quantity to be applied per plant; the diameters ranged from 1.5 to 2.0 m.

Each experimental plot consisted of three plants; the middle one was considered the useful plant. A solution containing both evaluated products, totaling approximately 1 to 2 L plant^{-1} depending on the canopy diameter, was applied to the soil near the base of the plant. The PBZ source used was Cultar® 250 SC. The source of humified organic compound used (Fulvumin®) consisted of water, lignosulfonate, soybean meal, leonhardite, peat, and sodium hydroxide.

After the applications, eight branches (two per quadrant) were randomly marked on each useful plant for subsequent evaluations of vegetative, physiological, reproductive, production, and post-harvest fruit quality characteristics.

Evaluations were carried out 90 days after the treatment applications. Branch length was determined by measuring the last vegetative flush with a tape measure; branch diameter was measured in the middle region with a caliper; leaf relative chlorophyll content (SPAD index) was measured using a chlorophyll meter (SPAD-502, Minolta, Japan).

The number of axillary panicles per branch was counted, and the length of the longest panicle on the branch was measured using a tape measure. Number of flowers was evaluated only in the first experiment (Season 1) by selecting the most vigorous axillary panicle of each branch, counting the numbers of hermaphrodite and male flowers, and calculating the total number of flowers and the percentage of hermaphrodite and male flowers. The number of fruits per branch was counted.

The fruits were harvested at the physiological maturity stage, which was determined based on the pulp color (intense yellow). The fruits were weighed on a mechanical scale in the field to obtain the production per plant. Fruit yield was determined based on the planting density of each orchard, multiplying the total weight of fruits from each plant by the number of plants per hectare.

Post-harvest fruit quality was analyzed in the

Fruit Production Laboratory and Post-harvest Laboratory of the State University of Montes Claros (Unimontes), in Janaúba, MG, Brazil. Four harvested fruits were randomly selected per experimental plot. Each fruit was weighed on a digital scale. Fruit length was measured from the base of the peduncle to the fruit tip, and fruit diameter was measured in the middle region of the fruit, using a digital caliper.

Fruit peel color was determined using a colorimeter [Color Flex 45/0 (2200), stdz Mode:45/0] with direct reflectance reading of the L* (lightness), a* (green to red hue), and b* (blue to yellow hue) coordinates of the Hunterlab Universal Software system. L* was obtained directly; the values of a* and b* were used to calculate the hue angle (°h*) and chroma saturation index (C*).

Pulp firmness was measured in the median region of the fruit, using a texture-meter (Brookfield model CT3 10 KG) and determined by the penetration force (Newton, N) needed for a 4-mm-diameter probe to penetrate 10 mm into the fruit.

Soluble solids content was determined in a pulp sample crushed in a mixer, using a digital refractometer (HANNA HI 9680) with a reading range of 0 to 85 °Brix. Pulp pH was determined using a digital pH meter (mPA210). Titratable acidity was determined using 10 g of pulp diluted in 90 mL of distilled water, which was titrated with standardized NaOH solution at 0.1 N, using phenolphthalein (2 drops per sample) as indicator; the result was expressed in mg of citric acid 100 mL^{-1} of juice.

The data obtained were subjected to analysis of variance at a 5% probability of error. Significant means were subjected to regression analysis (effect of humidified organic compound rates) and the F-test (effect of PBZ rates). All statistical analyses were carried out using the software Genes.

Results and Discussion

The treatments (combined application of humified organic compound and paclobutrazol rates) presented significant effects on the relative chlorophyll content (SPAD index) in Palmer mango trees in Season 1, when compared to the control. The humified organic compound rates had significant effects on total number of flowers, number of male flowers, and pulp soluble solids content. Paclobutrazol (PBZ) rates had significant effects on titratable acidity and pulp soluble solids content. The other characteristics evaluated in Season 1 and all characteristics evaluated in Season 2 were not affected by the factors or their interaction.

Season 1 (July 2018 to April 2019)

The overall mean of relative chlorophyll content in all treatments with humified organic compound rates combined with PBZ rates was 44.67, significantly higher than that found for the control (32.99), indicating a change in the leaf assimilation surface. The humic substances in the organic compound may have significantly affected chlorophyll biosynthesis, as found in a study evaluating Zebda mango trees (El-Hoseiny et al., 2020). This effect is attributed to humic acids, which can generate bioactive subunits that alter cellular metabolism and activate secondary transporters responsible for increasing absorption of macro and micronutrients, resulting in effects on plant physiological processes, such as increases in photosynthetic pigments (Baldotto & Baldotto, 2014).

The organic compound used may have been determinant for the increased chlorophyll content, although the effect of PBZ on chlorophyll biosynthesis has been found in Bangalora mango trees (Subbaiah et al., 2018). Chlorophyll content increases due to a higher chloroplast density in leaves as a response to decreases in leaf area and increases in leaf thickness (Chaney, 2005).

The other vegetative characteristics (branch length and diameter) were not significantly affected by the treatments, presenting means of 10.91 cm and 10.28 mm, respectively. Higher values were found for these characteristics in Haden and Tommy Atkins mango cultivars (Silva et al., 2014). Vegetative growth is an inherent factor in the cultivar; Palmer mango trees are characterized by moderate vigor and low vegetative capacity compared to other cultivars, demanding lower PBZ rates for the floral induction process (Oliveira et al., 2015).

The total number of flowers per axillary panicle presented significant linear increases as the humidified organic compound rate was increased, reaching the maximum estimate of 452 flowers at the rate of 25 mL $plant^{-1}$ (**Figure 2**A). The same effect was found for the number of male flowers per axillary panicle, with a maximum estimate of 373 flowers (Figure 2B). Ngullie et al. (2014) evaluated Kesar mango trees and found increases in male flowers per panicle directly proportional to the increase in humic acid rate, as also found for hermaphrodite flowers and panicle lengths.

Studies have reported that effects of humic substances on plant metabolism are attributed to presence of humic acids. They are responsible for releasing bioactive subunits with auxin activity, triggering responses typical of the action of this phytohormone in the plant (Nardi et al., 2007). Humic acids can improve

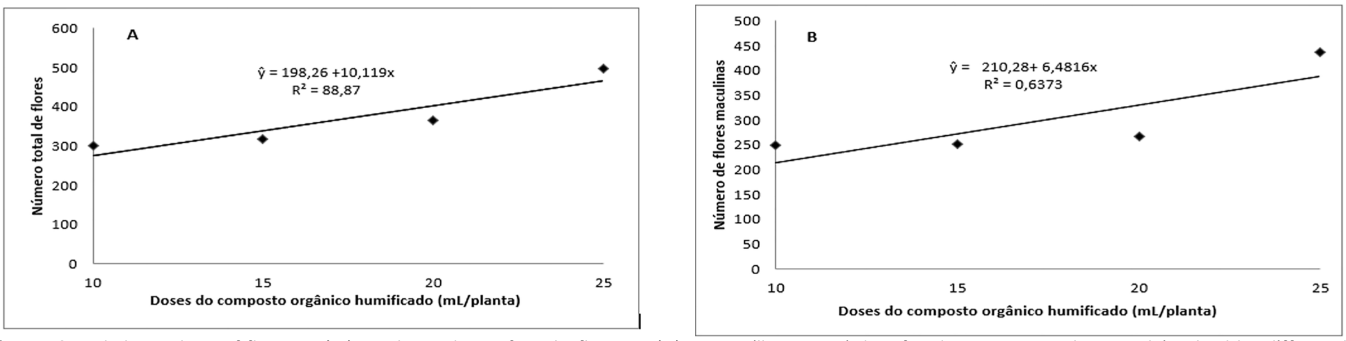

Figure 2. Total number of flowers (A) and number of male flowers (B) per axillary panicle of Palmer mango trees subjected to different humidified organic compound rates. Rio Doce Farm, Matias Cardoso, MG, Brazil.

nutrient availability, the number of flowers per plant, fruiting, fruit retention, and total fruit yield. Increases in upper biomass, flowering, and fruit production and quality have been found in mango trees (Ngullie et al., 2014; El-Hoseiny et al, 2020).

The overall mean of the total number of hermaphrodite flowers per axillary panicle was 55, with mean percentages of 17.41% for hermaphrodite flowers and 82.59% for male flowers. Although these results were not significant, they are consistent with those from other studies that found a lower quantity of hermaphrodite flowers compared to male flowers (Ngullie et al., 2014; Oliveira et al.,2017; Anusuya et al., 2018). Hermaphrodite flowers are the most important, as they are the ones that form the fruits.

The overall means of the number and length of axillary panicle per branch were 4 and 38.25 cm, respectively, and did not differ significantly among treatments. These values are close to those found in Kesar (Ngullie et al., 2014) and Palmer mango trees (Souza et al., 2018).

The soluble solids content (SSC) presented significant linear decreases as the organic compound rate was increased (**Figure 3**). All treatments with organic compound rates included application of PBZ, thus, the highest organic compound rates probably potentiated the action of PBZ on plant absorption. As a growth regulator, PBZ may have affected the plants by delaying the ripening of fruits, which were harvested on the same day and consequently presented low SSC. However, studies with Keitt (El-Hameid & Adel., 2018) and Zebda mango trees (El-Hoseiny et al, 2020) have shown increases in SSC as the humic acid rate is increased.

Significantly higher means of titratable acidity and SSC were found for the lowest PBZ rate (**Table 3**). Titratable acidity is determined by the content of organic acids, which varies with the fruit's maturation stage, decreasing with maturation and consumption of acids through the respiratory process. The application of the highest PBZ rate may have delayed the development of fruits, which were harvested on the same day, causing a decrease in SSC. Additionally, Yeshitela et al. (2004) reported that changes in the quality of Tommy Atkins mangoes due to the use of PBZ may be associated with the distribution of assimilates in the plant. As assimilate demand is unidirectional to the developing fruit, the assimilates that should be directed to the fruits are divided and directed to flowering, thus affecting fruit quality characteristics.

The following characteristics were not significantly different among treatments and are presented as mean values. The overall means of fruit production and yield (43.86 Kg plant^{-1} and 49,830 kg ha^{-1}, respectively) were

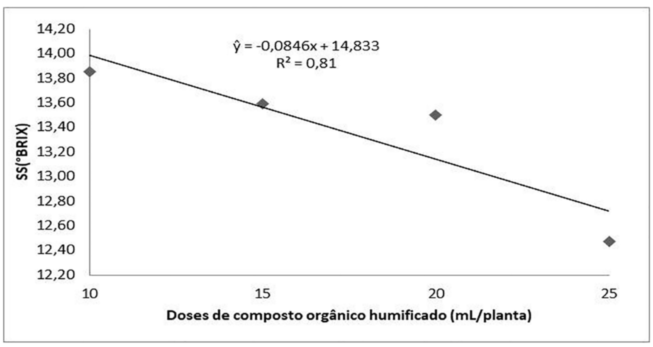

Figure 3. Soluble solids content (SSC) in fruits of Palmer mango trees subjected to different humidified organic compound rates. Rio Doce Farm, Matias Cardoso, MG, Brazil.

Table 3. Means of titratable acidity and soluble solids content in fruits of Palmer mango trees subjected to different paclobutrazol (PBZ) rates. Rio Doce Farm, Matias Cardoso, MG, Brazil

Characteristics	PBZ (g per meter of canopy diameter)		
	0.70	0.85	CV(%)
Titratable acidity [1]	0.25 a	0.19 b	53.38
Soluble solids content (° Brix)	13.73 a	13.03 b	14.99

[1]Equivalent to mg of citric acid 100 mL^{-1} of juice. Means followed by the same letter in the rows are not significantly different from each other by the F-test at a 5% probability level.

significantly high when considering the national mean, highlighting the importance of dense crops. The overall means of fruit fresh weight, length, and diameter were 500.1 g, 133.8 mm, and 86.47 mm, respectively. The means of pH, firmness, lightness, hue angle, and chroma of fruits were 4.11, 28.92 N, 35.91, 66.44, and 23.72, respectively. These results are close to those found by Serpa et al. (2014) for Palmer mangoes.

Season 2 (October 2018 to July 2019)

Considering that the treatments did not show significant differences in the second experiment (Season 2), the results are presented as means of evaluated the characteristics. Branches of Plamer mango trees presented length of 28.28 cm and diameter of 10.21 mm, with a relative chlorophyll content of 52.60 (SPAD index). The number and length of axillary panicles per branch were 3 and 43.96 cm, respectively. These means are consistent with those found by Souza et al., (2018) for Palmer mango trees. The fruit production and yield found were 91.18 kg plant^{-1} and 34,466 kg ha^{-1}. This fruit yield is well above the national mean (approximately 20,000 kg ha^{-1}), as also found in Season 1, denoting the importance of densification combined with other production technologies, as irrigation.

Regarding the fruit quality characteristics, the fruits had SSC of 13.96 °Brix, titratable acidity of 0.48 mg of citric acid 100 mL^{-1} of juice, and pH of 3.84. The fruits presented a fresh weight of 661.4 g, length of 149.2 mm, and diameter of 95.95 mm. Lima et al. (2016) evaluated Palmer mango trees and found similar results. This cultivar is characterized by presenting large fruits, varying from 12 to 15 cm in length and from 8.5 to 10 cm in width, with weights ranging from 510 to 900 g (Oliveira et al., 2017).

The fruit pulp firmness was 50.39 N and fruit peel lightness (L*) was 34.03. A study evaluating Palmer mangoes in the São Paulo Warehouses and General Warehouses Company (CEAGESP) showed that fruits with peels presenting L* varying from 17.43 to 46.67 are the most valued fruits (Chamber, 2017), which correspond to fruits with more brightness, i.e., more attractive to consumers. The hue angle and chromaticity found for fruit peel were 60.14 and 16.45, respectively; hue angles more distant from 90° represent greener fruits, whereas those closer to 90° represent yellower fruits (McGuire, 1992). According to the fruit classification, they exhibited a yellow-orange color.

The differences in characteristics between the production seasons may have occurred mainly due to the age of the plants, planting density, and phenology under the different climate conditions. Plants in Season 1 (1,136 plants ha^{-1}) were harvested at 5 years of age, and the treatments were applied during periods with lower temperatures and rainfall depths. Plants in Season 2 (378 plants ha^{-1}) were harvested at 8 years of age, and the treatments were applied during periods with higher temperatures and rainfall depths.

The reduced response to the applications of humidified organic compound and PBZ rates in Season 2 may be due to the climate conditions at the time of treatment applications (high temperatures and rainfall depths), which were less favorable to decreasing plant growth for subsequent floral induction. However, only few plant characteristics responded to the treatment applications under milder temperatures and absence of rain in Season 1. Therefore, further studies with higher organic compound rates and different production seasons are needed, considering that regions with tropical conditions and the potential for year-round mango production have different climate effects in each production season.

The number of hermaphrodite flowers, fruit production per plant, fruit yield, number and length of panicles, fruit fresh weight, and fruit length and diameter of Palmer mango trees are, in general, not affected by the application of different humidified organic compound rates combined with the tested paclobutrazol rates, regardless of the production season.

Conclusions

The application of increasing humidified organic compound rates, combined with paclobutrazol rates, in July resulted in linear increases in the number of male flowers and the total number of axillary panicles, as well as linear decreases in the fruit soluble solids content of Palmer mango trees.

The results found do not indicate benefits for the use of humidified organic compounds combined with paclobutrazol for the management of floral induction in Palmer mango trees. The isolate use of paclobutrazol at a rate of 0.7 g per meter of canopy diameter is recommended, although further studies on the subject are needed.

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