Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 19 June 2023
https://doi.org/10.14295/CS.v14.3946

Plant growth regulator via micro-sprinkler for 'Palmer' mango floral induction in Brazilian semi-arid region

Welson Lima Simões[1]*, Kalline Mendes Ferreira[2], Jucicléia Soares da Silva[1], Alessandro Carlos Mesquita[2], Maria Aparecida do Carmo Mouco[1], Vinicius Gonçalves Torres Junior[3], Kaio Vinicius Fernandes Barbosa[3], Yuri Rafael Alves Sobral[1]

[1]Brazilian Agricultural Research Corporation, Petrolina, Brazil
[2]State University of Bahia, Juazeiro, Brazil
[3]University of Pernambuco, Petrolina, Brazil
*Corresponding author, e-mail: welson.simoes@embrapa.br

Abstract

Application of the plant growth regulator paclobutrazol (PBZ) to aid floral induction has been widely performed by mango producers. However, its application has been done manually, resulting in low uniformity of application and losses with labor. The objective of this study was to adjust the PBZ dose to be applied via micro-sprinkler system for floral induction, indicating an efficient management of 'Palmer' mango in the Brazilian semi-arid region. The experiment was conducted at Saúde Farm, located in Petrolina-PE, Brazil, starting in October 2015, with harvests in June 2016 and 2017. The experimental design used was randomized blocks, with five doses of PBZ, applied via irrigation system (T1 - 0.56; T2 - 1.12; T3 -1.68; T4 - 2.24; and T5 - 2.80 g a.i. linear m^{-1} canopy) and a conventionally applied dose (T0 - 2.80 g a.i. linear m^{-1} of canopy, manually applied broadcast), with four replicates. The variables analyzed were: CO_2 assimilation, stomatal conductance, transpiration, leaf temperature, number and length of panicles, number of fruits per plant, average fruit weight, yield, pulp firmness, titratable acidity and total soluble solids in the fruits. At the conventionally applied dose (2.8 g a.i. linear m^{-1} of canopy), PBZ application via micro-sprinkler irrigation system proved to be the most efficient way to reduce CO_2 assimilation, stomatal conductance and transpiration. PBZ applied via micro-sprinkler irrigation system at a dose of 0.56 g a.i. linear m^{-1} of canopy promotes greater number of panicles and yield in 'Palmer' mango.

Keywords: *Mangifera indica* L., PBZ, physiology, yield

Introduction

Mango (*Mangifera indica* L.) is one of the most important fruit crops in the socioeconomic aspect, contributing significantly to the agenda of Brazilian exports of fresh fruits (Almeida et al., 2015). In 2018, Brazil had a production of 1,319,296 tons of mango, with the Northeast region accounting for 76.3%. Of this total, the participation of Pernambuco and Bahia states was 38 and 29%, respectively (IBGE, 2019). In the São Francisco Valley, mango is one of the main crops cultivated in irrigated areas and this region is one of the largest producers and exporters of this fruit, with its products also competing in the international market.

The possibility of production throughout the year is the differential for exploiting mango crop under semi-arid conditions, and this is possible, among other factors, due to the use of plant growth regulators that enable the control of the flowering season, with paclobutrazol (PBZ) being the most used in this crop (Mouco, 2015; Souza et al., 2018b).

The dose of the regulator to be applied will depend mainly on the mango variety, size of the mango tree, climatic conditions, especially temperature, types of soil and irrigation used, in addition to the residue factor, as this regulator can remain active in the soil for a long period and interfere with its biological balance (Ferracini et al., 2011), and on the form of application, which interferes in its availability in the soil for absorption by the root system (Mouco et al., 2012; Mouco, 2015; Silva et al., 2017).

Knowing the dose to be applied for each form of cultivation of a mango variety is important for establishing marketing strategies for periods of better market prices. PBZ has been conventionally applied in mango cultivation by diluting the commercial product in water and broadcasting it to the soil, close to the collar

Received: 09 March 2022
Accepted: 28 June 2022

region or under the canopy projection. In order to reduce labor costs and improve product use efficiency, the application via irrigation system has been tested by some producers, but with little technical validation in the Sub-middle region of the São Francisco (Souza et al., 2018b).

Different responses to PBZ application are obtained in mango crop because there are many commercially grown varieties. Therefore, studies are needed for each form of cultivation of varieties, especially the type of irrigation system, as it affects the water absorption capacity of the crop (Simões et al., 2020), in producing regions, to obtain a better economic return with the practice of floral induction (Mouco, 2015).

In this context, the objective of the present study was to adjust the PBZ dose to be applied via micro-sprinkler system for floral induction, indicating an efficient management of ‘Palmer’ mango in the Brazilian semi-arid region.

Material and methods

The study was conducted in two cultivation cycles, starting in October 2015, with harvests in June 2016 and 2017, in an orchard of Saúde Farm, in the municipality of Petrolina-PE, Brazil, at 373 m altitude. The climate of the region is classified as Semi-arid, ‘BSwh’ type according to Köppen’s climate classification. The rains are concentrated in the months from November to April, with average annual rainfall around 500 mm, irregularly distributed.

Mango plants, cv. ‘Palmer’, with 4 years of age and average canopy diameter of 2 m were planted at 6 x 3 m spacing. Irrigation was performed using a micro-sprinkler system with nominal flow rate of 40 L h^{-1} at the collar region of the plant.

Irrigation management was based on crop evapotranspiration (ETc), using climatic data provided by a weather station installed near the experimental area, as shown in **Figure 1**.

Cultural practices such as weeding, fertilization and spraying with pesticides were those usually adopted in the property and recommended by Mouco (2015). The PBZ source used to aid floral induction was the commercial product Cultar from Syngenta, with 25% active ingredient (a.i.).

The experimental design used was randomized blocks, with five doses of PBZ applied via micro-sprinkler irrigation system (T1 - 0.56; T2 - 1.12; T3 -1.68; T4 - 2.24; and T5 - 2.80 g a.i. linear m^{-1} of canopy), and an additional treatment, with a conventionally applied dose (T0 - 2.80 g a.i. linear m^{-1} of canopy, manually applied broadcast), with four replicates. Plots consisted of four plants, and the two central plants were used for evaluations.

Plants were pruned and, after the production of two vegetative flushes, PBZ was applied in the form and at the doses established in the treatments. After application, the irrigation system remained on in order to meet the daily evapotranspiration demand of the crop and assist in the distribution of the product in the soil profile, where the root system was distributed. After 65 to 70 days from PBZ application, a period with application of reduced irrigation depths, calcium nitrate began to be sprayed to induce sprouting of the branches that were already mature.

In the flowering period in both cycles, the number of panicles was counted and their length was measured using a ruler. Physiological evaluations were performed in the same phase, using the Portable Infrared Gas Analyzer (IRGA), Li-6400 model, using artificial light fixed at 2500 µmol m^{-2} s^{-1}. Readings were taken in leaves exposed to the sun in the morning between 9:00 and 11:00 a.m. The following variables were evaluated: CO_2 assimilation (*A*), stomatal conductance (*gs*), transpiration (*E*) and leaf temperature (LT).

At harvest, the number of fruits per plant was

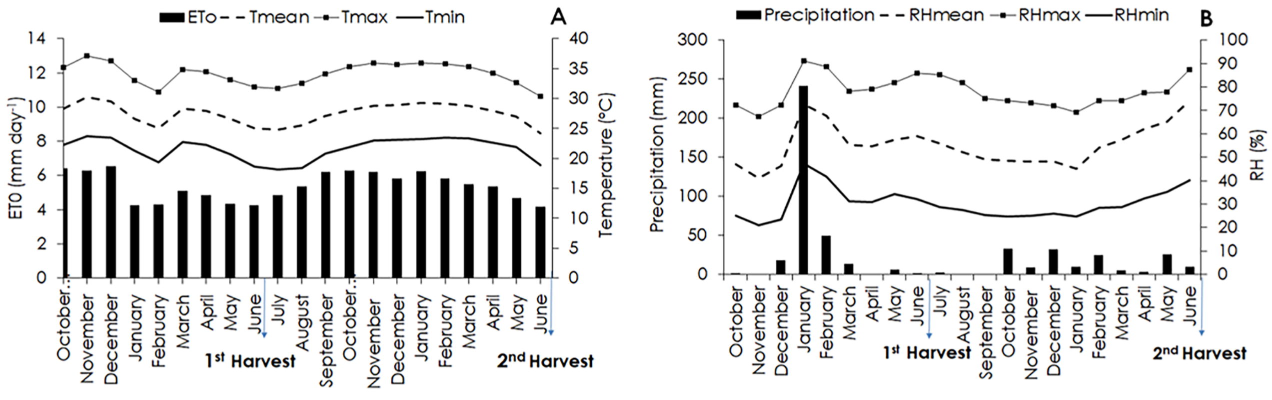

Figure 1. Recorded values of temperature (T) and reference evapotranspiration (ET_0) (A) and precipitation and relative humidity (RH) (B) in the two cycles of ‘Palmer’ mango, in the Brazilian semi-arid region. Petrolina-PE, Brazil.

counted and then the fruits were weighed to calculate the average fruit weight and total yield. Postharvest analyses were also performed, with pulp firmness (N) measured as penetration resistance using a penetrometer (McCormick model FT 327) with conical tip plunger. The fruits were crushed to determine total soluble solids by refractometry, using a portable manual refractometer ATAGO® N1, with reading in the range from 0 to 32° Brix, and titratable acidity by titrating 1 g of juice diluted in 50 mL of distilled water, with 0.1 N NaOH.

The data were subjected to analysis of variance to compare the methods of application and doses of PBZ. The mean values relative to the PBZ doses of 2.80 g a.i. linear m^{-1} of canopy via micro-sprinkler irrigation system and the conventional application were subjected to Tukey test ($p<0.05$), and the doses applied via micro-sprinkler irrigation system were subjected to regression when significant ($p<0.05$). The analyses were performed using the program SISVAR® 5.6 (Ferreira, 2003).

Results and discussion

According to the analysis of variance of the factors studied, there was no significant effect of the interaction ($p<0.05$) between the forms of PBZ application and the different cultivation cycles, for all variables evaluated. However, the cultivation cycles led to significant differences in the variables number and length of panicles, yield and average fruit weight (**Table 1**).

Table 1. Biometric and production characteristics in two cultivation cycles of 'Palmer' mango, with PBZ application for floral induction, in the Brazilian semi-arid region. Petrolina-PE, Brazil

	N° of panicles		panicle length (cm)		yield (t ha^{-1})		average fruit weight (g)	
1st cycle	66.24	b	14.93	b	15.96	b	484.86	b
2nd cycle	130.94	a	24.81	a	24.05	a	545.23	a
CV%	21.13		30.44		18.17		8.70	

Means followed by equal letters do not differ at 5% probability level by Tukey test

In general, higher averages of the characteristics related to flowering and production were obtained in the second cycle, compared to the first cycle (Table 1). This behavior may be related to the biannual characteristic of the mango crop, in which there is an alternation of production, with increase and decrease in the number of fruits from one cycle to the other (Souza et al., 2018a). According to Mouco et al. (2012), such alternate behavior in mango can be influenced by several factors, such as biological factors (flower structure, pollination, flowering); physiological factors (hormonal balance and reduction in plant nutrition); plant protection factors (disease occurrence); and edaphoclimatic factors (absence of well-defined dry season, intense precipitation during flowering, low temperatures after flowering and strong winds).

In addition, these lower averages in the 1st cycle of PBZ application may be related to the higher rainfall (332 mm) along the period of cultivation, as can be seen in the climatic data presented in Figure 1. The occurrence of rainfall induces vegetative vigor and compromises the rest (quiescence) of the branches necessary to differentiate the buds, hampering the management of mango flowering and production (Ramírez & Davenport, 2010). The biometric and production characteristics of the 2nd cycle, with the end of harvest coinciding with periods of occurrence of higher mean, maximum and minimum temperatures (28.04 °C, 35.59 °C and 22.37 °C), may also have accelerated fruit growth and development. In addition, very low temperatures can cause death of flowers and small fruits (Ramirez and Davenport, 2010).

Mouco et al., (2012), working with the 'Tommy Atkins' variety under semi-arid conditions, found the highest number and yield of fruits in the 1st harvest, which coincided with the flowering and fruiting period under conditions of lower temperatures. Souza et al. (2018a), evaluating the production performance of three mango varieties in three agricultural cycles, under the subtropical conditions of the state of São Paulo, also verified a higher yield in the second cycle.

Another important factor to be considered for such difference is that these were the first two production cycles of the plants, which had an increase in canopy size from one cycle to the other. Mango trees grown from grafted seedlings and managed with pruning and use of plant growth regulators can start production at three years of planting, but only stabilize or reach the maximum production capacity when conducted properly from the age of five (Mouco, 2015), which could also explain the differences observed between the first and second cycles of cultivation. The number and length of panicles, yield and average fruit weight were 49, 40, 34, and 11% higher, respectively, in the second year of the experiment. Therefore, the lower number of panicles led to a lower number of fruits per plant and, consequently, to reduction in yield.

Considering the forms of PBZ application, conventional and through fertigation at the highest dose (2.80 g a.i. linear m^{-1} of canopy), there were significant effects (**Table 2**) on CO_2 assimilation, stomatal conductance and transpiration. The conventional form of application caused a lower effect on plants, promoting values that were 21, 13 and 53% higher for CO_2 assimilation, stomatal conductance and transpiration,

Table 2. Physiological characteristics of CO_2 assimilation (*A*), stomatal conductance (*gs*), transpiration (*E*) and leaf temperature (LT) in 'Palmer' mango as a function of PBZ application in the Brazilian semi-arid region. Petrolina-PE, Brazil

Form of Application	*A* (µmol CO_2 $m^{-2}s^{-1}$)		*gs* (mol $m^{-2}s^{-1}$)		*E* (mol H_2O $m^{-2}s^{-1}$)		LT (°C)	
Conventional [1]	16.43	a	0.17	a	4.02	a	31.40	a
Via irrigation system [1]	13.57	b	0.14	b	2.63	b	31.65	a
CV%	19.58		26.29		18.52		1.53	

Means followed by equal letters do not differ at 5% probability level by Tukey test.
[1] Same dose in both forms of application (2.80 g a.i. linear m^{-1} of canopy)

respectively.

Souza et al. (2016), evaluating the effect of PBZ doses applied via irrigation and conventionally on the physiological variables of 'Palmer' mango, observed that the highest values of CO_2 assimilation and stomatal conductance were obtained in plants under conventional application of the product, corroborating the results observed in the present study. Souza et al. (2018b), analyzing the consequences of PBZ application on gas exchange of 'Tommy Atkins' mango, verified that plants not treated with PBZ showed higher means of CO_2 assimilation , stomatal conductance and transpiration. These same authors found an average transpiration of 4.6 mmol m^{-2} s^{-1} in plants subjected to PBZ doses applied conventionally, a result similar to that found in the present study. These results demonstrate that the product applied via irrigation system favors absorption by plants and promotes greater effect on stomatal closure, with consequent reductions in photosynthesis and transpiration.

By analyzing gas exchange as a function of PBZ doses applied via irrigation system, it was verified that the doses caused significant effect on most of the evaluated characteristics, except for leaf temperature (mean value of 31.32 °C). In general, the increase in PBZ doses promoted a reduction in mango gas exchange (**Figures 2**A; B and C). The lowest CO_2 assimilation (Figure 2A) was observed with the highest dose, 2.80 g a.i. linear m^{-1} of canopy, with an average value of 13.57 µmol CO_2 m^{-2} s^{-1}, causing a 21% reduction compared to the mean obtained with the lowest dose. Such reduction in CO_2 assimilation may be related to the reductions in stomatal conductance (Figure 2B) and transpiration (Figure 2C).

Stomatal conductance and transpiration showed negative linear behavior with the increase in PBZ concentrations, on the order of 20 and 33%, respectively, compared to the mean obtained with the lowest dose. Thus, the lowest means of stomatal conductance (0.15 mol m^{-2} s^{-1}) and transpiration (3.26 mol H_2O m^{-2} s^{-1}) were obtained with the application of the highest PBZ dose.

Souza et al. (2016) found significant reductions

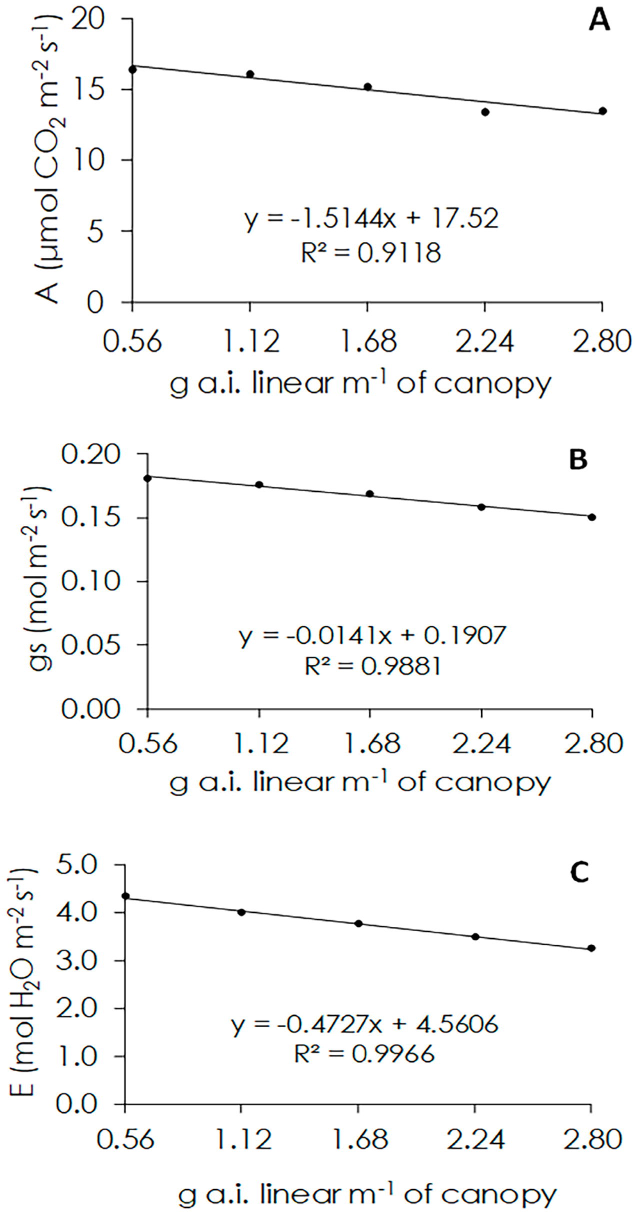

Figure 2. CO_2 assimilation - *A* (A), stomatal conductance - *gs* (B) and transpiration - *E* (C) of 'Palmer' mango as a function of PBZ doses applied via irrigation system, in the Brazilian semi-arid region. Petrolina/PE, Brazil.

in CO_2 assimilation, stomatal conductance and transpiration of 'Palmer' mango with the increase in PBZ doses. According to these authors, these results are associated with reduction in the diameter of xylem vessels caused by PBZ, as suggested by Oliveira et al. (2019), or due to negative effects of the product on the root system, which may have caused an increase in internal resistances to water flow, negatively influencing stomatal conductance, hence transpiration and, to a lesser extent, photosynthesis. Souza et al. (2016) also observed results similar to those obtained in this study, where the highest values of gas exchange were obtained with the lowest doses of PBZ applied by drip irrigation in 'Palmer' mango, which demonstrates that this application is effective and that it is possible to reduce the application dose through the irrigation system. These same authors affirm that the increase in PBZ doses promoted stomatal closure, which is an adaptive mechanism of plants to avoid excessive water losses, especially under stress conditions.

By evaluating the influence of PBZ doses applied via micro-sprinkler irrigation system on biometric and production variables, it was observed that these variables were individually affected by the doses and cultivation cycles, with no interaction between these factors. In the analysis of the doses factor, the number of panicles and total yield (**Figure 3**) decreased with the increase in the PBZ doses applied. The PBZ dose of 0.56 g a.i. linear m^{-1} of canopy promoted a higher number of panicles (169) and yield (23.7 t ha^{-1}) among the treatments, whereas the dose of 2.80 g a.i. linear m^{-1} of canopy led to a lower number of panicles (142) per plant and yield of 17.4 t ha^{-1}, as can be seen in Figures 3A and B, respectively.

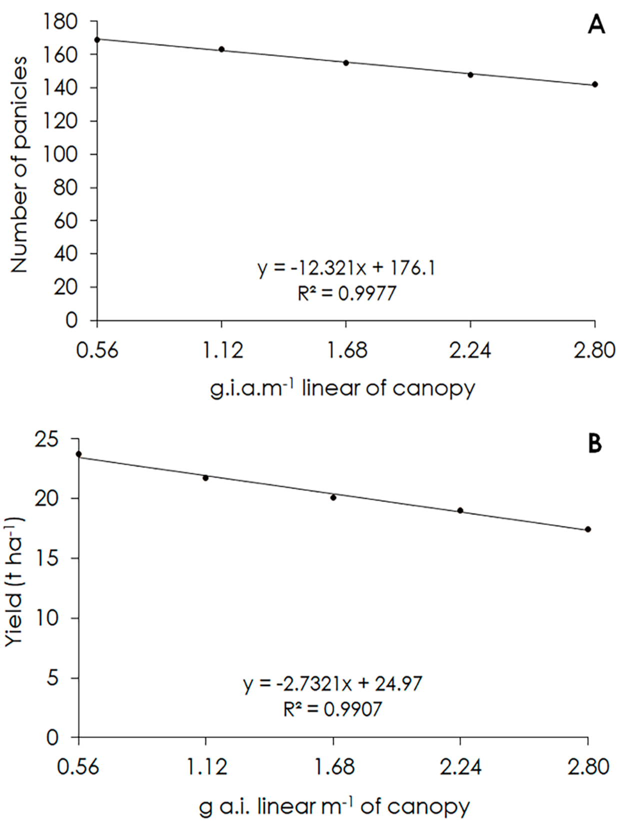

Figure 3. Number of panicles (A) and total yield (B) of 'Palmer' mango as a function of PBZ doses applied via irrigation system, in the Brazilian semi-arid region. Petrolina/PE, Brazil.

According to Taiz et al. (2017), lower rates of stomatal conductance, transpiration and photosynthesis induce significant reductions in production, as observed in the present study.

Application of paclobutrazol by irrigation system is more efficient than the conventional application; 1.4 g a.i. linear m^{-1} of canopy promoted a greater number of fruits and production per plant, in 'Tommy Atkins' mango (Ferreira et al., 2020).

Souza et al. (2018b), also evaluated 'Palmer' mango and PBZ application via drip irrigation system and reported that the dose of 1.3 g a.i. linear m^{-1} of canopy promoted higher number of fruits per plant and the highest yield of the experiment. The differences observed between the most efficient PBZ doses in the two irrigation systems can be attributed to the distribution of water in the mango root zone, with a larger wetted area under the plant canopy promoted by the micro-sprinkler system, compared to the drip system (Cotrim et al., 2019).

The highest number of panicles (131) was found at the dose 0.5 g a.i. linear m^{-1} of canopy. The dose of 2.5 g a.i. linear m^{-1} of canopy led to a lower number of panicles per plant (113). Ferreira et al. (2020), using a micro-sprinkler irrigation management as a way of applying PBZ, obtained similar values for the number of panicles in 'Tommy Atkins' mango, but the values obtained in this work, using the micro-sprinkler irrigation system, were higher than those reported by the authors.

Coelho et al. (2014), analyzing the effect of different PBZ doses on flowering and fruiting of mango cultivated in the Paraguassu Valley region, verified that the application of PBZ at all doses increased flowering percentage compared to the control. This same behavior was observed by Cardoso et al. (2007), who evaluated the flowering and fruiting of the 'Rosa' variety under different doses of PBZ and conventional application. These authors verified that the number of panicles increased as the PBZ dose increased, up to the concentration of 0.80 g a.i. linear m^{-1} of canopy. Thus, the reduction in the number of panicles observed in the present study, due to the increase in PBZ doses, may be related to the fact that different responses to PBZ application in mango crop are obtained because there are many commercially grown varieties. According to Mouco et al. (2012), the dose and form of application also influence the response of plants to PBZ, since some have the ability to vegetate more intensely than others, so they need higher doses. The sensitivity to PBZ will also depend on the climate and on plant age and vigor. In addition, high doses of PBZ used in the mango crop, especially in the management aimed at production in the first half of the year, tend to compact the panicles .

Souza et al. (2018), when working with 'Palmer' mango, using different doses of PBZ applied via irrigation system, also found a significant reduction with the increase in doses, and the PBZ dose of 0.7 g a.i. linear m^{-1} of canopy promoted higher yield (35.8 t ha^{-1}), corroborating the results obtained in the present study. Chatzivagiannis et al. (2014), when analyzing the 'Palmer' variety as a function of different PBZ concentrations, found the highest yield at the dose of 0.4 g a.i. linear m^{-1} of canopy. The mango yield found in the present study was higher than the national average, 15.20 t ha^{-1} (AGRIANUAL, 2019).

Figure 4 shows that panicle length in the first cycle showed the same behavior as the number of panicles (Figure 3), with linear reduction as the PBZ dose increased. However, in the second cycle, panicle length showed a quadratic behavior, differing from that of the number of panicles, with highest value of length (36.83 cm) at the dose of 1.12 g a.i. linear m^{-1} of canopy.

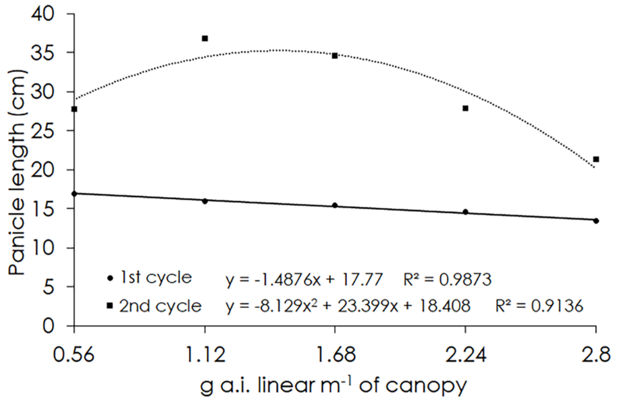

Figure 4. Panicle length in 'Palmer' mango as a function of PBZ doses applied via irrigation system, in the Brazilian semi-arid region. Petrolina/ PE, Brazil.

Souza et al. (2018b) observed that increasing doses of PBZ applied via fertigation led to linear reduction in the number and length of panicles, also in 'Palmer' mango. This same behavior was observed in the work conducted by Ferreira et al. (2020) but using the micro sprinkler irrigation system in 'Tommy Atkins' mango.

Regarding the post-harvest data of the fruits, it can be observed in **Figure 5** that the characteristics total soluble solids and titratable acidity were influenced by the different PBZ doses and cultivation cycles. However, no significant variations were detected in the values of pulp firmness, with mean values of 10.64 and 10.06 N in the first and second cycles, respectively.

Titratable acidity in the fruits showed higher values in the 1st cycle, while the total soluble solids were higher

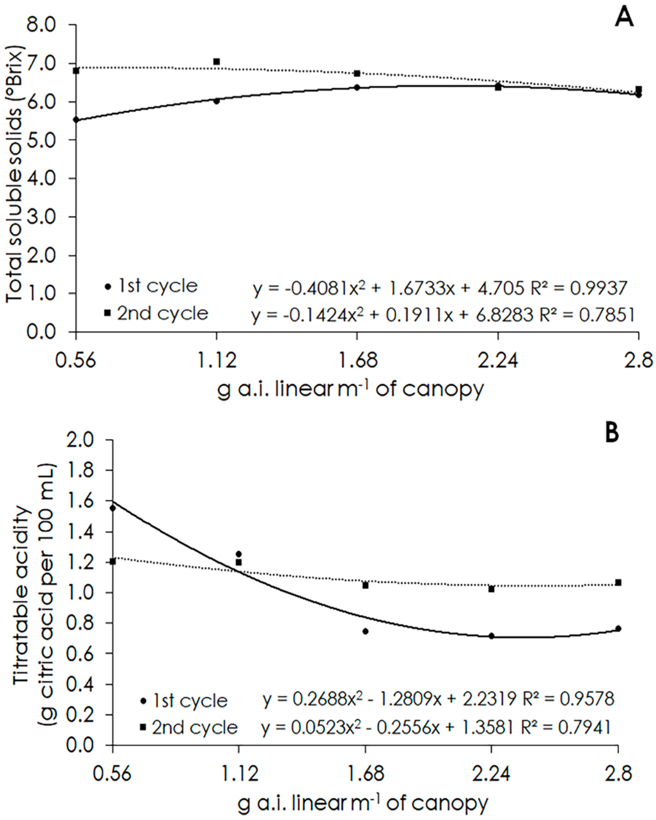

Figure 5. Total soluble solids (A) and titratable acidity (B) of 'Palmer' mango as a function of PBZ doses applied via irrigation system, in the Brazilian semi-arid region. Petrolina/PE, Brazil.

in the 2nd cycle. These differences may be associated with the harvest period of the 2nd cycle, which had higher mean, maximum and minimum temperatures (28.04 °C, 35.59 °C and 22.37 °C), than the first cycle, which may have influenced fruit development and maturation.

Total soluble solids increased up to the PBZ doses of 2.24 and 1.12 g a.i. linear m^{-1} in the first and second cycles, respectively (Figure 5A). However, the opposite behavior was observed for titratable acidity, which decreased up to the dose of 2.24 g a.i. linear m^{-1} in both cycles (Figure 5B).

Total soluble solids content in 'Tommy Atkins' mango showed a quadratic behavior (Ferreira et al., 2020), in which the increase in doses promoted an increase in total soluble solids content up to a maximum dose of 1.3 g a.i. linear m^{-1} of canopy, which correspondeds to 7.64 °Brix. Similar effect was observed in Figure 5A.

Although the titratable acidity data decreased already from 0.56 g a.i. linear m^{-1} of canopy in the present study, Souza et al. (2018b) found that this variable only decreased from the dose of 1.0 g a.i. linear m^{-1} of canopy in 'Palmer' mango with the PBZ applied via drip system. This difference may indicate that this characteristic of the fruit may change depending on the form by which the product is being applied. Corroborating the result for total soluble solids of the present study, Chitarra & Chitarra (2005) report that the ripening process reduces acidity and increases the amount of sugars. Considering that the reduction in pulp titratable acidity is related to fruit ripening, this result may indicate a possible acceleration in the vegetative cycle with the increase in the PBZ dose applied.

Conclusions

For the conventionally applied dose (2.8 g a.i. linear m^{-1} of canopy), the application of paclobutrazol via micro-sprinkler irrigation system proved to be the most efficient way to reduce CO_2 assimilation, stomatal conductance and transpiration;

Paclobutrazol applied via micro-sprinkler irrigation system at a dose of 0.56 g a.i. linear m^{-1} of canopy promotes a greater number of panicles and yield in 'Palmer' mango;

High doses of paclobutrazol reduces the number and length of panicles and titratable acidity of fruits.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.