ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.26, n.4, p.239-247, 2022
agriambi
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v26n4p239-247

Gas exchanges and photosynthetic pigments of 'Tommy Atkins' mango as a function of fenpropimorph[1]

Trocas gasosas e pigmentos fotossintéticos de mangueira 'Tommy Atkins' em função de fenpropimorfe

Daniel de A. Carreiro[2*], Renata A. e Amariz[2], Luciana G. Sanches[2], Jackson T. Lobo[3], Vespasiano B. de Paiva Neto[2] & Ítalo H. L. Cavalcante[2]

[1] Research developed at Petrolina, PE, Brazil
[2] Universidade Federal do Vale do São Francisco/Departamento de Engenharia Agronômica/Centro de Ciências Agrárias, Petrolina, PE, Brazil
[3] Universidade Federal da Paraíba/Departamento de Fitotecnia e Ciências Ambientais/Centro de Ciências Agrárias, Areia, PB, Brazil

HIGHLIGHTS:
Fenpropimorph promotes a higher physiological activity in mango.
Fenpropimorph favors carbon assimilation in mango.
Fenpropimorph dose of 1.3 g per linear meter of plant canopy promotes higher transpiration and stomatal conductance in mango.

ABSTRACT: The objective of the present study was to evaluate the influence of the application of fenpropimorph and paclobutrazol on gas exchanges and photosynthetic pigments of 'Tommy Atkins' mango grown in the semi-arid region in different evaluation periods. Two experiments were carried out in 'Tommy Atkins' mango orchards in the first production cycle between September and December 2018 (first experiment) and between September and December 2019 (second experiment) in Petrolina, PE, Brazil. The experimental design adopted was randomized blocks in split plots in time, 4 × 4 + 1, with four replicates. The plots corresponded to the concentrations of fenpropimorph: 0, 0.7, 1.0, and 1.3 g per linear meter of plant canopy diameter plus the additional paclobutrazol treatment (1 g per linear meter of plant canopy diameter), and the subplots corresponded to the evaluation dates (0, 30, 60, and 90 days after the first application of treatments). The following traits were evaluated: CO_2 assimilation rate, stomatal conductance, internal CO_2 concentration, transpiration, water use efficiency, chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids. The fenpropimorph dose of 1.3 g per linear meter of plant canopy promotes a higher rate of CO_2 assimilation; however, paclobutrazol was more effective in the accumulation of chlorophyll a and total chlorophyll, and the use of fenpropimorph did not interfere in the concentration of photosynthetic pigments.

Key words: *Mangifera indica* L., growth regulator, plant physiology

RESUMO: O objetivo do presente estudo foi avaliar a influência da aplicação de fenpropimorfe e paclobutrazol nas trocas gasosas e pigmentos fotossintéticos de mangueira 'Tommy Atkins' cultivada no semiárido em diferentes períodos de avaliação. Foram realizados dois experimentos em pomares de mangueira 'Tommy Atkins' no primeiro ciclo produtivo entre setembro e dezembro de 2018 (primeiro experimento) e entre setembro e dezembro de 2019 (segundo experimento) em Petrolina, PE, Brasil. O delineamento experimental adotado foi o de blocos casualizados em parcelas subdivididas no tempo, 4 × 4 + 1, com quatro repetições. As parcelas corresponderam às concentrações de fenpropimorfe: 0; 0,7; 1,0 e 1,3 g por metro linear de diâmetro da copa mais o tratamento adicional paclobutrazol (1 g por metro linear de diâmetro da copa), e as subparcelas corresponderam às datas de avaliação (0, 30, 60 e 90 dias após a primeira aplicação dos tratamentos). As seguintes características foram avaliadas: taxa de assimilação de CO_2, condutância estomática, concentração interna de CO_2, transpiração, eficiência do uso da água, clorofila a, clorofila b, clorofila total e carotenoides. Basicamente, a dose de 1,3 g de fenpropimorfe por metro linear do dossel da planta promove uma maior taxa de assimilação de CO_2; porém, o paclobutrazol foi mais eficaz no acúmulo de clorofila a e clorofila total, e o uso de fenpropimorfe não interferiu na concentração dos pigmentos fotossintéticos.

Palavras-chave: *Mangifera indica* L., regulador de crescimento, fisiologia vegetal

• Ref. 251761 – Received 02 May, 2021
* Corresponding author - E-mail: daniel.almeida.sb@gmail.com
• Accepted 26 Sept, 2021 • Published 07 Oct, 2021
Editors: Lauriane Almeida dos Anjos Soares & Hans Raj Gheyi

Introduction

The mango (*Mangifera indica* L.) crop has high biosynthesis of gibberellins that favor vegetative growth and inhibit flowering (Sandip et al., 2015). Therefore, the use of gibberellin biosynthesis inhibitors, especially triazoles such as paclobutrazol (PBZ) and uniconazole (UCZ), has been adopted for flowering management (Cavalcante et al., 2020).

The application of these plant regulators promotes a series of chain reactions to favor floral bud differentiation, including the increase of total soluble sugars in the apical bud (Upreti et al., 2014), of cytokinin levels, and the C:N ratio (Upreti et al., 2013). Furthermore, there is evidence of the influence of gas exchange on the branch maturation phases and, consequently, on the period before floral induction in mango (Upreti et al., 2014).

In the mango crop, the effects of gibberellin biosynthesis inhibitors on gas exchange and photosynthetic pigments are little studied. However, the use of paclobutrazol (PBZ) has tended to reduce net CO_2 assimilation rate and transpiration by increasing stomatal resistance in 'Palmer' mango grown in the semi-arid region (Souza et al., 2016), and the chlorophyll concentrations in 'Banganpalli' mango grown in India (Subbaiah et al., 2018).

At present, the PBZ is the only molecule recorded for mango cultivation (MAPA, 2021) and, due to its high persistence in the soil, it can cause long-term harm (Silva et al., 2020). A molecule with the potential to inhibit the biosynthesis of gibberellin is fenpropimorph, a morpholine with a regulating effect on the synthesis of sterols and plant hormones, whose efficiency for this purpose has already been verified in *Poa annua* L. (Ramoutar et al., 2010). However, there are no studies about the effects of this molecule on mango physiology.

In this perspective, this study aimed to evaluate the influence of the application of fenpropimorph and paclobutrazol on gas exchanges and photosynthetic pigments of 'Tommy Atkins' mango grown in the semi-arid region in different evaluation periods.

Material and Methods

Two-and-half-year-old mango trees, cultivar Tommy Atkins, with uniform size and vigor in the first production cycle, were used in this study. The experiments were accomplished from September to December 2018 (first experiment) and from September to December 2019 (second experiment) in experimental orchards located in Petrolina (09° 18' 19.2" S and 40° 33' 55.9" W; at an altitude of 365.5 m above sea level) in the state of Pernambuco, Brazil. The climate of this region is classified as BSh (Alvares et al., 2013), which corresponds to a semi-arid region. Climatic data during the experiments were recorded in an automatic meteorological station (Figure 1).

The two experiments were carried out in two different orchards with the same mango cultivar, using as a plant parameter for fenpropimorph (FEN) application in the second vegetative flush developed after pruning, with the same management characteristics, in an experimental unit of

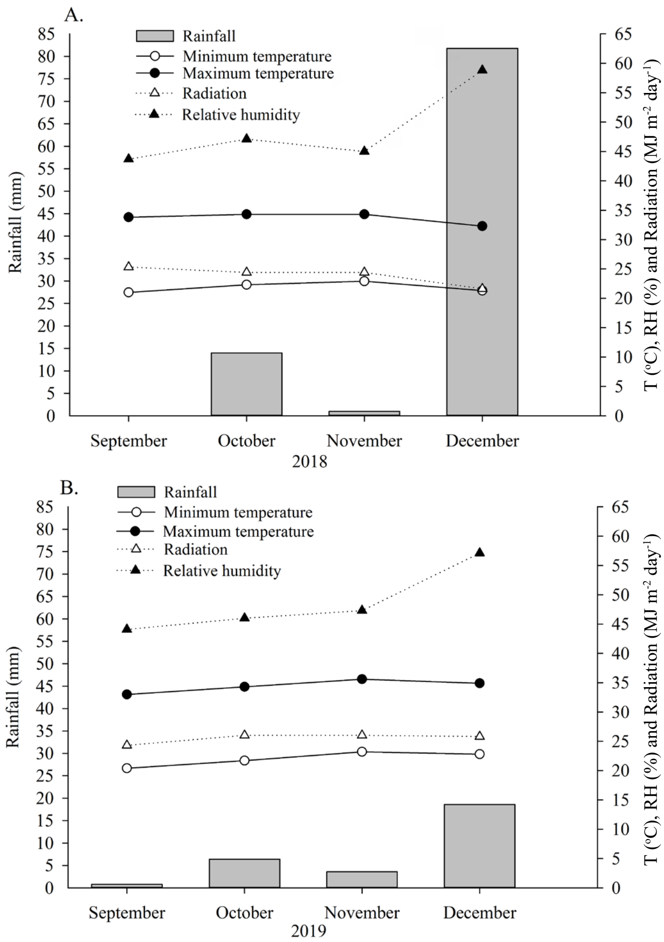


Figure 1. Accumulated rainfall, and average values for minimum, maximum air temperature, average relative humidity of air, and global solar radiation recorded in the first (A) and second (B) experiments

7.0 m^2. It was imperative to perform the experiments in mango orchards in the first production cycle to avoid residues of paclobutrazol, which is a gibberellin inhibitor for mango trees and is widely used in Brazil. Table 1 describes the physical and chemical characteristics of the soils of both areas.

The trees, spaced by 7.0 m between the rows and 2.0 m between the trees (714 trees ha^{-1}), were daily irrigated (micro-sprinkler) with one emitter per tree, with a flow of nearly 70 L h^{-1}. All management practices such as pruning, control of weeds, pests, diseases, and break of dormancy (calcium nitrate and potassium nitrate) were performed following the instructions of Genú & Pinto (2002), except for branch maturation, which was performed following Cavalcante et al. (2018), adding the application of algae extract in the last two sprays in the second experiment. In the first experiment, from 40 to 90 days after treatments (DAT), the water depth was reduced, irrigating with 33% of crop evapotranspiration (ETc) from 40 to 60 DAT and with 66% of ETc from 60 to 90 DAT; while in the second experiment, the water depth reduction was performed simultaneously to the first application of treatments, irrigating with 66% of ETc until 90 DAT. Nutrient management was performed through a fertigation system, according to plant demand (Genú & Pinto, 2002). Tip pruning was performed to synchronize vegetative flush events in the canopy.

The experimental design adopted was a randomized block design in split-plots in time (4 × 4 + 1) with four replicates, with

Table 1. Chemical and physical soil characteristics of the mango orchards studied in the first and second experiment

First experiment									
Soil layer (cm)	pH (H_2O)	EC (dS m^{-1})	P (mg dm^{-3})	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	SB
				(cmol$_c$ dm^{-3})					
0-20	7.24	0.13	123.35	1.74	0.13	4.05	2.06	0.00	7.98
20-40	7.26	0.11	595.34	1.41	0.13	3.59	2.11	0.00	7.24
	OM	FA	HA	HU	Sand	Silt	Clay	Texture	
	(g kg^{-1})				(dag kg^{-1})				
0-20	14	2.41	1.44	10.01	68.65	14.25	17.1	Sandy Loam	
20-40	15.1	1.63	1.12	9.99	67.78	17.12	15.1	Sandy Loam	
Second experiment									
	pH (H_2O)	EC (dS m^{-1})	P (mg dm^{-3})	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	SB
				(cmol$_c$ dm^{-3})					
0-20	7.30	0.37	616.90	2.59	0.70	4.27	3.02	0.00	10.58
20-40	7.56	0.22	298.07	1.56	0.56	3.70	2.17	0.00	7.99
	OM	FA	HA	HU	Sand	Silt	Clay	Texture	
	(g kg^{-1})				(dag kg^{-1})				
0-20	12.14	3.35	3.11	4.13	75.91	9.69	14.40	Sandy Loam	
20-40	10.26	3.32	2.69	4.44	77.72	8.78	13.50	Sandy Loam	

EC - Electrical conductivity; P, K, Na - Melich-1; Al, Ca, Mg - 1 M KCl extractant; SB - Sum of bases; OM - Organic matter; FA - Fulvic acids; HA - Humic acids and HU - Humin

five plants per experimental unit (first experiment) and three plants per experimental unit (second experiment). The plots consisted of fenpropimorph (FEN) at 0, 0.7, 1.0, or 1.3 g per linear meter of the plant canopy, with an additional treatment with 1.0 g of paclobutrazol (PBZ) per linear meter of the plant canopy, while the subplots corresponded to the evaluation dates (ED) (0, 30, 60, and 90 days after the first application of treatments). In the first experiment, treatments were applied by soil drenching once at 90 days after production pruning, while in the second experiment, the doses of fenpropimorph were applied at intervals of 15 days, with four applications.

The FEN source used was Versatilis® (75% a.i. fenpropimorph), while the paclobutrazol source was Cultar SC® (25% a.i. paclobutrazol). The FEN weight of each treatment was diluted in 2 L of water and applied at 50 cm away from the plant stem. The treatments were applied following the recommendations of Genú & Pinto (2002) for mango and the product manufacturers.

The following evaluations were performed at 0, 30, 79, and 90 days after the first application of the treatments (ED): CO_2 assimilation rate (A) (μmol CO_2 m^{-2} s^{-1}), stomatal conductance (gs) (mol m^{-2} s^{-1}), internal concentration of CO_2 (Ci) (mmol m^{-2} s^{-1}), and transpiration (E) (mmol H_2O m^{-2} s^{-1}) through an infrared gas analyzer - IRGA (Mod. Li-COR® 6400 XT) (irradiation of 1800 μmol photons m^{-2} s^{-1}), and water-use efficiency (WUE) was calculated as the ratio between CO_2 assimilation rate and transpiration; while at 0, 30, 60, and 90 ED, the following traits were evaluated: chlorophyll a (mg g^{-1}); chlorophyll b (mg g^{-1}); total chlorophyll (mg g^{-1}), and carotenoids (mg g^{-1}) following the methodology proposed by Lichtenthaler & Buschmann (2001).

Data were submitted to analysis of variance (ANOVA) and regression analysis, while the fenpropimorph doses and PBZ were compared with each other by Dunnett's test on each evaluation date and in the entire experiment, using the R software (R Core Team, 2017).

Results and Discussion

When comparing the general average PBZ and fenpropimorph doses (Table 2), there were differences for CO_2 assimilation rate (A) and CO_2 internal concentration (Ci) in the first experiment and for CO_2 assimilation rate and transpiration in the second experiment.

The evaluation dates (ED) affected all variables studied and there was an individual effect of the doses of fenpropimorph on water-use efficiency (WUE), while in the second experiment all variables were significantly improved and there was an individual effect of the doses of fenpropimorph on stomatal conductance, transpiration, and water-use efficiency (Table 2).

When comparing the CO_2 assimilation rate between PBZ and fenpropimorph doses (Table 2), the FEN dose of 1.3 g per linear meter of plant canopy promoted a greater CO_2 assimilation rate in both experiments, indicating a different mode of action on this variable. Souza et al. (2016) observed that PBZ reduced the CO_2 assimilation rate in the 'Palmer' mango in the semi-arid region. In this context, the application strategy in the second experiment (more applications) promoted the superiority in CO_2 assimilation with the FEN dose of 1.3 g per linear meter of plant canopy (6.86%) compared to PBZ.

Desta & Amare (2021) observed that the response is highly species-dependent; however, growth regulators can positively influence photosynthetically active leaves, responsible for carbon dioxide assimilation.

For the CO_2 assimilation rate in the second experiment, the value found with the FEN dose of 0 g per linear meter of plant canopy was lower (10.01%) than that of the treatment with PBZ at 30 days after the first treatment application, and the other doses had a similar performance to that mentioned regulator, thus indicating that fenpropimorph also promotes a satisfactory CO_2 assimilation rate (Figure 2A).

Regarding the influence of the evaluation dates on the CO_2 assimilation rate (A) in the first experiment ($y = 14.1877 - 0.2599^{**}x + 0.0028^{**}x^2$, $R^2 = 0.56$), the coefficient of determination was rather low and it should not be used for estimating the assimilation rate; however, the highest value was found in the last evaluation, at 90 ED, which was 155.73% higher than the lowest value found (79 ED). There was a different behavior in the second experiment, in which the highest value was obtained at 79 ED and was 97.84% higher than the lowest value, found at 30 ED (Table 2).

Table 2. Summary of analysis of variance ('F' value) for CO_2 assimilation rate (A), stomatal conductance (gs), internal CO_2 concentration (Ci), transpiration (E), and water use efficiency (WUE) as a function of treatments (fenpropimorph and paclobutrazol) and evaluation dates

FEN (g per linear meter of plant canopy)	A (μmol CO_2 m^{-2} s^{-1})	gs (mol m^{-2} s^{-1})	Ci (mmol m^{-2} s^{-1})	E (mmol H_2O m^{-2} s^{-1})	WUE (μmol CO_2 $mmol^{-1}$ H_2O)
First experiment					
0.0	11.55	0.12	202.87	3.02	4.19
0.7	10.85	0.10	188.58	2.96	3.88
1.0	10.77	0.12	216.01*	2.99	3.87
1.3	11.68*	0.12	200.64	3.02	4.02
PBZ	11.29	0.11	195.84	2.96	4.06
ED	72.61**	51.12**	11.82**	65.04**	19.64**
0	13.19	0.16	229.89	3.78	3.52
30	11.89	0.14	221.86	3.85	3.14
79	5.58	0.04	162.57	1.29	4.55
90	14.27	0.13	188.83	3.04	4.79
FEN	1.03^{ns}	1.24^{ns}	1.11^{ns}	0.02^{ns}	0.63**
FEN X ED	0.90^{ns}	2.26*	0.29^{ns}	0.70^{ns}	0.30^{ns}
CV (%)	16.52	27.5	21.09	24.55	19.26
Second experiment					
0.0	12.24	0.11	185.65	3.53	3.56
0.7	12.41	0.11	174.92	3.56	3.52
1.0	12.84	0.11	171.67	3.78	3.47
1.3	13.71*	0.14	196.37	4.76 *	2.97
PBZ	12.83	0.11	181.83	3.76	3.46
ED	41.32**	20.05**	6.15**	18.69**	20.73**
0	14.85	0.14	184.98	3.94	3.90
30	7.88	0.07	193.73	2.53	3.20
79	15.59	0.15	195.27	4.27	3.70
90	12.89	0.10	154.39	4.78	2.78
FEN	0.91^{ns}	3.93**	0.48^{ns}	11.66**	4.31**
FEN X ED	0.58^{ns}	0.53^{ns}	1.51^{ns}	1.18^{ns}	1.05^{ns}
CV (%)	21.64	23.14	35.58	17.38	15.73

FEN - Fenpropimorph; ED - Evaluation dates; FM - Fresh mass; CV - Coefficient of variation; ** - Significant at $p \leq 0.01$ probability of error by 'F' test; * - Significant at $p \leq 0.05$ probability of error by Dunnett's Test (compared to PBZ); ns - Non-significant

However, there was a greater reduction in the CO_2 assimilation rate in comparison to the previous date in experiment 1 (53.07%) and compared to experiment 2 (46.94%), highlighting that, in experiment 2, two fenpropimorph applications had already been performed on the date when the lowest CO_2 assimilation rate value was obtained (30 ED). The soil in the second experiment had a significant superiority regarding the concentrations of fulvic (64.85%) and humic (126.56%) acids compared to the soil in the first experiment (Table 1).

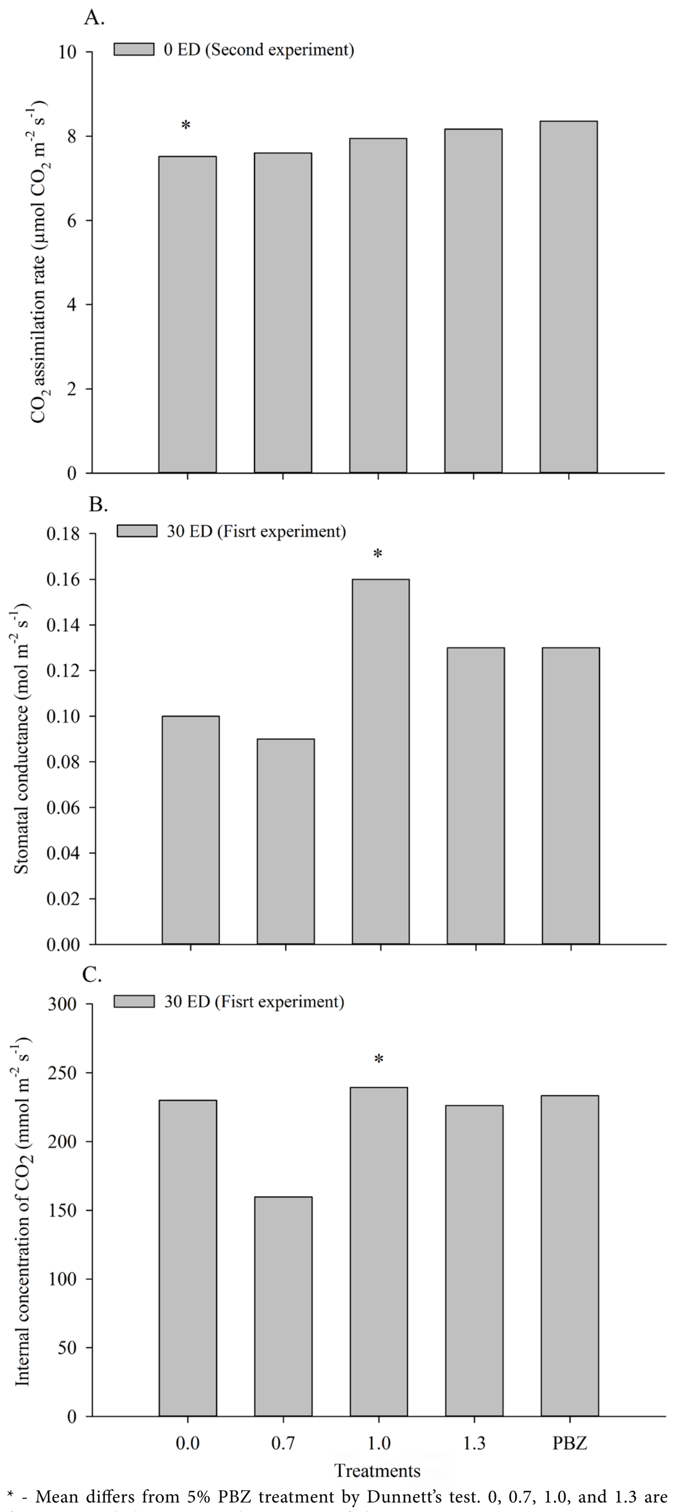
In this perspective, the fenpropimorph together with fulvic and humic acids may have briefly mitigated the deleterious effects of water stress, especially in experiment 2 (more applications of fenpropimorph). Silva et al. (2021) observed a positive effect of PBZ with fulvic acid during the water depth reduction period on the maintenance of CO_2 assimilation rate in soil with a similar texture as in this experiment, while Olk et al. (2018) stated that the accumulation of humic substances might become a primary response mechanism under drought conditions.

Comparing the general averages of the fenpropimorph doses and PBZ for the internal concentration of CO_2 and water-use efficiency in the first experiment (Table 2), the FEN dose of 1.3 g per linear meter of plant canopy promoted a higher internal concentration of CO_2 compared to PBZ, which is beneficial since this higher concentration will positively influence the conversion of carbon into energy for the plant (Cunha, 2019).

For stomatal conductance and internal CO_2 concentration in the first experiment, a superior performance (18.46 and 2.51%) was observed for the 1.0 g per linear meter dose of fenpropimorph compared to PBZ at 30 days after the first application of treatments (Figures 2B and C), which is an important factor in the maturation phase of mango branches, as these variables correlate with the production of energy reserves necessary for the flowering stage (Upreti et al., 2014).

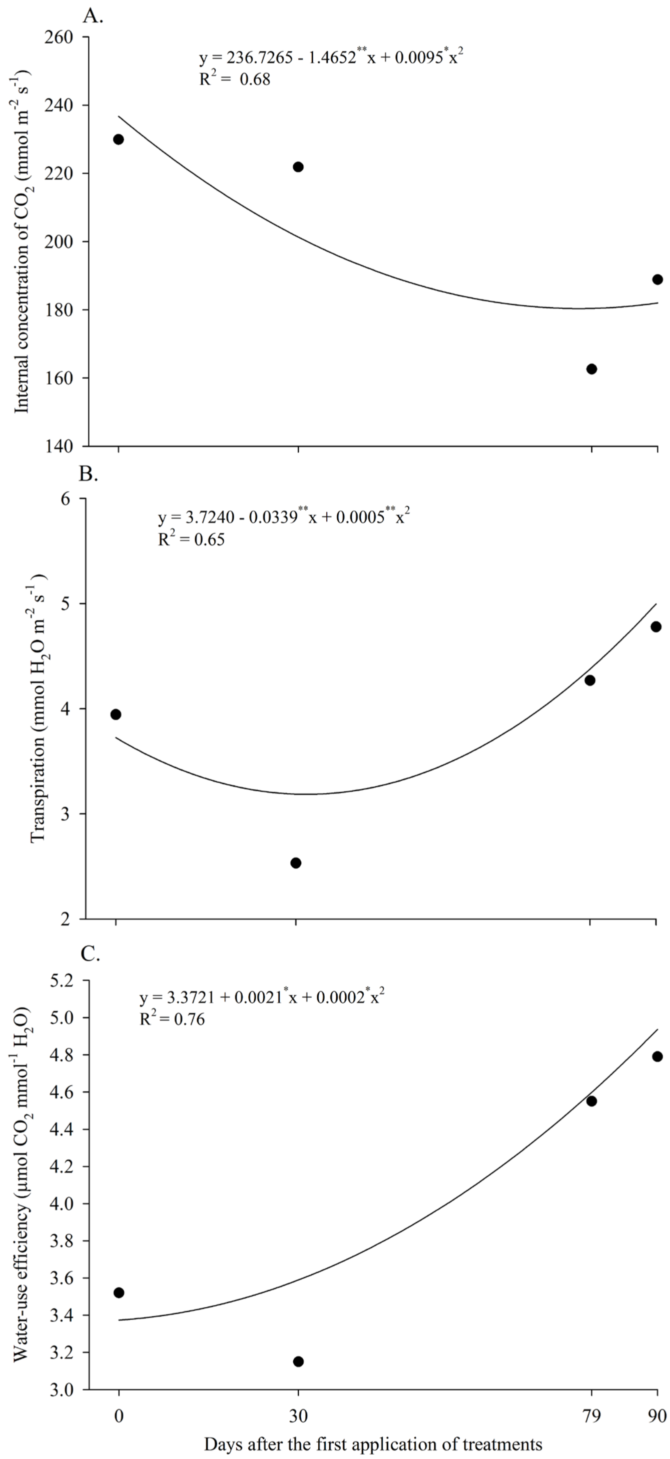
The FEN doses of 1.0 and 1.3 g per linear meter of plant canopy favored carbon assimilation. The greater stomatal opening and internal concentration of CO_2 indicate that, despite the reduction in vegetative growth, the plants submitted to this treatment continued to maintain the photosynthetic rate and production of assimilates, which is necessary for flowering (Silva et al., 2021).

Regarding stomatal conductance (gs) (Table 2), although the data were described by a quadratic model ($y = 0.1685 - 0.0031^{**}x + 0.0001^{**}x^2$, $R^2 = 0.56$), but the value of the coefficient of determinatio was low; however, the highest value in the first experiment was obtained at 0 ED, which was 300% higher than the value found at 79 ED, whereas, in the second experiment, the data were not described satisfactorily by any model and the highest value was found at 79 ED, two times greater compared to that at 30 ED. A trend toward stability is observed in the behavior of this variable, although it was reduced as a function of water depth reduction in both experiments. However, there



* - Mean differs from 5% PBZ treatment by Dunnett's test. 0, 0.7, 1.0, and 1.3 are fenpropimorph doses in g per linear meter of plant canopy

Figure 2. CO_2 assimilation rate at 0 day after the first treatment application in the second experiment (A), stomatal conductance (B), and internal concentration of CO_2 (C) at 30 days after the first treatment application in the first experiment in ‘Tommy Atkins’ mango cultivated in the semi-arid region of Brazil



**, *, ns - Significant at p ≤ 0.01 and p ≤ 0.05, and not significant by F test, respectively

Figure 3. Internal CO_2 concentration in the first experiment (A), transpiration in the second experiment (B), and water-use efficiency in the first experiment (C) as a function of days after the first application of treatments in ‘Tommy Atkins’ mango cultivated in the semi-arid region of Brazil

was a lower range of values in the second experiment, following the CO_2 assimilation rate.

For the internal CO_2 concentration (Ci) (Table 2), along the evaluation dates, in the first experiment, there is quadratic fit with a value of 201.96 mmol m^{-2} s^{-1} at 21 days after the first treatment application (Figure 3A), while there was no regression fit of Ci data as a function of time elapsing in the second experiment.

However, there was no positive relationship between internal CO_2 concentration and stomatal conductance with CO_2 assimilation rate in this experiment since at 90 ED there was a lower stomatal conductance, internal CO_2 concentration, and higher CO_2 assimilation rate compared to 0 ED, showing an inverse behavior; in the first phase, there was probably a better use of the available carbon, that is, greater carboxylation efficiency by the enzyme RuBisCO (Santos et al., 2015).

In the first experiment, despite the significance of the data, the value of the coefficient of determination was low ($y = 4.1305 - 0.0581^{**}x + 0.0005^{**}x^2$, $R^2 = 0.44$); however, when evaluating transpiration (E) as a function of the evaluation dates in the second experiment (Figure 3B), there was a quadratic fit of the data with a maximum response of 9.72 mmol H_2O m^{-2} s^{-1} at 33 days after the first treatment application (Figure 3C), indicating a relationship with the internal concentration of CO_2, and consequently a greater physiological activity of plants in the second experiment.

Regarding the water use efficiency on the different evaluation dates in the first experiment (Figure 3C), there was a quadratic fit, with the estimated maximum value of 5.18 μmol CO_2 $mmol^{-1}$ H_2O at 90 days after the first application of treatments. In the second experiment, despite the significance of the data, the value of R^2 was low (0.55).

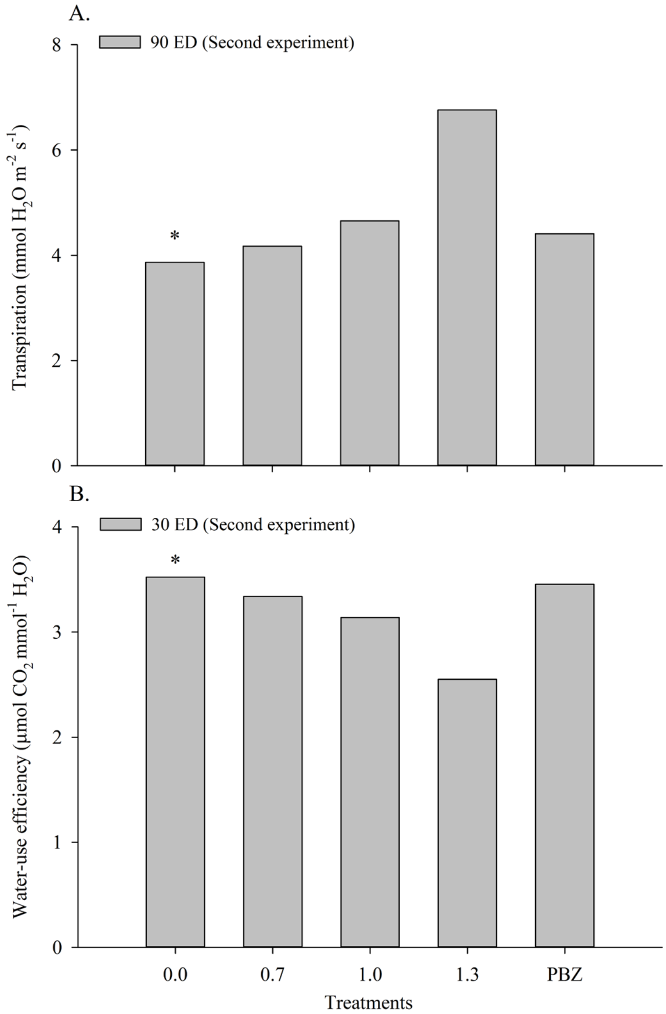
For transpiration, in the second experiment, in general, the FEN dose of 1.3 g per linear meter of plant canopy promoted high transpiration as the CO_2 assimilation rate, which indicates that this dose, as a whole, promoted high physiological activity of the plants (greater stomatal opening and production of photoassimilates). The FEN dose of 0 g per linear meter of plant canopy led to smaller transpiration compared to PBZ at 90 days after the first application of treatments (Figure 4A) and greater water-use efficiency at 30 days after the first application of treatments (Figure 4B).

Souza et al. (2016) observed a reduction in transpiration of the 'Palmer' mango grown in the semi-arid region as a function of paclobutrazol, a result attributed to the increase in stomatal resistance as a consequence of the reduction in the water potential of the root system.

It is highlighted that the morpholines, among which fenpropimorph is present, move to the plant shoot via the xylem according to the transpiration flow (Chamberlain et al., 1998). In this perspective, the change in the application strategy and the greater volume of the molecule applied in the second experiment may have induced higher transpiration to absorb the molecule, also noting that the referred concentration, although not differing significantly, also promoted higher overall CO_2 assimilation rate, stomatal conductance, and internal CO_2 concentration.

In that experiment, treatments with fenpropimorph and paclobutrazol showed lower water use efficiency compared to the 0 g m^{-1} treatment at 30 ED (Figure 4B), and this data distribution may indicate that the control plants were under greater stress, as observed by Silva et al. (2009). The water use efficiency relates the water volume lost by the plant with the photosynthetic activity. Mudo et al. (2020) observed that this behavior favored floral induction in the same mango cultivar grown under similar conditions.

Again, it is possible to note the influence of water depth management on the reduction of this variable, in agreement with the behavior of CO_2 assimilation rate and stomatal conductance. However, when observing the reduction of this variable as a function of the previous date in the first (from 30 to 79 ED) and second (from 0 to 30 ED) experiments, a lower reduction was verified in the second experiment (35.79%), with similar behavior for CO_2 assimilation rate, which may be due to the organic composition of the soil, mitigating the stress caused by water depth reduction.



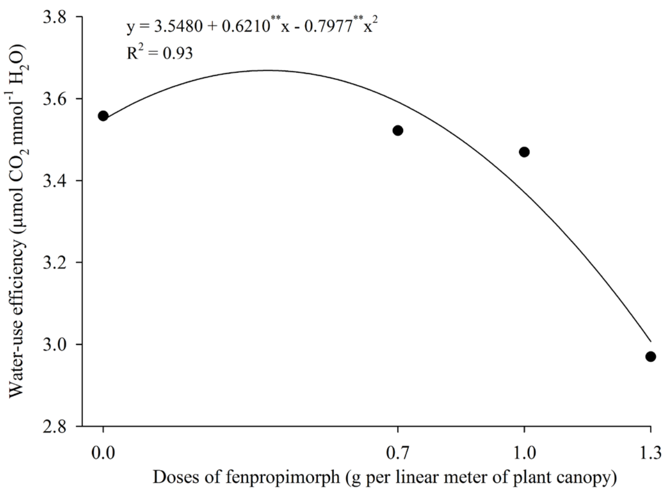
* - Mean differs from 5% PBZ treatment by Dunnett's test. 0, 0.7, 1.0, and 1.3 are fenpropimorph doses in g per linear meter of plant canopy

Figure 4. Transpiration (A) and water use efficiency (B) at 90 and 30 days after the first treatment application in the second experiment in 'Tommy Atkins' mango cultivated in the semi-arid region of Brazil

Under suitable environmental conditions, plants tend to have high physiological activity, including high transpiration rates (Silva et al., 2009). Mudo et al. (2020) observed that high transpiration rates and internal CO_2 concentrations are positively related to a larger number of reproductive buds, consequently favoring flowering and fruit yield.

In the second experiment, considering the doses of fenpropimorph, there was a quadratic response with the maximum value of 3.66 μmol CO_2 $mmol^{-1}$ H_2O for the estimated dose of 0.4 g FEN per linear meter of plant canopy (Figure 5).

In the second experiment, the highest water-use efficiency values were positively related to the highest CO_2 assimilation rates; however, this trend was only observed for the highest value in the first experiment. In this perspective, there seems to exist a relationship between these variables under suitable environmental conditions, especially regarding the water supply.



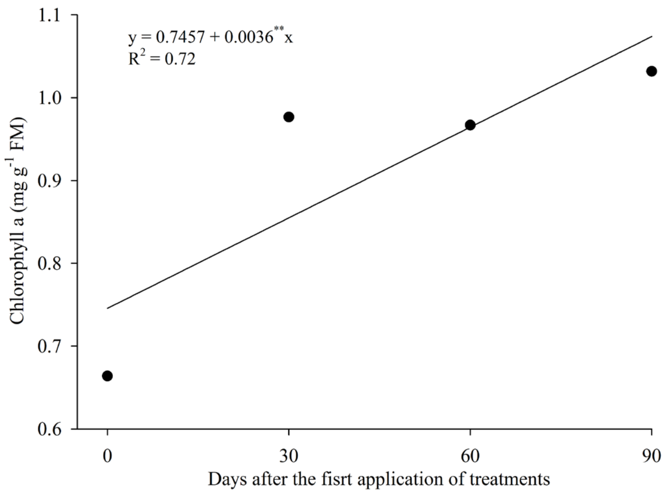
** - Significant at $p \leq 0.01$ by F test

Figure 5. Water-use efficiency as a function of fenpropimorph doses in the second experiment in 'Tommy Atkins' mango cultivated in the semi-arid region of Brazil

According to the results of gas exchanges, a higher plant physiological activity was observed at the beginning (0 and 30 ED) and at the end (90 ED) of the first experiment, which was severely affected by the water stress applied. This stress may have negatively affected the production and accumulation of reserves (carbohydrates) for the floral induction process, probably inducing a high photosynthetic activity in the period before floral induction (90 ED) to compensate for these possible losses.

The analysis of variance of the photosynthetic pigments (Table 3) reveals the difference between the treatments (fenpropimorph) in comparison to PBZ for chlorophyll a and total chlorophyll in the first experiment, with an individual effect of the evaluation dates.

In the chlorophyll a evaluation as a function of the evaluation dates, a significant effect was verified in the first experiment, with a linear fit (Figure 6), with an estimated



** - Significant at $p \leq 0.01$ by F test; FM - Fresh mass

Figure 6. Leaf chlorophyll a concentration in the first experiment as a function of days after the first application of treatments in 'Tommy Atkins' mango cultivated in the semi-arid region of Brazil

Table 3. Summary of analysis of variance for chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids as a function of treatments and evaluation dates

FEN (g per linear meter of plant canopy)	Chlorophyll a	Chlorophyll b	Total chlorophyll	Carotenoids
	(mg g^{-1} FM)			
		First experiment		
0.0	0.91*	0.27	1.18*	0.37
0.7	0.90*	0.29	1.19*	0.38
1.0	0.87*	0.29	1.16*	0.35
1.3	0.87*	0.29	1.15*	0.37
PBZ	1.00	0.33	1.33	0.41
ED	13.37**	7.16**	11.16**	11.23**
0	0.66	0.24	0.90	0.30
30	0.98	0.37	1.35	0.42
60	0.97	0.28	1.24	0.39
90	1.03	0.28	1.31	0.40
FEN	0.19^{ns}	0.23^{ns}	0.08^{ns}	0.31^{ns}
FEN X ED	1.07^{ns}	0.77^{ns}	1.09^{ns}	1.81^{ns}
CV (%)	24.71	26.78	22.93	22.72
		Second experiment		
0.0	0.73	0.25	0.98	0.32
0.7	0.76	0.22	0.98	0.32
1.0	0.84	0.19	1.03	0.33
1.3	0.81	0.23	1.04	0.34
PBZ	0.80	0.24	1.05	0.35
ED	1.59^{ns}	0.67^{ns}	1.38^{ns}	2.51^{ns}
0	0.78	0.21	0.99	0.35
30	0.74	0.21	0.95	0.30
60	0.76	0.25	1.01	0.31
90	0.87	0.24	1.11	0.35
FEN	0.69^{ns}	1.06^{ns}	0.20^{ns}	0.26^{ns}
FEN X ED	1.04^{ns}	1.29^{ns}	1.07^{ns}	1.20^{ns}
CV (%)	29	39.91	28.01	26.44

FEN - Fenpropimorph; ED - Evaluation dates; FM - Fresh mass; CV - Coefficient of variation; ** - Significant at $p \leq 0.01$ probability error by 'F' test; * - Significant at $p \leq 0.05$ probability error by Dunnett's Test (compared to PBZ); ns – Not significant maximum value of 1.07 at 90 days after the first application of treatments. In this perspective, these results suggest a response of the crop during the period of preparation for floral induction, especially in the synthesis of this specific pigment. However, due to the inhibition of vegetative growth and the advance of the physiological maturation of the branches during these phases, this pigment may naturally increase in the crop due to the non-emergence of new vegetative flushes and consequently lower leaf area/pigments ratio (Cunha, 2019).

For chlorophyll b, according to the evaluation dates in the first experiment, the highest value was found at 30 ED, differing from the remaining dates, and the regression model ($y = 0.2558 + 0.0033^{**}x - 0.00004^{**}x^2$, $R^2 = 0.43$) had a low coefficient of determination. The increase in chlorophylls a and b did not follow proportional patterns.

Regarding the total chlorophyll concentration as a function of the evaluation dates, a data distribution similar to that of chlorophyll a was observed in the first experiment (Table 3), but, adversely, the data were described by a linear regression model ($1.0330 + 0.0038^{**}x$, $R^2 = 0.51$), though the coefficient of determination was low, which is not recommended to estimate the total chlorophyll concentration.

The highest values of the chlorophyll a and total chlorophyll were recorded on the last three evaluation dates, confirming the probable accumulation of these pigments in response to the branch maturation phase for floral induction. The values found for total chlorophyll in this study are lower than those reported by Subbaiah et al. (2018) for 'Banganpalli' mango grown in India, with higher values of chlorophyll a and similar values of chlorophyll b.

Cunha (2019), in a study evaluating the influence of the application of proline and the algal extract of *Ascophyllum nodosum* in the 'Tommy Atkins' mango grown under conditions similar to those of this study observed higher values for all chlorophylls evaluated; however, the author reported that the water deficit caused by the reduction of water depth negatively affected the total chlorophyll concentration, which was not observed in this study. In this perspective, the use of biostimulants for branch maturation, in both experiments, may have reduced the stress and positively acted in the synthesis and mitigation of chlorophyll degradation with the supply of amino acids (Machold & Stephan, 1969).

For carotenoid results, a difference was recorded between PBZ and the other treatments in the first experiment, and the regulator promoted higher chlorophyll a and total chlorophyll in the general average (Table 3). Desta & Amare (2021) stated that this triazole (PBZ) acts on the accumulation of this specific pigment; however, Khalil & Khan (1995) observed that fenpropimorph did not interfere in the biosynthesis of chlorophylls and carotenoids in maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.).

When evaluating the carotenoid concentration as a function of evaluation dates in the first experiment, the data were described by a linear regression model ($y = 0.3351 + 0.0009^{**}x$, $R^2 = 0.42$), but the coefficient of determination was not high enough for it to be a reliable model for estimation purposes. Higher values of carotenoid concentration were also verified on the last three evaluation dates, differing from the first evaluation date (0 ED), which showed an inferior result, following the pattern of chlorophyll a and total chlorophyll. It is worth noting that the water depth reduction did not negatively affect the concentrations of leaf pigments, highlighting that carotenoid has a protective function against the injuries caused by excessive radiation (Taiz et al., 2017); therefore, it may have protected the remaining photosynthetic pigments.

Conclusions

1. The fenpropimorph dose of 1.3 g per linear meter of plant canopy promotes a higher rate of CO_2 assimilation in 'Tommy Atkins' mango cultivated in the semi-arid region.

2. Fenpropimorph application does not affect the accumulation of photosynthetic pigments in the 'Tommy Atkins' mango grown in the semi-arid region.

3. Paclobutrazol promotes greater accumulation of chlorophyll a and total chlorophyll in 'Tommy Atkins' mango cultivated in the semi-arid region.

Acknowledgements

The authors gratefully thank Fundação de Amparo a Ciência e Tecnologia do Estado de Pernambuco (FACEPE) for granting the scholarship under grant number IBPG-0146-5.01/18; Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for granting the research fellowship under grant number 307480/2019-4; and AJA Agrícola and FRUTAVI (Petrolina, Pernambuco, Brazil) for providing the structural support necessary to accomplish the experiments.

Literature Cited

Alvares, C. A.; Stape, J. L.; Sentelhas, P. C.; Gonçalves, J. L. M.; Sparovek, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v.22, p.711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507

Cavalcante, I. H. L.; Santos, G. N. F. dos; Silva, M. A. da; Martins, R. dos S.; Lima, A. M. N.; Modesto, P. I. R.; Alcobia, A. M.; Silva, T. R. de S.; Amariz, R. A.; Beckmann-Cavalcante, M. Z. A new approach to induce mango shoot maturation in Brazilian semi-arid environment. Journal of Applied Botany and Food Quality, v.91, p.281-286, 2018.

Cavalcante, Í. H. L.; Silva, G. J. N.; Cavacini, J. A.; Amariz, R. A.; Freitas, S. T. de; Sousa, K. Â. O. de; Silva, M. A. da; Cunha, J. G. da. Metconazole on inhibition of gibberellin biosynthesis and flowering management in mango. Erwerbs-Obstbau, v.62, p.89-95, 2020. https://doi.org/10.1007/s10341-019-00466-w

Chamberlain, K.; Patel, S.; Bromilow, H. Uptake by roots and translocation to shoots of two morpholine fungicides in barley. Pesticide Science, v.54, p.1-7, 1998. https://doi.org/10.1002/(SICI)1096-9063(199809)54:1%3C1::AID-PS792%3E3.0.CO;2-O

Cunha, J. G. da. Fornecimento de prolina e extrato de algas como atenuante do estresse abiótico em mangueira 'Tommy Atkins' cultivada no semiárido. Petrolina: UNIVASF, 2019. 90p. Dissertação Mestrado

Desta, B.; Amare, G. Paclobutrazol as a plant growth regulator. Chemical and Biological Technologies in Agriculture, v.8, p.1-15, 2021. https://doi.org/10.1186/s40538-020-00199-z

Genú, P. J. de C.; Pinto, A. C. de Q. A cultura da mangueira. 1.ed. Brasília: EMBRAPA, 2002. 452p.

Khalil, I. A.; Khan, S. Effect of morpholine systemic funigicides on the chloroplast pigments of wheat and maize. Giornale Botanico Italiano, v.129, p.791-795, 1995. https://doi.org/10.1080/11263509509436169

Lichtenthaler, H. K.; Buschmann, C. Chlorophylls and carotenoids: Measurement and characterization by UV-VIS spectroscopy, Current Protocols in Food Analytical Chemistry, v.1, p.431-438, 2001.

Machold, O.; Stephan, U. W. The function of iron in porphyrin and chlorophyll biosynthesis. Phytochemistry, v.8, p.2189-2192, 1969. https://doi.org/10.1016/S0031-9422(00)88179-0

MAPA. Ministério da Agricultura, Pecuária e Abastecimento. Brasília: MAPA, 2020. Available on: <https://agrofit.agricultura.gov.br>. Accessed on: Mar. 2021.

Mudo, L. E. D.; Lobo, J. T.; Carreiro, D. de A.; Cavacini, J. A.; Silva, L. dos S.; Cavalcante, Í. H. L. Leaf gas exchange and flowering of mango sprayed with biostimulant in semi-arid. Revista Caatinga, v.33, p.332-340, 2020. https://doi.org/10.1590/1983-21252020v33n206rc

Olk, D. C.; Dinnes, D. L.; Scoresby, J. R.; Callaway, C. R.; Darlington, J. W. Humic products in agriculture: Potential benefits and research challenges - a review. Journal of Soils and Sediments, v.18, p.2881-2891, 2018. https://doi.org/10.1007/s11368-018-1916-4

R Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2017. Available on: <https://www.r-project.org/>. Accessed on: Feb. 2020.

Ramoutar, D.; Cowles, R. S.; Requintina Jr, E.; Alm, S. R. Synergism between deinethylation inhibitor fungicides or gibberellin inhibitor plant growth regulators and bifenthrin in a pyrethroid-resistant population of *Listronotus maculicollis* (Coleoptera: Curculionidae). Journal of Economic Entomology, v.103, p.1810-1814, 2010. https://doi.org/10.1603/EC09374

Sandip, M.; Makwana, A. N.; Barad, A. V.; Nawade, B. D. Physiology of flowering - the case of mango. International Journal of Applied Research, v.1, p.1008-1012, 2015.

Santos, M. R. dos; Neves, B. R.; Silva, B. L. da; Donato, S. L. R. Yield, water use efficiency and physiological characteristic of "Tommy Atkins" mango under partial rootzone drying irrigation system. Journal of Water Resource and Protection, v.7, p.1029-1037, 2015. https://doi.org/10.4236/jwarp.2015.713084

Silva, L. dos S.; Silva, P. T. de S.; Cavalcante, Í. H. L. Impact of fulvic acid and free amino acids on paclobutrazol absorption by 'Keitt' mango. Revista Ambiente & Água, v.15, p.1-12, 2020. https://doi.org/10.4136/ambi-agua.2519

Silva, L. dos S.; Sousa, K. Â. O. de; Pereira, E. C. V.; Rolim, L, A.; Cunha, J. G. da; Santos, M. C.; Silva, M. A. da; Cavalcante, Í. H. L. C. Advances in mango 'Keitt' production system: PBZ interaction with fulvic acids and free amino acids. Scientia Horticulturae, v.277, p.109787, 2021. https://doi.org/10.1016/j.scienta.2020.109787

Silva, V. de P. R. da; Campos, J. H. B. da C.; Azevedo, P. V. de. Water-use efficiency and evapotranspiration of mango orchard grown in northeastern region of Brazil. Scientia Horticulturae, v.120, p.467-472, 2009. https://doi.org/10.1016/j.scienta.2008.12.005

Souza, M. A. de; Mésquita, A. C.; Simões, W. L.; Ferreira, K. M.; Araujo, E. F. J. Physiological and biochemical characterization of mango tree with paclobutrazol application via irrigation. Pesquisa Agropecuária Tropical, v.46, p.442-449, 2016. https://doi.org/10.1590/1983-40632016v4642829

Subbaiah, K. V.; Reddy, N. N.; Padmavathamma, A. S.; Reddy, M. L. N.; Rao, A. V. D. D.; Manjula, R.; Reddy, A. G. K. Effect of paclobutrazol on hermaphrodite flowers, leaf chlorophyll contents and soil microorganisms. International Journal of Current Microbiology and Applied Sciences, v.7, p.54-48, 2018.

Taiz, L.; Zeiger, E.; Moller, I. M.; Murphy, A. Fisiologia e desenvolvimento vegetal. 6.ed. Porto Alegre: ArtMed, 2017. 888p.

Upreti, K. K.; Prasad, S. R. S.; Reddy, Y. T. N.; Rajeshwara, A. N. Paclobutrazol induced changes in carbohydrates and some associated enzymes during floral initiation in mango (*Mangifera indica* L.) cv. Totapuri. Indian Journal of Plant Physiology, v.19, p.317-323, 2014. https://doi.org/10.1007/s40502-014-0113-8

Upreti, K. K.; Reddy, Y. T. N.; Prasad, S. R. S.; Bindu, G. V.; Jayaram, H. L.; Rajan, S. Hormonal changes in response to paclobutrazol induced early flowering in mango cv. Totapuri. Scientia Horticulturae, v.150, p.414-418, 2013. https://doi.org/10.1016/j.scienta.2012.11.030