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Effects of paclobutrazol and mepiquat chloride on the growth and development of plantain Dominico Hartón (*Musa* AAB)

Efectos de paclobutrazol y cloruro de mepiquat sobre el crecimiento y desarrollo del plátano Dominico Hartón (*Musa* AAB)

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First symptoms of the effect of growth regulators on plantain.

Photo: J.S. Arias-García

ABSTRACT

Colombia is the fourth largest producer of plantain in the world, with a harvest of 3,539,252 t. Various biotic and abiotic factors affect yields, including phytoparasitic nematodes that are a major constraint in this crop. For this reason, strategies are being sought to improve the performance of this plant with this cosmopolitan pest. This research evaluated the effect of two hormonal regulators on the growth and development of the Dominico plantain. The experiment design had treatments that were divided plots, where the main plot corresponded to the type of product, and the sub-plot corresponded to the concentrations of paclobutrazol and mepiquat chloride in the different doses: 0, 250 and 500 mg L^{-1}. The experiment unit consisted of ten plants with four replicates. The evaluated variables were plant height, diameter of the pseudostem, number of functional leaves, length and diameter of the roots, number of nematodes and variables for production quality. The two growth regulators reduced the plant height before emergence of the flower; paclobutrazol reduced the height by up to 40%, while mepiquat chloride reduced the height by up to 6.7%. There were no statistical differences in the production per plant, where the production with paclobutrazol was 14 kg/plant and, with mepiquat chloride, was 15 kg/plant. The control was 14.5 kg/plant. The use of growth regulators did not significantly restrict the damage caused by nematodes; however, paclobutrazol performed better as a growth regulator in the Dominico Hartón plants.

Additional keywords: crop management; yield; overturned; phytonematodes; bioregulators.

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RESUMEN

Colombia es el cuarto productor mundial de plátano con una cosecha de 3.539.252 t. Diversos factores bióticos y abióticos afectan a los rendimientos, siendo los nematodos fitoparásitos una de las principales limitaciones de este cultivo. Por esta razón, actualmente se están buscando estrategias para mejorar el rendimiento de esta planta con esta plaga cosmopolita. Esta investigación evalúa el efecto de dos reguladores hormonales en el crecimiento y desarrollo del plátano Dominico. El diseño experimental de los tratamientos se realizó en parcelas divididas, donde la parcela principal corresponde al tipo de producto, y la subparcela a las concentraciones de paclobutrazol y cloruro de mepiquat a diferentes dosis: 0, 250 y 500 mg L^{-1}, respectivamente. La unidad experimental constaba de diez plantas con cuatro réplicas. Las variables evaluadas fueron la altura de la planta, el diámetro del pseudotallo, el número de hojas funcionales, la longitud y el diámetro de las raíces, el número de nematodos y las variables de calidad de la producción. Los dos reguladores del crecimiento muestran una reducción de la altura de la planta antes de la emergencia de la flor, el paclobutrazol reduce la altura hasta un 40%, mientras que el cloruro de mepiquat reduce la altura hasta un 6,7%. No hay diferencias estadísticas en la producción por planta, la producción con paclobutrazol fue de 14 kg/planta, el cloruro mepiquat 15 kg/planta y el control con 14,5 kg/planta. El uso de reguladores de crecimiento no restringe significativamente el daño causado por los nemátodos, sin embargo, el paclobutrazol muestra un mejor desempeño como regulador de crecimiento en las plantas de Dominico Hartón.

Palabras clave adicionales: manejo del cultivo; rendimiento; volcamiento; fitonemátodos; reguladores de crecimiento.

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INTRODUCTION

Plantains are grown in all regions of the dry and humid tropics in Colombia, Ecuador and Venezuela and constitute one of the most consumed fruits in the world. Global plantain production is over 39 million tons (FAO, 2018). Colombia is among the top producers with 3,580,845 t (FAO, 2018). Production is led by Antioquia, Arauca and Valle del Cauca with 32% of the total production, as well as by the departments Meta, Quindío and Caldas (MADR, 2018). Farmers, particularly in the tropics, face considerable phytosanitary risks that often result in lost crops, reduced income, export restrictions and more (Avelino *et al*., 2012).

The management of plantain crops in the Colombian coffee zone presents phytosanitary problems as the result of yellow and black Sigatokas (*Mycosphaerella fijiensis* and *M. musicola*), bacteria that cause Moko (*Ralstonia solanacearum* Raza 2), and phytoparasitic nematodes, among others (Bautista *et al*., 2014).

Nematodes are some of the most limiting biotic factors worldwide and can generate up to 157 million US dollars in annual losses (Hassan *et al*., 2013). Phytonematodes affect bananas and cause direct damage to the roots by reducing mass and causing necrosis, as well as increased stem detachment and reduced bunch weights (Coyne *et al*., 2013). Accurate assessments of the effects of phytonematodes on banana and plantain production are scarce. Losses exceeding 50% have been confirmed in field evaluations (Roderick *et al*., 2012). In Colombia, although different varieties exist in the market, the Dominico Hartón plantain has the highest volume of commercialization. However, its susceptibility to nematode attack and height result in a higher incidence of overturning, which creates greater losses of productive units. In Caldas, losses from dumping have reached 70% (Guzmán *et al*., 2012). A reduction in plant height, an increase in pseudostem thickness and an increase in the lignification and thickness of roots in plantain plants not only reduce the probability of falling because of wind but also restrict attacks by nematodes, thereby providing a management alternative for this problem.

Several studies have shown a restriction in plant growth when using plant hormone inhibitors, finding that doses can influence some responses of plants, such as reducing vegetative growth, promoting flowering and fruit set (Ramirez *et al*., 2010), increasing fruit weight (Singh and Bhattacherjee, 2004), increasing root biomass (Partida *et al*., 2007), and reducing shoot elongation (Rademacher, 2015), among others.

Paclobutrazol inhibits gibberellin biosynthesis and has been widely used to improve agronomic traits such as plant height, abiotic stress resistance and antioxidant content (Fan *et al*., 2018). It also influences the physiological and morphological aspects of plants (Pal *et al*., 2016). In banana plants, Cavatte (2012) showed that treatments with paclobutrazol reduced the length of the pseudostem; likewise, Albany (2005), obtained not only a reduction in height but an increase in the diameter of the pseudostem in banana plants evaluated under *in vitro* conditions. Another inhibitor is mepiquat chloride, which works by inhibiting the synthesis of gibberellic acid, reducing the length of internodes, accelerating maturity and delaying abscission (Quintás *et al*., 2004). In bulb onions, mepiquat chloride increased the storage capacity of substances in the bulb, reduced plant height and increased yield and weight (El Sayed *et al*., 2012).

Reports on the use of growth regulators in banana cultivation are incipient. Strategies are being sought to improve the performance of plants with cosmopolitan pest management alternatives that facilitate the control of this pathogen and improve plant characteristics. The present study aimed to evaluate the effect of two hormonal regulators on the growth and development of plantain Dominico Hartón.

MATERIALS AND METHODS

This research was carried out in 2016-2017 on the Montelindo experimental farm of the University of Caldas (Palestina, Caldas), at 5°05' N and 75°40' W, with an altitude of 1,050 m a.s.l, an average temperature of 22.5 °C, relative humidity of 76%, annual rainfall of 2,100 mm and annual sunshine of 2,010 h (University of Caldas, 2016; Cenicafé, 2020).

The experiment design used treatments that were divided into plots, where the main plot corresponded to the type of product, and the sub-plot corresponded to the different concentrations of paclobutrazol and mepiquat chloride at a rate of 0, 250 and 500 mg L^{-1} . The experiment unit was ten plants with four replicates.

Corms (agronomic "seeds") with a similar weight from mother plants on the same farm were used, which were scraped and immersed for two hours in a solution with the growth regulators corresponding to each treatment. The planting was done using one corm per site, with 3 m between rows and 2 m between plants, for a population density of 1,666 plants/ha.

Fertilization: Four applications were done every 3 months: the first done at sowing with technical borax (5 g/plant) and urea (50 g plant), the second done with a physical mixture of DAP + KCl + urea at a rate of 100 g/plant of each; and the third and fourth done with KCl + urea at a rate of 200 g/plant.

Phytosanitary leaf removal: Four months after planting, leaves with more than 50% of leaf area with necrosis resulting from Sigatoka were removed weekly.

Weed management: Three applications of glyphosate (Round up®) were made with doses of 1.2 L ha^{-1}: the first done during preparation for sowing. The chemical handling was rotated with mechanical control using a string trimmer.

Dried plantain leaves of the pseudostem were removed every 3 months.

Flower removal: the flower structure of the plants was removed every 15 d after emergence of the flower.

Enfolding: after the flower removal, a perforated plastic bag covered the bunches to protect them from pathogens and insects.

The growth regulating products were applied to both the corm and the leaves. The corms were immersed before sowing in a solution with the two regulating products at concentrations of 0, 250 and 500 mg L^{-1}. Foliar applications of each product were made according to the treatment concentrations of 0, 250 and 500 mg L^{-1}. A total of three applications distributed in the first 6 months of the crop were used that started in the first month after sowing. Each plant was sprayed with 100 mL of the solution for the respective treatment.

The variables evaluated after emergence of the plant were plant height, expressed in meters (m), and diameter of the pseudostem, measured in the middle and expressed in centimeters (cm). These variables were measured every 30 d. Later, at emergence of the bunch, data were taken for the number of functional leaves. At harvest, data were taken for the number of hands, total bunch weight (kg), weight of the middle finger (g), length of the middle finger (cm) and diameter of the middle finger (cm).

Once the flower emerged, roots were extracted from two of the eight useful plants in each treatment and in each replication. The methodology entailed removing part of the soil from the base of the plant where the roots were located, leaving them exposed. Later, five root fragments were taken at random, and their diameter was measured at the middle part with a caliper kingpin, followed by the nematode extraction procedure in the laboratory.

The extraction of nematodes was carried out with the flotation of nematodes principle in a sugar solution, Araya (1995), which consisted of removing the roots and washing them with ordinary water, allowing them to dry at ambient temperature. 30 g samples were weighed on a precision balance (Analytical Plus 250). Scissors were used to transversely cut 1 cm pieces, which were then homogenized. These pieces were placed in a blender (Osterizer, model 565-15) with 500 mL of water and liquefied, turning the blender on and off three times for a period of 10 sec at 5 s intervals. The liquefied pieces were deposited on different sizes of sieves: 250, 106 and 25 μm. The sample was washed with water under pressure so that the nematodes and the material remaining on the 25 μm sieve were released. Then, the entire contents, approximately 25 mL, were deposited in 50 mL centrifuge tubes. 25 mL of 50% sucrose (sugar solution) were added to each tube, and the tube was centrifuged at 3800rpm for 5 min. There was sedimentation of the heavy particles at the bottom of the tube. The nematodes were in an intermediate layer (sucrose gradient). All the water was extracted from each tube, where the interface with the nematodes was located, using a syringe connected to a hose to facilitate extraction. After the nematodes were removed, they were placed on a 25 μm sieve and washed with plenty of water to prevent the sugar from affecting the nematodes. Finally, 20 mL were collected in a Petri dish for counting and identification.

The data obtained with all the response variables were subjected to analysis of variance and the Tukey comparison test for separation of the treatment media. In addition, a regression analysis was made for the variable plant height. The models adjusted by the means of regression were chosen based on significance at 5% probability, using the statistical package SAS (System of Statistical Analysis) version 9.0.

RESULTS AND DISCUSSION

The plant height showed statistical differences between the products . Ninety days after planting, the plants treated with Paclobutrazol had an average height of 21 cm, while the plants treated with mepiquat chloride had a height of 34 cm, with a difference of 13 cm. At this developmental stage, the average height of the control treatment was 35 cm; the inhibitory effect on plant elongation by paclobutrazol was evident although mepiquat chloride also generated this inhibitory effect but to a lesser extent (Fig. 1).

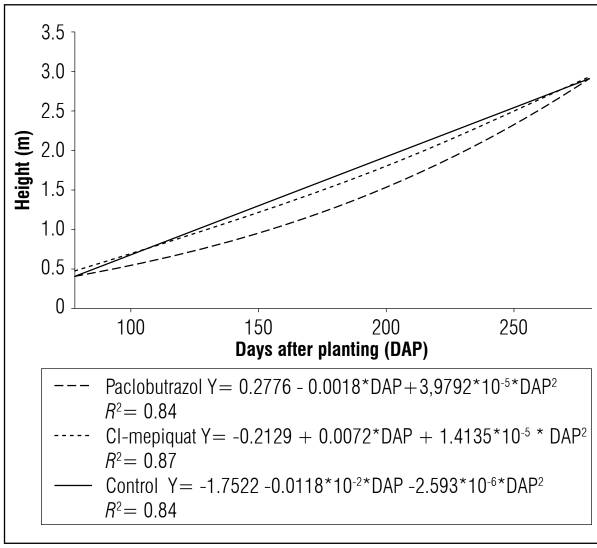

Figure 1. Effect of the application of paclobutrazol and mepiquat chloride on the pseudostem height of Dominico Hartón plantain plants in Palestina, Caldas (Colombia).

The opposite occurred with mepiquat chloride. The initial stages did not have a decrease in plant height but, at 60 d after planting, the plants delayed growth, and the restrictive effect of the treatment was evident. However, although there was no constant trend in the inhibiting effect of the products on plant growth, a reduced plant height was always generated (Fig. 1). This behavior can be explained by the fact that one of the main functions of gibberellic acid is the elongation of the hypocotyls and stems (Bose *et al*., 2013); the synthesis of this hormone is affected by inhibitors, with a consequent reduction in plant height, as reported by Cavatte (2012) in banana plants that were subjected to different treatments with paclobutrazol, with a reduction in pseudostem length of up to 57%. Likewise, banana plants sprayed at the apex of the stem with paclobutrazol had lower height values than the control (Chang *et al*., 2019). Kamran *et al*. (2018) reported that maize plants treated with mepiquat chloride had reduced stem and ear heights.

Thus, this study showed that both mepiquat chloride and paclobutrazol affect cell elongation under field conditions and, therefore, decrease plant height by up to 40% when compared to the control.

For pseudostem diameter, this study revealed that both paclobutrazol and mepiquat chloride generated a reduction in the thickness of the pseudostem when compared to the control (Tab 1). This result is similar to that obtained by Maia *et al*. (2008), who submitted two banana cultivars to treatments with paclobutrazol via foliar spraying and obtained a reduction in the diameter of the pseudostem.

Variables such as bunch weight and number of hands did not show significant differences when subjected to the application of hormonal inhibitors (Tab 2). According to Cavatte (2012), the application of paclobutrazol to banana plants does not influence the productivity of the crop. However, Li-Na *et al*. (2018) reported that the mixture of potassium phosphate and paclobutrazol applied to banana pseudostems improves some quality characteristics in the mother plant; nevertheless, it should be noted that this procedure resulted in the death of pseudostems treated with the mixture, indirectly caused the effect on some variables of the mother plant.

For the variable root thickness, the statistical differences between treatments were highly significant. While, the plants treated with mepiquat chloride had an average root thickness of 0.60 mm, those treated with paclobutrazol were 0.67 mm thick (Tab 2). De Souza *et al*. (2010) worked with banana plants FHIA 01 in micropropagation and obtained an increase in the percentage of rooting with the application of paclobutrazol. It is likely that the variation in root thickness from one treatment to another was due to the increase in cytokinins generated by the action of the hormone inhibitors. The application of phytoregulators such as paclobutrazol not only inhibit the synthesis of gibberellins in the plant but also increase the biosynthesis of cytokinins, which are responsible for stimulating root growth and the appearance of shoots. In carrot plants (*Daucus carota*), for example,

Table 1. Effect of the application of paclobutrazol and mepiquat chloride on the growth of the pseudosteam in Dominico Hartón plantain plants in Palestina, Caldas (Colombia).

Inhibitor	Diam 1 (cm)	Diam 2 (cm)	Diam 3 (cm)	Diambel (cm)
Paclobutrazol	7.8±0.98 a	10.5±1.47 b	13.6±1.70 a	18.9±0.28 a
Cl-mepiquat	8.2±0.51 a	11.4±0.81 a	12.4±1.34 b	19.1±1.04 a
Control	8.6±0.60 a	11.8±0.61 a	14.3±0.92 a	19.3±0.43 a
DMS (10%)	0.68	0.9	0.97	0.52

Diam: Diameter of pseudostem after emergence 1(30 dae), 2 (60 dae), 3 (90 dae); Diambel: Diameter of the pseudostem at flowering. */ Means in each column followed by different letters denote significant differences according to Tukey's test (5%). ± indicates the standard deviation and variation of the data according to the average. DMS: LSD value of Tukey's test.

Table 2. Effect of the application of paclobutrazol and mepiquat chloride on the growth of the Dominico Hartón plantain plants in Palestina, Caldas (Colombia)

Inhibitor	Hfun	Prac (kg)	NMR	PDC (g)	LDC (cm)	DDC (cm)	Grora (mm)	Numne
Paclobutrazol	10±1.35 a	14.1±0.84 a	5.4±0.64 a	366±64.32 a	25±1.51 a	4,6±0.2 a	0.67±0.05 a	2332±444.39 a
Cl-mepiquat	10±0.09 a	15±0.77 a	5.3±0.40 a	339±36.60 a	24±0.47 a	4.6±0.28 a	0.60±0.08 b	1928±1038.09 a
Control	10±0.21 a	14.5±1.43 a	5.2±053 a	367±42.33 a	25±1.77 a	4.6±0.27 a	0.65±0.05 a	2607±2350.15 a
DMS (10%)	0.49	1.42	0.63	38.68	1.32	0.22	0.03	1481

Hfun: Functional leaves; Prac: Bunch weight; NMR: Number of hands on the bunch; PDC: Weight of the middle finger; LDC: Length of middle finger; DDC: Middle finger diameter; Grora: Thickness of roots; Numne: Number of nematodes. Means in each column followed by different letters denote significant differences according to Tukey's test (5%) ± indicates the standard deviation and variation of the data according to the average. DMS: LSD value of Tukey's test.

the application of paclobutrazol inhibited gibberellins and increased cytokinin biosynthesis, leading to increased starch content and dry matter accumulation in the root (Gopi *et al*., 2007).

In tomato plants (*Solanum lycopersicum* Mill.), paclobutrazol reduced plant height, increased stem thickness and increased root development (Berova and Zlatev, 2000), explaining the increase in banana root thickness.

No statistically significant differences were found between the treatments for the number of nematodes, confirming that the increase in the size of the roots was due to an increase in cell division that was apparently generated by the effect of cytokinins. This stimulus was not associated with a strengthening of the cell wall and was, therefore, independent of the increase in the thickness of the roots. The nematodes did not have difficulty penetrating the cells, causing cell death and colonizing the root system of the plant.

CONCLUSION

Paclobutrazol and mepiquat chloride reduced the plant height by 40% and 6.7% but did not shorten the production cycle or significantly increase bunch weight in the Dominico Hartón plantain.

The application of paclobutrazol increased the thickness of the roots but did not restrict the presence of phytoparasitic nematodes.

The use of hormonal regulators appears to be an alternative for diminishing the negative effects of attacks by phytoparasitic nematodes in Dominico Hartón plantain plants.

The use of these hormone inhibitors at doses over 250 mg L^{-1} generated initial symptoms of poisoning in the Dominico Hartón plantain plants.

Conflict of interests: The manuscript was prepared and reviewed with the participation of the authors, who declare that there exists no conflict of interest that puts at risk the validity of the presented results.

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