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SCIENTIFIC ARTICLE

# Use of paclobutrazol and ethylene in the potted production of ornamental pineapple

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**Abstract**

The expansion of residential areas has increased the demand for exotic and increasingly compact landscape plants. In this context, this work aimed to evaluate the effects of paclobutrazol (PBZ) and the timing of ethylene application on growth reduction and flowering anticipation in ornamental pineapples grown in pots. The randomized block design was used with factorial arrangement (2 x 5) and 4 replications and 4 plants per plot. The primary treatments are the presence and absence of PBZ. The secondary treatments were five times of floral induction with ethylene: 90; 120; 150; 180; 210 days after transplanting (DAT) the seedlings into the pots. It was evaluated the variables: height ratio between the heights of the pot and the plant; rosette diameter; leaves length 'D' and flowering index. At 255 DAT, although the plants did not respond to floral induction with ethylene, only those treated with PBZ were more compact and had different characteristics such as smaller size and a ratio below 1/3 of the height of the vase in relation to the plant that to favor its commercialization, in pot.

**Keywords:** *Ananas comosus* L., floral induction, plant growth regulator.

**Resumo**

**Uso de paclobutrazol e etileno na produção envasada de abacaxizeiro ornamental**

A diminuição das áreas residenciais tem aumentado a demanda por plantas paisagísticas exóticas e cada vez mais compactas. Neste contexto, o objetivo deste trabalho foi avaliar os efeitos do paclobutrazol (PBZ) e das épocas de aplicação de etileno na redução do crescimento e na antecipação da floração em abacaxizeiro ornamental cultivado em vaso. O delineamento experimental utilizado foi o de blocos ao acaso, em arranjo fatorial (2 x 5), com 4 repetições e 4 plantas por parcela. Os tratamentos primários foram a presença e a ausência de PBZ. Os tratamentos secundários foram cinco épocas de indução floral com etileno: 90; 120; 150; 180; 210 dias após o transplantio (DAT) das mudas, para os vasos. Foram avaliadas as variáveis: altura da planta; relação entre as alturas do vaso e da planta; diâmetro da roseta; comprimento da folha 'D' e índice de florescimento. Aos 255 DAT, apesar das plantas não responderem à indução floral com o etileno, apenas aquelas tratadas com PBZ apresentaram-se mais compactas e com características diferenciadas como menor porte e relação abaixo de 1/3 da altura do vaso em relação a da planta que favorecer sua comercialização, em vaso.

**Palavras-chave:** *Ananas comosus* L*,* indução floral, regulador vegetal.

## Introduction

The Brazil, due to its geographic location, has easy access to the international market in the productive sector of flowers and ornamental plants, which can generate opportunities for new ventures (Costa Junior et al., 2016). In 2021, floriculture agribusiness registered around 210 thousand jobs, thus proving the significant social and economic impact of this sector (Ibraflor, 2022). The characteristics of the landscape effect of ornamental plants are usually associated with their degree of exoticity, durability and forms of commercialization. In this context, the ornamental pineapple tree is of great importance for the sector, as it is an exotic species, with high durability and that can be marketed as flowers, foliage and cut mini-fruits

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and also as potted plants (Lima et al., 2017a; Nóbrega et al., 2017; Pereira et al., 2018).

The most expressive segment was that of potted plants, which in 2021 represented 58% of the cultivated area in Brazil (Ibraflor, 2022). The growing demand for pot cultivation (Santos et al., 2021; Pereira et al., 2018) motivated Embrapa to develop a hybrid resulting from the cross between *Ananas comosus* var. *bracteatus* with *A. comosus* var. *erectifolius* (Costa Junior et al., 2016). This hybrid, called the 'D' hybrid, is mainly aimed at potted cultivation (Carvalho et al., 2019, Nascimento et al., 2019). It is worth mentioning that the main varieties of ornamental pineapple commercialized are *A. comosus* var. *erectifolius*, *A. comosus* var. *bracteatus* and *A. comosus* var. *ananassoides* (Costa Junior et al., 2016).

In addition to the development of new genotypes, the use of plant regulators is an alternative to accelerate the production of plants with reduced size and adjusted to commercial standards (Petri et al., 2016; Junqueira and Peetz, 2017; Lima et al., 2017b). Regulators such as paclobutrazol (PBZ) and ethylene can, respectively, reduce the growth and induce flowering of various crops (Taiz et al., 2017), such as peppers (*Capsicum annuum* and *C. chinense*) (França, et al., 2018; Mortate et al., 2018; Nascimento et al., 2022), physalis (*Physalis angulata*) (Bosch et al., 2016) and edible pineapple *A. comosus* var. *comosus* (Mendes et al., 2011).

Regardless of the genotype, pineapple production is long, as the response to floral induction depends on the age and/or size of the plant (Fernandes et al., 2018; Ribeiro et al., 2019). Normally, this response occurs 10 - 12 months after planting the seedling in the field or pots (Costa Junior et al., 2016; Carvalho et al., 2019).

In this context, the use of PBZ in ornamental pineapple presents itself as an alternative to reduce the size of the plants and/or make them more attractive to consumers, who seek exotic, more compact, durable and simple to handle products. Ethylene, on the other hand, if applied at the right time, would make it possible to accelerate the flowering and commercialization of the product.

As information on growth reduction and anticipation of floral induction of ornamental pineapple is lacking, this work aimed to evaluate the effects of PBZ and ethylene application times on the growth and flowering 'D' hybrid of ornamental pineapple grown in pots.

## Materials and Methods

The experiment was carried out in the experimental area of Embrapa Agroindústria Tropical, located in Fortaleza, Ceará State, Brazil (3°45'05"S, 38°34'35" W and 30 m altitude). The climate of the region, according to the Köppen climate classification, is Aw', characterized as rainy tropical, very hot, with predominant rainfall in the summer and autumn seasons, and an average temperature above 18 °C (Santos, 2017). The temperature and relative humidity data were recorded during the experiment using dataloggers installed in the cultivation area (Figure 1).

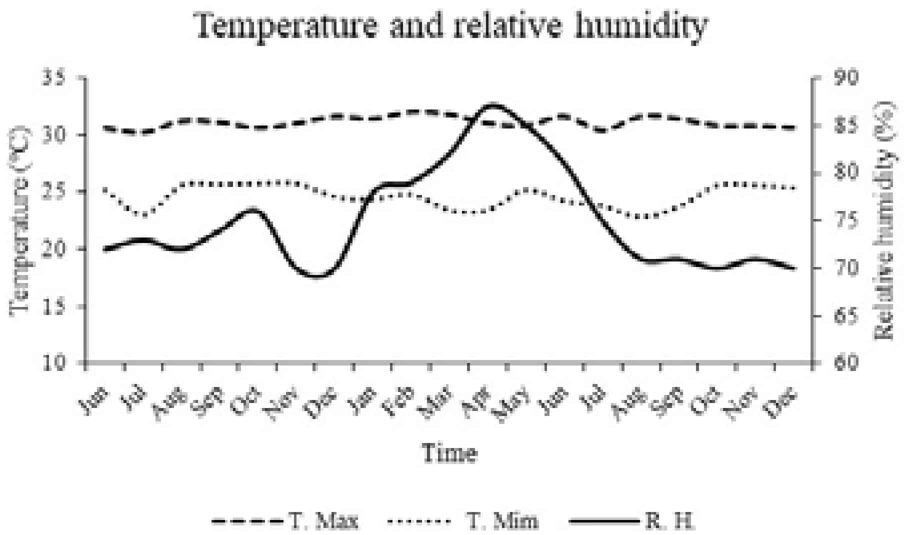


**Figure 1.** Mean monthly values of maximum and minimum temperatures and relative air humidity, throughout the experiment with the ornamental pineapple hybrid (*Ananas comosus* var. *bracteatus* x *A. comosus* var. *erectifolius*), under pot cultivation, in the greenhouse at Embrapa Agroindústria Tropical, Fortaleza, Ceará State. 2018/2019.

Micropropagated seedlings of ornamental pineapple, hybrid 'D', were used, acclimatized for four months in a greenhouse with 70% shading (Colombo et al., 2017). During this period, the seedlings were placed in plastic trays and a liter of macro and micronutrient solution from MS (Murashige and Skoog, 1962; Reinhardt et al., 2018) at 50% concentration was used for their weekly fertilization and irrigated by micro-sprinkler.

After acclimatization, the seedlings, with 5.0 to 8.0 cm in height and 12 to 16 leaves, were selected and transplanted to a 50% shading screen, containing a transparent plastic cover to eliminate rainfall interference.

The commercial substrate (Germina Horta®) used throughout the cultivation cycle was peat-based recommended for seed germination and the production of vegetable seedlings. This substrate replaces the soil and eliminates the use of methyl bromide in sowing, has a pH of 5.8 ± 0.2, and electrical conductivity (EC) of 0.5 ms/cm. The commercial vessel used was nº 15, with an upper diameter of 0.14 m, a lower diameter of 0.10 m, a height of 0.12 m and an approximate volume of 1.0 L, spaced 0.15 m apart and between rows, on the benches of the screen.

Fertilization was carried out with 13.2 g plant$^{-1}$ of NPK 15-09-12 (Osmocote©). This dose was divided into three quarterly applications (4.4 g plant$^{-1}$ application), after transplanting, as recommended by Santos et al. (2021). The irrigation water of the plants had the following physicochemical characteristics: 0.4 mmol L$^{-1}$ Ca; 1.2 mmol L$^{-1}$ Mg, 2.5 mmol L$^{-1}$ Na; 0.2 mmol L$^{-1}$ K; 4.6 mmol L$^{-1}$ Cl; EC of 0.45 dSm$^{-1}$; RAS of 1.97 and pH of 6.8, classified as $C_2S_1$.

Irrigation was carried out by automated superficial drip. The main features of this system include: timer; solenoid valve; water reservoir; pump assembly; disk filter; PVC main and branch lines ($\phi$ = 32 mm) and side lines ($\phi$ = 16 mm); ball registers; manometer with glycerin; and self-compensating drippers with a flow rate of 2 L h$^{-1}$. The coefficient of uniformity of water distribution was superior to 90% in the irrigation system.

The water depth used was between 1.4 and 5.5 mm, depending on the stage of plant development, divided into two irrigation pulses (08:30 am and 04:30 pm), from transplanting to 90 days after transplant (DAT). The choice of irrigation depth (ID) was based on the low water demand of young plants and the water retention curve (WRC) of the substrate. After this period, the ID was increased to 5.5 mm in three irrigation pulses (8:30 am; 01:30 pm and 05:00 pm), according to observations on drainage and plant status after irrigation.

The randomized block experimental design was used with factorial arrangement (2 x 5), 4 replications and 4 plants per plot. The primary treatments were the presence and absence of paclobutrazol. PBZ (purity 90 mg a.i. L$^{-1}$) was dissolved in 50 mL of distilled water and applied to the rosette of each plant (Bosch et al., 2016), at 150 days after planting, a period in which the crop presented adequate vegetative growth (Carvalho et al., 2019). The secondary treatments were five times of floral induction with ethylene: at 90, 120, 150, 180 and 210 days after transplanting the seedlings to the pots (DAT). A solution containing 0.5 mL of Ethrel® 240 (Bayer), 0.35 g of calcium hydroxide and 20 g of urea in 1 L of water with a final pH between 7 and 8 was used. 40 mL of this solution were manually applied on the rosette of each plant, according to the methodology recommended by Mendes et al. (2011).

For pot cultivation, Souza et al. (2012) recommend the following characteristics: plant height ≤65 cm; rosette diameter ≤80 cm; leaves length ‹D› ≤ 60 cm; peduncle length ≤ 30 cm; syncarpium length ≤ 5 cm; syncarpium diameter ≤ 3 cm; crown length ≤ 5 cm; and the crown/syncarpium ratio should be close to 1. In addition, the plants should not have thorns of the leaf's margins, ideally being a ratio of 1/3 in the height of the pot in relation to the plant.

At 255 DAT, the variables of plant height and diameter, number of leaves, ‹D› leaves length, aesthetic quality, pot height/plant height ratio and flowering index were evaluated. The aesthetic quality was obtained according to the correlation between the data obtained and the required commercial characteristics and the flowering index by counting the plants that flowered.

The variables were obtained from the sampling of all the plants of each treatment: A) the height of the plant: distance from the neck of the plant to the insertion of the highest leaf, without altering its architecture; B) the diameter of the rosette: distance between the two opposite leaves of greater length; C) the number of sheets: counting in a simple manual way; and D) the length of leaves ‹D›: distance from the insertion of the leaves in the stem to the apex of the leaf. All measurements were made with the aid of a graduated measuring tape.

Statistical analysis was performed with the help of the SISVAR software. After submitting the data to ANOVA, the primary treatments (presence and absence of PBZ) were compared by the Tukey test and the secondary treatments (applications of ethylene) by regression analysis of variance (linear and quadratic models). All analyzes were performed considering the 5% probability level ($p < 0.05$).

## Results and Discussion

According to the analysis of variance, the vegetative growth variables responded only to the application of PBZ and there was no difference in the application of ethylene and also for the interaction between PBZ **x** ethylene (Table 1).

The average values of the vegetative growth variables in plants with and without PBZ are shown in Table 2.

The plants treated with PBZ, when compared to the untreated ones, showed a reduction in all the evaluated variables of vegetative growth. This reduction was, on average, 58% (plant height and rosette diameter), 41% (number of leaves per plant), 64% (leaves length 'D') and the pot height/plant height ratio was 1/2 within the recommended parameter of 1/3 (Souza et al., 2012). The difference in height, rosette diameter, number of leaves and the length of leaves 'D' shows the effect of PBZ on plant development (Figure 2).

**Table 1.** Summary of analysis of variance for the vegetative growth variables of the ornamental pineapple 'D' hybrid (*A. comosus var. bracteatus x A. comosus var. erectifolius*) grown in pots, under greenhouse conditions, at 255 DAT.

| SV | DL | Medium Square ($p < 0{,}05$) | | | | |
|---|---|---|---|---|---|---|
| | | PH | HP/PH | RD | NL | LLD |
| Block | 3 | $43.3^{ns}$ | $0.009^{ns}$ | $86.3^{ns}$ | $43.6^{ns}$ | $11.5^{ns}$ |
| PBZ (P) | 1 | $12281.5^{*}$ | $0.832^{*}$ | $16091.3^{*}$ | $14830.2^{*}$ | $9520.9^{*}$ |
| Ethylene (E) | 4 | $92.6^{ns}$ | $0.006^{ns}$ | $71.4^{ns}$ | $22.7^{ns}$ | $57.3^{ns}$ |
| P x E | 4 | $52.9^{ns}$ | $0.003^{ns}$ | $41.8^{ns}$ | $203^{ns}$ | $57.4^{ns}$ |
| Erro | 27 | 63.4 | 0.007 | 56.7 | 42.3 | 53.1 |
| CV (%) | | 18.5 | 23.4 | 15.2 | 8.8 | 22.2 |

* significant; $^{ns}$ not significant; SV: source of variation; DL: degrees of liberty; CV: coefficient of variation; PH: plant height; PH/HP: relationship between pot height and plant height; RD: rosette diameter; NF: number of leaves LLD: leaves length 'D'.

**Table 2.** Mean values of the vegetative growth variables of the ornamental pineapple 'D' hybrid (*A. comosus var. bracteatus x A. comosus var. erectifolius*) cultivated in pots, under greenhouse conditions, at 255 DAT.

| PBZ | PH (cm) | HP/PH | RD (cm) | NL | LLD (cm) |
|---|---|---|---|---|---|
| WITH | 25.5 b | 0.49 a | 29.6 b | 55.1 b | 17.5 b |
| WITHOUT | 60.6 a | 0.21 b | 69.7 a | 93.6 a | 48.3 a |

Means followed by the same letters or without letters in the columns do not differ from each other by the Tukey test ($p < 0.05$); PH: plant height; HP/PH: relationship between pot height and plant height; RD: rosette diameter; NL: number of leaves; LLD: leaves length 'D'; WITH: plants treated with paclobutrazol (PBZ); WITHOUT: plants not treated with PBZ.


**Figure 2.** Differences between plants of the ornamental pineapple 'D' hybrid (*A. comosus* var. *bracteatus* x *A. comosus* var. *erectifolius*), grown in pots and treated with (left) and without paclobutrazol (right), after application of ethylene, at 255 DAT, Fortaleza, Ceará. 2019. A) lateral perspective of plants; B) aerial perspective of the rosettes of the plant treated with (above) and without paclobutrazol (below).

The results show that plant development was influenced by the effects of paclobutrazol as a growth regulator. The PBZ is a gibberellin inhibitor and acts to reduce cell elongation, which generates a reduction in the size of plant organs, its effect is proportional to the dose applied to the species used (Taiz et al., 2017; Xin et al., 2019). The meristematic regions of the stem and leaves are the organs most influenced by PBZ, as observed by Bosch et al. (2016) in *physalis* and Ribeiro et al. (2019) on *Capsicum* sp.

The application of ethylene did not induce flowering of the plants until 255 DAT. Costa Junior et al. (2016) observed that plants of this same ornamental pineapple hybrid, grown in the field in the same region, responded to floral induction when they had a height of 60 cm and leaves length 'D' of 53 cm. Factors such as photoperiod and temperature environmental conditions may have interfered in the results obtained (Cunha, 2009; Küster et al., 2017; Xin et al., 2019).

Nascimento et al. (2018), some cultivars of ornamental peppers, such as Peloteira and Jalapeño, showed resistance to ethylene when subjected to increasing concentrations of PBZ. According to this author, a secondary effect of ethylene application was the increase in leaves and fruit abscission in plants treated with and without PBZ. Nascimento et al. (2022) also reported variation in the level of ethylene sensitivity in ornamental pepper genotypes.

According to Ribeiro et al. (2019) the effects of hormones depend on the species and stage of development of the plant. Although in most higher plants ethylene is active at low concentrations, the intensity of its effects is mainly due to the sensitivity of the species (Taiz et al., 2017; Xin et al., 2019). In the case of ornamental plants, sensitivity is generally defined at the taxonomic family level and rusticity, such as pineapple (Serek et al., 2006).

It was found that plants treated with PBZ were more sensitive to ethylene than untreated plants. In some plants, necrosis was observed in the edges of the leaves near the apex (Figures 3A and 3B). Ethylene is an important hormone in the senescence process, however, it can have negative effects on fruits, flowers and leaves and reduce the vase life of many cut flower species (Serek et al., 2006; Nascimento et al., 2018).

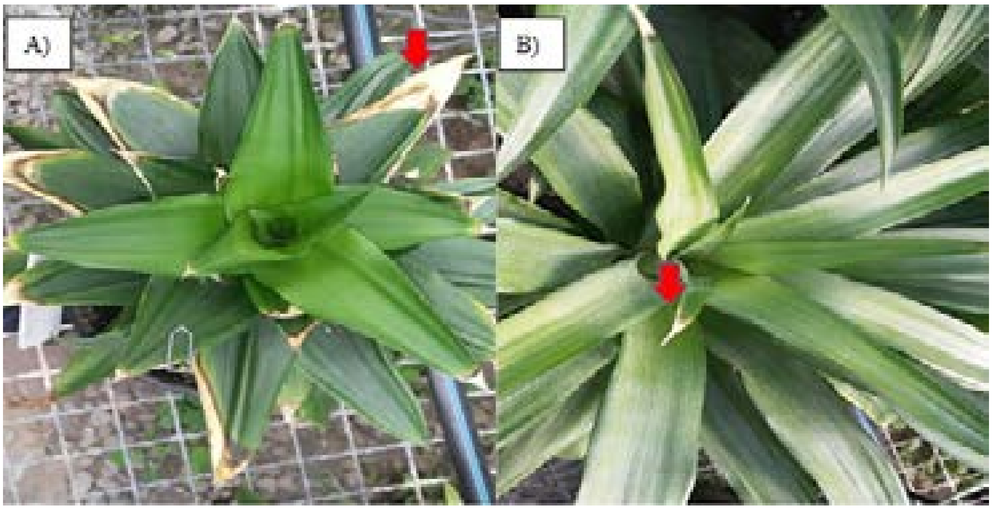


**Figure 3.** Necrosis, on the edges of the leaves near the apex, generated by the application of ethylene in the 'D' hybrid of ornamental pineapple (*A. comosus* var. *bracteatus* x *A. comosus* var. *erectifolius*), treated with (A) and without (B) PBZ, at 255 DAT.

Correia et al. (2011) observed that ornamental pineapple plants (*A. comosus* var. *erectifolius*) obtained by micropropagation responded to floral induction with ethylene between 10 and 12 months after planting in the field. Carvalho et al. (2019), used young seedlings of the same hybrid, grown in pots and kept in a greenhouse with 50% shading, found a response to ethylene at 10 - 12 months after planting. Costa Junior et al. (2016) found that plants of this genotype responded to ethylene between 13.5 and 15 months after planting in the field, under climatological conditions similar to the present study.

In edible cultivars, the nutritional stage, type, seedling weight and planting time are factors that interfere in the response of plants to floral induction (Reinhardt et al., 2018). In addition, it is clear that the response to natural or artificial induction is generally determined by the age and size of the plant, as well as by environmental factors in the growing region (Cunha, 2009; Fernandes et al., 2018; Ribeiro et al., 2019).

The seedlings used in the experiment were initially acclimatized in plastic trays during 120 DAP in an environment with 70% of shading. Subsequently, they were transplanted to the definitive planting site, which contained 50% shading, and covered with transparent plastic for another 255 days. Maybe the initial 70% shading generated a lower incidence of direct radiation, reducing the photosynthetic activity of the plant and consequently prolonging its juvenility (Taiz et al., 2017; Xin et al., 2019).

In the transition from the vegetative to the reproductive (flowering) phase, plants must be physiologically mature (Küster et al., 2017). The lack of floral differentiation occurs when plants are not physiologically developed (Ribeiro et al., 2019), which possibly occurred in the present work.

Floral differentiation, in plants treated with paclobutrazol, may present specificities in relation to untreated plants, due to PBZ, which, in addition to inhibiting the biosynthesis of gibberellins, can also alter the levels of cytokinins, abscisic acid and ethylene, with repercussions for a longer period juvenile of plants (França et al., 2018; Ribeiro et al., 2019; Nascimento et al., 2022).

Taiz et al. (2017) report that PBZ is an effective inhibitor of ethylene synthesis, due to the inhibitory effect on the conversion of ACC (1-aminocyclopropane-1-carboxylic acid) to ethylene. This inhibition by PBZ possibly must have influenced the process of floral induction of the seedlings. Furthermore, Oliveira et al. (2021) mention that micropropagated pineapple seedlings are more sensitive and have greater juvenility, even when they are correctly acclimatized.

Regarding aesthetics, the application of PBZ, in addition to reducing the size of the plants (Figure 4A), accentuated the color of the leaves and increased the symmetry of the rosette (Figure 4B). These different characteristics in relation to untreated plants (Figures 4C, D) make the ornamental pineapple even more exotic, favoring its commercialization as a potted plant, even without the presence of the flower stem.


**Figure 4.** Plants of the 'D' hybrid (*Ananas comosus* var. *bracteatus* x *A. comosus* var. *erectifolius*) of ornamental pineapple treated with paclobutrazol at 210 DAT: lateral perspective of the plant (A) and aerial perspective of the rosette (B), and untreated plants: lateral perspective of the plant (C) and aerial perspective of the rosette (D).

The plants are more compact and have a different visual appearance due to the accentuation of the color of the leaves, which may probably be due to the higher concentration of chloroplasts in relation to the smaller leaves area. In addition, the lack of spines of the 'D' hybrid requires simpler handling and is highly resistant to adverse conditions such as water deficit (Mendes et al., 2011; Nóbrega et al., 2017), desired circumstances in ornamental plants for interior decoration (Pereira et al., 2018).

The plants not treated with PBZ, even with the recommended dimensions for potted cultivation, presented a pot height/plant height ratio greater than 1/3. This disproportionate relationship caused the plants to fall, making commercialization impossible and making cultural practices difficult throughout the cycle (Figure 5). Souza et al. (2012) reports that the relationship between plant height and pot size is important to form a harmonic set, suggesting that it should be 1.5 to 3 times the height of the pot.

**Figure 5.** Tumbled plant of ornamental pineapple hybrid 'D' (*A. comosus* var. *bracteatus* x *A. comosus* var. *erectifolius*) not treated with paclobutrazol, at 255 DAT

As a suggestion for future work, it is recommended to test different doses and times of application of PBZ and ethylene in micropropagated seedlings of ornamental pineapple, under pot cultivation, in order to obtain floral induction.

## Conclusions

Micropropagated plants of the 'D' hybrid (*Ananas comosus* var. *bracteratus* x *A. comosus* var. *erectifolius*) of ornamental pineapple, grown in pots and under greenhouse conditions, did not respond to floral induction with ethylene until 255 days after transplanting.

Ornamental pineapple plants not treated with paclobutrazol did not meet the recommended dimensions for commercialization in pots, especially with a pot/plant height ratio above 1/3, causing tipping over.

The ornamental pineapple plants treated with 4.5 mg plant$^{-1}$ the paclobutrazol met all the dimensions recommended for commercialization in pots related to plant height, leaves length 'D' and pot/plant height ratio lower 1/3 and showed morphophysiological changes that may favor their negotiation with more intense green coloration, reduced size and greater symmetry of the rosette.

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#### Author Contribution

**HOT, GVB:** conceptualization; **HOT, GVB:** data curation; **GVB:** formal analysis; **HOT:** research; **GVB, ACPPC:** methodology; **HOT, GVB, ACPPC**: administration of projects; **ACPPC; BMA:** supervision; **ACPPC, BMA:** validation; **HOT, GVB:** visualization; **HOT:** Writing - original draft; **GVB, ACPPC, BMA:** Writing - proofreading and editing.

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