

Flower induction in MD-2 pineapple using growth regulators and leaf pruning to obtain off-season fruit

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ABSTRACT

Objective: To prevent natural flowering of pineapple using concentrations of CPA and pruning levels, as well as to determine the flowering efficiency of MD-2 pineapple covered with shade netting, with the application of ethylene, in order to obtain off-season fruit.

Design/methodology/approach: The experiment to prevent flowering was a randomized block design with four replications, in split plots; a: 0, 75, and 128 mg L⁻¹ of 2,3-chlorophenoxypropionic acid (CPA) and; b: 0, 30, and 50% pruning; treatments were applied on November 6, 2022. Flowering percentage was measured in February and April 2022. The experiment on floral induction consisted of: a) plants covered with shade netting and b) plants in open air; 18 samplings were performed with 20 plants; inflorescences were counted and analyzed using Student's t-test ($\alpha=0.05$); the per-hectare dose was applied three times with 2 kg of ethylene with 20 kg of activated charcoal.

Results: Pruning decreased natural flowering, and the response improved when combined with 75 mg L⁻¹ of CPA. At 128 mg L⁻¹ of CPA, excellent results were obtained, but the dose can be reduced to achieve the same effect when combined with pruning. The treatment without shade netting had 94% floral induction efficiency, while the one covered with shade netting had 49%.

Study limitations/implications: These results can be applied in Veracruz and Oaxaca, Mexico, in plantations with plastic mulch.

Findings/conclusions: Pruning prevented flowering, and its effect was enhanced with the lower concentration of CPA; additionally, shade netting reduced flowering when ethylene was applied during periods of high temperatures.

Keywords: *Ananas comosus*, floral inhibition, floral differentiation, shade netting.

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INTRODUCTION

Pineapple (*Ananas comosus* var. *comosus*) is among the top five tropical fruit crops in the world, and in Mexico, 22,000 ha are established annually with a production of 1,292,000 tons of fruit (SIAP, 2025). The crop generates around 35,000 annual jobs, both direct and indirect, and an economic output of 34 billion pesos. Eighty percent of the pineapple in



Mexico corresponds to the MD-2 hybrid, 15% to the Cayena Lisa cultivar, and the rest to other cultivars such as ‘Champaka F153’, ‘Cabezona’, and some landraces such as ‘Coita’ from Chiapas, ‘Criolla de Guerrero’, and ‘Criolla de Nayarit’, among others (Rebolledo-Martínez *et al.*, 2025).

This species is one of the few that respond to exogenous ethylene application to stimulate floral differentiation, allowing harvest scheduling throughout the year (Bartholomew *et al.*, 2003; Cunha, 2005). If flowering occurs naturally, it is promoted by factors that increase ethylene production, including the physiological and nutritional status of the plant, varietal sensitivity, photoperiod, temperature, radiation, and stress, among others (Bartholomew, 2018; Kuan *et al.*, 2005; Rabie *et al.*, 2011).

This situation makes flowering one of the main problems for producers in pineapple-growing regions worldwide, mainly caused by short days, long nights, and low temperatures during winter, provided that the plant has sufficient size and age (Rebolledo *et al.*, 2016; Farid *et al.*, 2015).

Mexico is no exception; the pineapple-growing region is located around 18° north latitude, where winter meets several of these factors, promoting the occurrence of untimely natural flowering, which becomes more pronounced at higher latitudes.

From November to February, minimum temperatures generally reach around 17 °C; this causes approximately 25% of the production to be concentrated in June and July. This overproduction leads to a market gap in which fruit prices drop significantly, resulting in decreased profitability for producers. On the other hand, a period of fruit scarcity is observed during September and October, representing a window of opportunity for producers to obtain the best pineapple prices (Rebolledo *et al.*, 2016; Uriza *et al.*, 2018).

To attempt to minimize this problem, the effect of different inhibitors that block the ethylene biosynthesis pathway and, consequently, flowering has been evaluated (Sanford and Bartholomew, 1981; IRFA, 1987; Scott, 1992; Rebolledo *et al.*, 1997); including research using genetic engineering to identify promising transgenic lines that prevent natural flowering inhibition (Trusov and Botella, 2006). Evidence shows that silver nitrate, at concentrations ranging from 30 to 180 mg L⁻¹, divided into six applications at 15-day intervals and starting two months before floral differentiation, reduces or delays flowering; the same applies to silver thiosulfate, which, although more economical, has phytotoxic effects on the crop (IRFA, 1987). However, in Mexico, in ‘Cayena Lisa’, silver nitrate only achieved 47% floral inhibition, while gibberellic acid and bromacil had no inhibitory effect (Rebolledo *et al.*, 1998). In another study, Scott (1992) evaluated CPA (2,3-chlorophenoxypropionic acid) and Paclobutrazol at various doses, where the best treatments of both products resulted in only 8.2% and 28% natural flowering, respectively, while the untreated controls reached between 48% and 55% flowering. In Mexico, in ‘Cayena Lisa’, with 100 mg L⁻¹ of active ingredient CPA 8%, divided into three equal applications starting at the beginning of October and spaced 15 days apart, flowering was inhibited up to 90% without causing plant burns, with more favorable responses in higher planting densities, younger and better-nourished plants; a single application of 100 mL L⁻¹ resulted in 32% plant mortality due to burns (Rebolledo *et al.*, 1997; Rebolledo *et al.*, 2000).

CPA was also evaluated in the MD-2 pineapple hybrid, and it was found that concentrations of 130 mg L^{-1} with four equal applications spaced 15 days apart, starting at the end of October, in plants weighing 2.02 kg at the time of growth regulator application, inhibited flowering by more than 95%, compared to 19% in the control; the 130 mg L^{-1} single-application treatment had the highest percentage (100%) of non-flowering plants, but resulted in 16% of plants with burns caused by CPA, which is undesirable (Rebolledo *et al.*, 2021).

Recently, in Mexico, it has been discovered that horizontal leaf pruning has a positive effect in preventing natural flowering in pineapple (Rebolledo *et al.*, 2022), where it was found that 30% pruning in MD-2 achieved 74% floral inhibition; however, when this pruning level was combined with half of the recommended CPA dose (66 mg L^{-1}) in two applications, floral inhibition was very close to 100%, compared to 16% in the control, in plants weighing 1.98 kg. That is, pruning allowed a 50% reduction of CPA, and it is also an environmentally friendly practice.

López *et al.* (2023) found that 30% pruning combined with the application of the inhibitor product aminovinylglycine hydrochloride (AVG) reduced natural flowering by 80% compared to the control; while, compared to the treatment without pruning plus AVG, natural flowering was reduced by 49%. Likewise, Rebolledo-García *et al.* (2024) obtained conclusive results, close to 95% flowering control, compared to 16% in the control, with pruning levels of 60% and 90% in a plastic mulch planting system, far superior to 30% pruning, when pruning was performed at the end of October in plants weighing 1.7 kg; plants pruned at 90%, although they did not flower, experienced delayed development, which did not occur in 60% pruning. The same authors achieved values close to 100% with a single application of 128 mg L^{-1} CPA, without causing leaf burns.

On the other hand, plants that do not flower naturally must reach an adequate weight (2.5-3.2 kg) to induce flowering in March, April, and early May in order to obtain off-season fruit from late August to October. Consequently, flowering induction in pineapple is achieved through the application of growth regulators that act on ethylene synthesis, the compound responsible for floral differentiation (Rebolledo *et al.*, 2016). Floral induction in pineapple using calcium carbide, Ethrel, and ethylene gas is a common practice in nearly all plantations in Mexico. Ethylene gas has been the most widely used in recent years due to its high efficiency and the ability to be applied mechanically; this practice is carried out using 2 kg ha^{-1} of ethylene gas in two applications, mixed with 20 kg of activated charcoal per 3,000 liters of water (Rebolledo *et al.*, 2016).

With the use of 50/50 black shade netting placed over the pineapple plants to prevent radiation damage, many producers avoid removing the netting to apply the flowering inducer, expecting the same results as when the product is applied directly to the plant (Uriza *et al.*, 2018); however, not removing the netting could reduce flowering efficiency, depending on the conditions at the time of application, plant weight and age, nutrition, ambient temperature, among others (Bartholomew and Sanewski, 2018).

Based on the above, the objective was to prevent natural flowering of pineapple using CPA concentrations and pruning levels, as well as to determine the flowering efficiency of

MD-2 pineapple covered with shade netting with ethylene application, in order to obtain off-season fruit.

MATERIALS AND METHODS

Experiment 1: Inhibition of natural flowering: The experiment was established in the pineapple-growing region of Bajo Papaloapan, in the municipality of Juan Rodríguez Clara, in the locality Ejido 5 de Mayo (17° 50' 22.9" N, 95° 22' 50.6" W at 190 m above sea level); the coldest period is from December to February, with an average temperature of 19 °C, and the hottest period is from April to June, with an average maximum temperature of 37 °C. The climate of the area is classified as warm subhumid (Aw0) with a rainy season from June to October and a dry season from January to May. The soil is a dystric cambisol, predominantly sandy-loam in texture, poor in organic matter (1.54%) and nutrients, with a pH of 5.2 and electrical conductivity of 0.06 dS/m.

The plantation was established in February 2021 with MD-2 pineapple propagative material called “gallo” or slip, weighing 500 g, at a planting density of 41,000 plants per hectare, in raised beds of 1.2 m apart from center to center, with two rows of pineapple per bed and 40 cm between plants. Prior to establishment, the land was cleared, left fallow, harrowed twice with a heavy harrow, and the beds were constructed; immediately afterward, the soil was covered with black plastic film, gauge 150. Agronomic management of the crop was carried out according to the technical recommendations for the region of this study (Rebolledo *et al.*, 2016).

The experimental design was a randomized block design with four replications, and treatments arranged in split plots; for factor a, the levels were concentrations of 2,3-chlorophenoxypropionic acid (CPA 8%) applied in a single application: 0, 75, and 128 mg L⁻¹, while for factor b, the levels were horizontal leaf pruning: 0, 30, and 50% of plant height. The experimental unit consisted of four pineapple rows of 6 m (14.4 m²).

The treatments were applied on November 16, 2021, when the plants weighed an average of 2.3 kg. Leaf pruning was performed with a machete, and CPA was applied using manual backpack sprayers at a dose of 50 mL of solution, spraying the entire plant. The percentage of natural flowering and the percentage of non-flowering plants were measured on February 2 and April 19, 2022. Fruits from natural flowering matured in June, while plants that did not flower naturally were induced with ethylene in May and harvested in October 2022. Analysis of variance ($\alpha=0.05$) and Tukey's multiple range tests ($p\leq 0.05$) were performed using the Statistical Analysis System (SAS), while figures and statistical regression models were generated using SigmaPlot version 12.0.

Experiment 2: Flowering induction was conducted in the pineapple-growing area known as Los Robles, in the municipality of Medellín, Veracruz, Mexico (18° 56' 13" N; 96° 11' 38" W). Average minimum and maximum temperatures ranged between 23 °C and 33 °C, respectively, with temperatures exceeding 35 °C recorded during May, June, and July; the rainy season began in early June. The soil had a pH of 5.7, 2.14% organic matter, sandy-loam texture with 13% clay, 73% sand, and 14% silt. Concentrations of nitrate N, P-PO₄³⁻, S-SO₄²⁻, K⁺, Ca²⁺, Mg²⁺, Fe²⁺, Zn²⁺, Cu²⁺, Mn²⁺, and B³⁺ were 64.0, 3.0, 23.7, 135.0, 2280.0, 610.0, 46.7, 1.6, 1.1, 7.9, and 0.26 ppm, respectively.

The study was conducted in an MD-2 pineapple plantation with 600 g slips in June 2021, planted in two rows per bed at a density of 55,000 plants per hectare, with 100% of the soil previously covered with black plastic film, gauge 150. In April 2022, to prevent sunburn damage, 50/50 black shade netting was placed over the plants. At the time of floral induction treatment application on July 11 at 22:00 h, shade netting was removed from part of the plantation (0.5 ha), while the rest of the crop (2 ha) remained covered. The dose used for floral induction in both treatments was 2 kg of ethylene gas per-hectare per application, mixed with 20 kg of activated charcoal in 4,000 L of water.

Three applications were carried out, spaced two days apart. Fifty days after the treatment for floral differentiation, 18 samplings were conducted for each treatment, with 20 plants per sampling, counting the number of inflorescences per plant, which allowed determination of the percentage of pineapple flowering obtained in each treatment. Plant height and weight were also evaluated. Statistical analysis was performed using Student's t-test for independent samples at a 95% confidence interval, carried out with SigmaPlot version 12.0.

RESULTS AND DISCUSSION

Experiment 1. Floral inhibition

Table 1 presents the results of flowering for each of the evaluated treatments on February 2. Statistically significant differences ($\alpha=0.05$) were observed for each level of both factors, but the same was not true for the interactions. CPA concentrations were statistically equal among themselves and higher than the control, which by that date already had 7.6% of plants flowering; pruning levels were also statistically equal, but different from the control, which showed 6.3% of plants with flowering.

At these dates, the initiation of the floral differentiation process is just beginning, occurring approximately 40 days before the emergence of floral primordia, which took place at the end of December; however, environmental conditions will cause this phenomenon to continue in the rest of the plants (Bartholomew, 2018), according to the evaluated treatments, as shown in Figure 1. By April 19, the pineapple plants had completed their winter natural flowering process, with more than 90% flowering, and only the inhibitory treatments showed their response to this phenomenon.

On this sampling date, April 19, analysis of variance showed statistically significant differences in both factors and their interactions ($\alpha=0.05$). CPA concentrations of 128 and

Table 1. Percentage of non-flowering MD-2 pineapple plants under different CPA concentrations and leaf pruning levels on February 2. Different letters indicate statistically significant differences.

CPA concentration (mg L ⁻¹)	Value of leaf pruning (%)			
	30	50	0	Mean
128	100	100	100	100 a
75	100	100	96.6	98.7 ab
0	97.72	95.15	84.4	92.4 b
Mean	99.2 a	98.38 a	93.69 b	97.1

CV (%)=4.73; Tukey \leq 0.05.

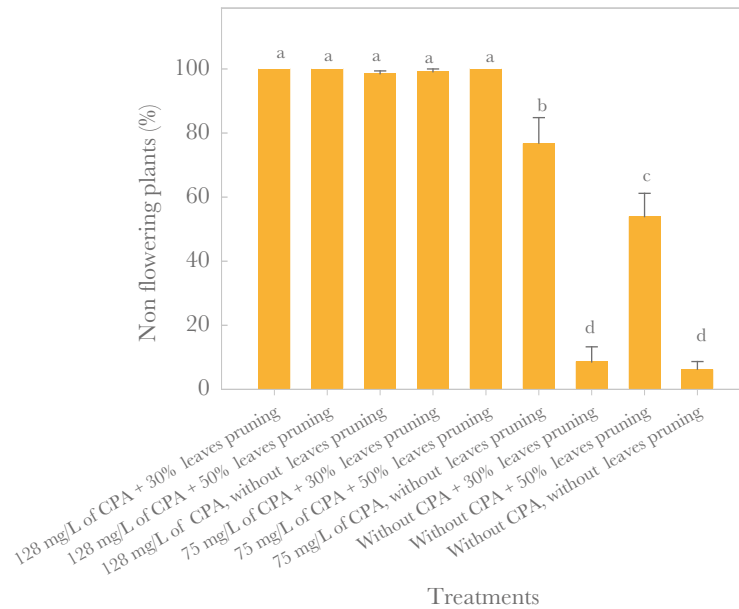


Figure 1. Percentage of non-flowering MD-2 pineapple plants under different CPA concentrations at three leaf pruning levels. Different letters indicate statistical differences between treatments (Tukey ≤ 0.05) within each pruning level at each CPA concentration. Bars represent \pm standard error. Coefficient of variation = 11.09%.

75 mg L⁻¹ were statistically equal and differed from the control, which had 22.9% non-flowering plants, in contrast with 92% and 99% obtained with 75 and 128 mg L⁻¹ CPA, respectively. Regarding factor b, the three pruning levels were statistically different from each other, with percentages of non-flowering plants of 60.5, 84.6, and 69.2 for the 0%, 50%, and 30% pruning treatments, respectively (Table 2).

Interaction values are presented in Figure 1; the CPA concentration of 128 mg L⁻¹ showed statistically equal values ($\alpha=0.05$) at the three pruning levels; that is, with this applied dose, this practice is not required. CPA at 75 mg L⁻¹ is more efficient when combined with 30% or 50% pruning, since 99% non-flowering plants were achieved, compared to 76.8% obtained without the CPA/pruning combination. The control without CPA within the pruning levels showed that, statistically ($\alpha=0.05$), the best treatment was 50% pruning with 54% non-flowering plants, while in the other two levels of this factor the values were 7.4% on average. Regarding the results for CPA concentration and pruning percentage, through

Table 2. Percentage of non-flowering MD-2 pineapple plants at different CPA concentration levels with the average of pruning levels, and percentage of natural flowering at different pruning levels with the average of CPA concentration levels, in the April 19 sampling.

CPA concentration (mg L ⁻¹)	Value of non-flowering plants (%)	Value of leaf pruning (%)	Value of non-flowering plants (%)
128	99.50 a	30	69.2 a
75	91.98 a	50	84.6 b
0	22.92 b	0	60.5 c

Different letters indicate statistically significant differences (Tukey ≤ 0.05).

regression, each of these factors was fitted to a second-order ($r^2=0.9570$) and fourth-order polynomial ($r^2=0.9570$), respectively. Figure 2 shows that, as CPA concentration increases, the response increases; however, for pruning levels, the effect begins after 40% pruning (Figure 3).

These results are closely related to those obtained in other studies: regarding CPA, it was applied in a single dose and no plant damage was observed, as reported by Rebolledo *et al.* (1997) in ‘Cayena Lisa’ with 100 mg L^{-1} and Rebolledo *et al.* (2021) with 128 mg L^{-1} in ‘MD-2’; although these authors worked in these experiments only with the vegetative material called ‘clavo’ or ‘stem shoot’ (buds that emerge from the stem) with plantations established at the beginning of summer, whereas in this study suckers called ‘gallo’ or ‘slip’ (buds that emerge from the peduncle) planted in February were used; that is, plants of

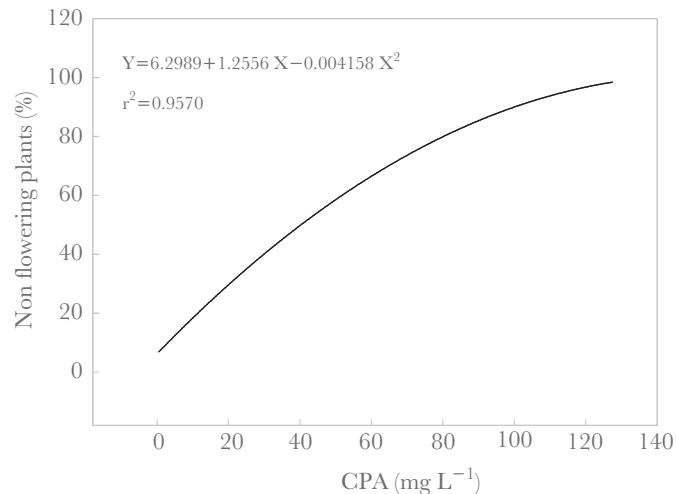


Figure 2. Second-degree polynomial line fit and regression equation between CPA concentration and the percentage of non-flowering MD-2 pine-apple plants.

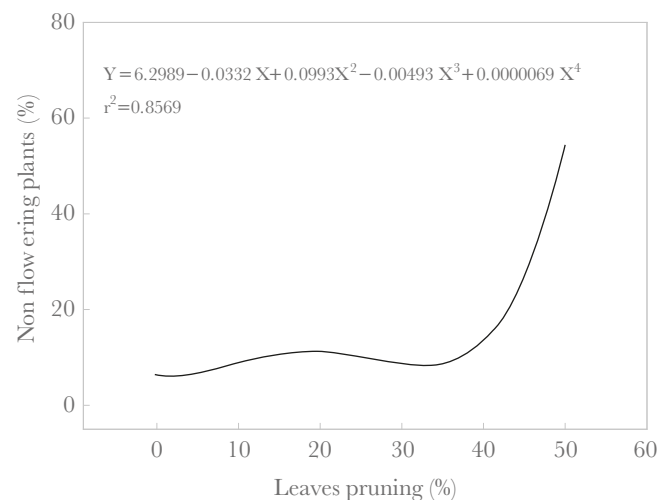


Figure 3. Fourth-degree polynomial line fit and regression equation between pruning levels and the percentage of non-flowering MD-2 pineapple plants.

greater age and size (2.3 kg). However, Rebolledo-García *et al.* (2024) obtained the same results as in this study when using 128 mg L^{-1} in a single dose, without finding leaf burns, in plantations established in July with ‘clavos’.

Pruning had an important effect, since at the 50% level flowering was significantly reduced; if pruning is more severe, the response improves, as it has been found that 90% pruning has a 100% effect but delays growth by approximately three months; likewise, 60% pruning has been found to achieve more than 90% reduction in flowering (Rebolledo-García *et al.*, 2024). In this study, 50% pruning in combination with CPA at 75 mg L^{-1} produced the best result, coinciding with Rebolledo *et al.* (2022) and Rebolledo-García *et al.* (2024), who found that CPA doses can be reduced by 50% when pruning is applied, which implies savings in application and less environmental damage due to agrochemical use.

Experiment 2

There was a statistically significant difference between the evaluated treatments for floral induction in pineapple. Better results were obtained when ethylene gas was applied to plants without shade netting compared to those that had shade netting (Figure 4).

Keeping the plant covered with 50/50 shade netting reduces the efficiency of ethylene gas entry into the plant, since much of the solution first comes into contact with the netting; secondly, the application period is the most difficult for the plant to undergo organogenic changes toward flowering, due to the occurrence of the longest days of the year and high temperatures that favor vegetative growth and lower ethylene production, as mentioned by Bartholomew and Sanewski (2018).

For the plant height variable, the treatment with shade netting was statistically higher (Figure 5), which is explained by the reduction of solar radiation in that environment (Uriza *et al.*, 2018); shade netting produces shading that stimulates apical meristem growth and the

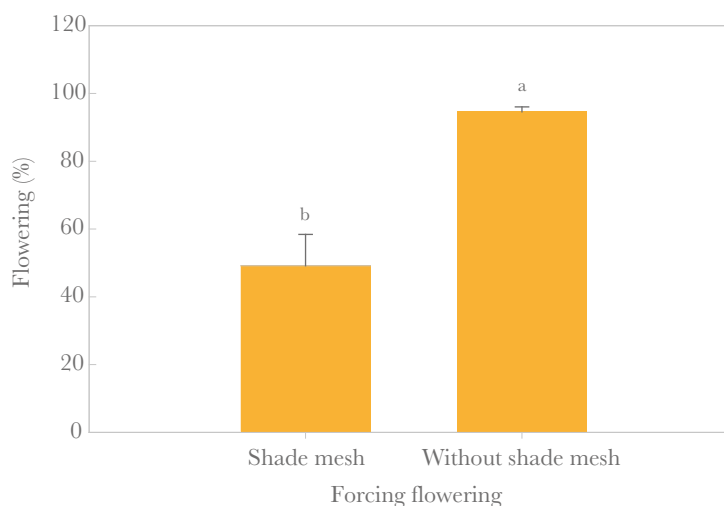


Figure 4. Percentage of flowering of MD-2 pineapple in two floral induction treatments applied to plants with shade netting and without netting. Bars, \pm standard error; different letters represent statistically significant differences ($p < 0.01$).

plant continues its vegetative growth, although this could be compensated by the reduction in temperature that occurs in the controlled environment created by the netting; however, under the conditions of this study this phenomenon was not observed. On the other hand, plant weight may have influenced flowering efficiency (Figure 6), since large plants tend to respond less to floral induction (Rebolledo *et al.*, 2016); however, no statistically significant differences were observed between treatments.

Finally, when the plant is highly developed and there is soil moisture at field capacity due to the beginning of the rainy season, and flowering induction is intended mainly during June and July, shade netting should be removed before applying the floral induction treatment.

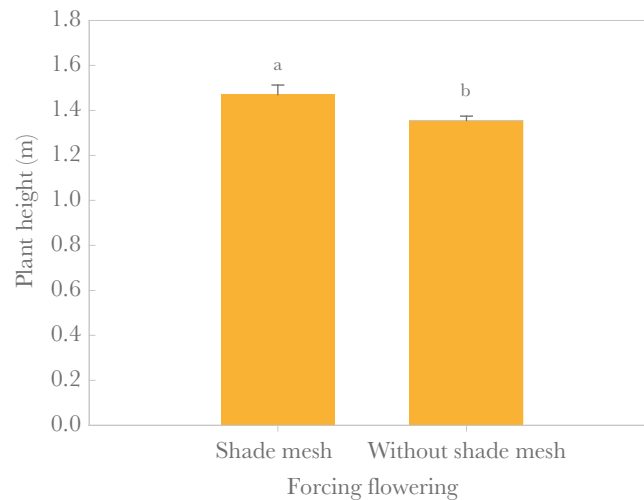


Figure 5. Plant height of MD-2 pineapple in two floral induction treatments applied to plants with shade netting and without netting. Bars, \pm standard error; different letters represent statistically significant differences; $p=0.049$.

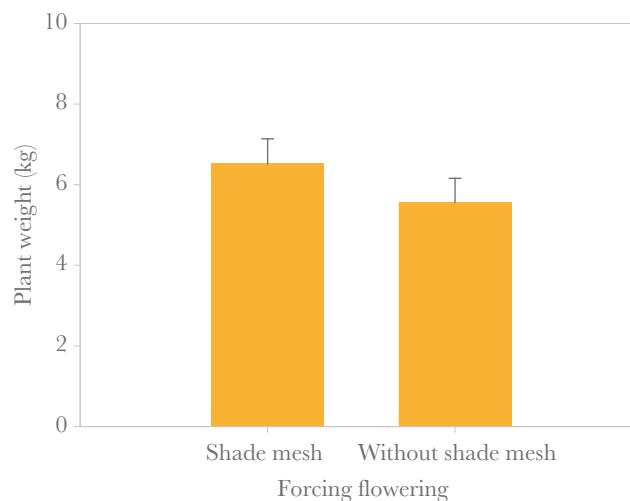


Figure 6. Plant weight of MD-2 pineapple in two floral induction treatments applied to plants with shade netting and without netting. Bars, \pm standard error; no statistically significant difference was observed, $p = 0.312$.

CONCLUSIONS

Pruning significantly reduced natural flowering, and the response improved when it was combined with the application of 75 mg L⁻¹ CPA. The 128 mg L⁻¹ CPA dose in a single application, although it produced good results, can be reduced by half to achieve the same effect when combined with pruning. When ethylene gas was applied in the treatment without shade netting, 94% floral induction efficiency was obtained, while in the treatment with shade netting only 49% efficiency was achieved. By inhibiting flowering and subsequently forcing it, it is possible to obtain off-season production.

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