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Flowering and fruit production of pineapple improve with activated carbon and ethylene

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ABSTRACT

Pineapple fruit production (*Ananas comosus* L. Merr.) is negatively affected by inhomogeneous natural flowering, but flowering can be exogenously induced by growth regulators such as Ethephon (2-chloroethylphosphonic acid), resulting in greater production and yield in this crop. Thus, this study aimed to evaluate the application of Ethephon and ethylene + activated carbon to increase flowering and the qualitative and yield components of pineapple. The experiment was set up in a randomized block design with three treatments and five replications (blocks). After checking that the variance of the data sets was homogeneous, they were subjected to analysis of variance. Subsequently, the difference between the means of the treatments was determined using the Tukey test ($P \leq 0.05$). There was a significant difference in costs and gains between using and not using flowering inducers, representing a significant difference in the benefit-cost ratio (BCR). Therefore, the use of activated carbon + ethylene proved to be economically viable. We conclude that activated carbon associated with ethylene provided a higher percentage of flowering in pineapple fruit. However, this inducer and Ethephon were similarly effective in increasing yield in this crop.

Keywords: *Ananas comosus,* Ethephon, Flowering inducers, Fruit growing.

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A floração e a produção de frutos de abacaxizeiro melhoram com carvão ativado e etileno

RESUMO

A produção dos frutos do abacaxizeiro (*Ananas comosus* L. Merr.) é afetada negativamente por uma floração natural não homogênea, no entanto a floração pode ser induzida de forma exógena por reguladores de crescimento como etephon (ácido 2-cloroetilfosfônico), resultando em uma maior produção e produtividade nessa cultura. Dessa forma, o objetivo deste trabalho foi avaliar a aplicação do etephon e o etileno associado com carvão ativado, com o intuito de aumentar a floração, e os componentes qualitativos e produtivos da produção do abacaxizeiro. O experimento foi instalado em campo foi utilizado o delineamento em blocos casualizados. Cada bloco com três tratamentos e cinco blocos. Após verificação da homogeneidade das variâncias dos conjuntos de dados, estes foram submetidos à análise de variância. Posteriormente, a diferença entre as médias dos tratamentos foi determinada com o teste de Tukey ($P \leq 0,05$). Houve uma grande diferença nos gastos e ganhos entre o uso e não uso de indutores de floração acabam representando uma grande diferença na Razão (B/C). Dessa forma, o uso do Carvão ativado + etileno se mostrou economicamente viável. Conclui-se que o carvão ativado associado ao etileno proporcionou maior porcentagem de floração em frutos de abacaxizeiro. No entanto, esse indutor assim como o etephon foram eficientemente semelhantes no aumento da produtividade nesta cultura.

Palavras-chave: *Ananas comosus,* Ethefon, Indutores de floração, Fruticultura.

1. Introduction

The pineapple (*Ananas comosus* L. Merr.) is an herbaceous monocot that reaches a maximum height of 1.5 m (Teixeira et al., 2001). This plant species is the most important of the Bromeliaceae family and is cultivated in all tropical and subtropical regions of the world (Lobo and Paull, 2017; Li et al., 2022). The fruit originates from South America, mainly Brazil, Argentina, and Paraguay (Coopens and Leal, 200; Lima et al., 2017). Although Costa Rica and Brazil are some of the largest producers of this fruit globally (Teixeira et al., 2001), countries such as Mexico, Thailand, the Philippines, Indonesia, China, India, Nigeria, and Kenya produce more than 70% of pineapple fruit (Wali, 2019; Li et al., 2022). The fruit is among the three most consumed worldwide, second only to bananas and citrus (Li et al., 2022).

Pineapple is a source of fiber and water (89%), as well as carbohydrates (5.8%), cellulose (3.2%), lipids (0.5%), proteins (0.3%), minerals (0.3%), and others (Crestani et al., 2010; Cherian et al., 2011). The fruits mainly contain calcium, iron, manganese, magnesium, potassium, and vitamins A, B1, B2, and C (Hossain et al., 2015). In addition to its nutritional properties, pineapple has medical potential and can be used to treat skin diseases and improve the cardiovascular, digestive, and immune systems (Wali, 2019).

The Gold cultivar, also known as MD-2, has replaced the Smooth Cayenne cultivar and is one of the most important commercial pineapple genotypes (Sabando-Ávila et al., 2017). According to Bartholomew (2009), this hybrid was developed by the Pineapple Research Institute breeding program in Hawaii, has a high yield potential, and is resistant to diseases and insect pests. According to the author, when comparing the fruits of the MD-2 hybrid with those of the Smooth Cayenne, the former stands out in terms of its high vitamin C and soluble solids content, as well as its taste, characterized by lower acidity levels.

Inhomogeneous natural flowering negatively affects pineapple fruit production (Teixeira et al., 2001). Flowering can, therefore, be induced exogenously by growth regulators such as Ethephon (2-chloroethylphosphonic acid), resulting in greater production and yield in this crop (Van de Poel et al., 2009). Although Ethephon can be applied multiple times to ensure greater flower induction in the pineapple tree, its efficient absorption can be affected by unfavorable climatic conditions, such as high temperatures and low relative air humidity (Turnbull et al., 1999). Another product that induces flowering in pineapple is ethylene, associated with activated carbon, making its absorption more efficient and long-lasting due to the slow release of the gas (Van de Poel et al., 2009).

Although ethylene is more effective than Ethephon in inducing flowering in pineapple, this gas is difficult to apply to the crop (Py et al., 1984). In Ecuador, to date, there have been no comparative studies demonstrating an efficient method that induces greater flowering and fruit production. Therefore, this study aimed to evaluate the application of Ethephon and ethylene + activated carbon to increase flowering and the qualitative and yield components of pineapple.

2. Material and Methods

This experiment was conducted under field conditions on the San Remo farm, belonging to the Terrasol Corps company, in Puerto Limón, Santo Domingo de los Tsáchilas, Ecuador. The site has an average temperature of 22ºC, an average relative air humidity of 98%, and a total rainfall of 3150 mm.

Seedlings of the MD-2 hybrids were established at 0.45 m between rows and 0.30 m between plants in deep, well-drained soil with a loamy-clay loam texture and a pH ≥ 5.6. This pH was maintained to avoid problems such as root and stem rot caused by fungi or other etiological agents and to prevent the low availability of nutrients such as potassium and calcium. Healthy seedlings replaced dead or diseased plants six weeks after transplanting. Weed, disease and pest management, and fertilization were carried out according to the crop needs.

Each plot had an area of 6.75 m^2 (1.8 m wide and 2.7 m long), with a space between blocks and treatments of 1 and 2 m, totaling an experimental area of 231.84 m^2. Each plot consisted of five rows and 50 pineapple plants. The following treatments were used to evaluate the effect of the application of activated carbon associated with ethylene and Ethephon on flowering and the quantity and quality of pineapple fruit production: activated carbon (15 kg ha^{-1}) + ethylene (3 Lb. ha^{-1}), Ethephon (2 L ha^{-1}), and the control.

This last treatment consisted of a group of plants not treated with either product. Sixty days after the application of the inducers, on ten plants chosen at random in the useful plot (three central rows), flowering (%), crown weight (g) in plants, fruit weight (kg), and fruit yield (t ha^{-1}) were quantified. Also, diameter (cm), length (cm), soluble solids (ºBrix), and titratable acidity (% citric acid) in the fruits were assessed (Figure 1).

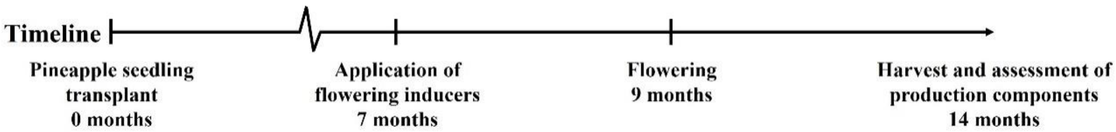

Figure 1. Timeline (in months) of planting activities and application of inducers (treatments) to pineapple plants.

The analysis of production costs and the economic viability of the crop was based on the operating cost model developed by the São Paulo Institute of Agricultural Economics and described by Matsunaga et al. (1976) and Pessoa et al. (2000). For the analysis, the costs of soil preparation, agricultural inputs, and labor (cost per hectare) were used, as well as the net benefits and the calculation of the benefit-cost ratio (BCR). The experiment was conducted in a randomized block design with four replications (blocks). After checking the homogeneity of data sets, they were subjected to analysis of variance. Subsequently, the means relative to the treatments were compared by the Tukey test ($P \leq 0.05$).

3. Results and Discussion

Concerning the quantitative component, only flowering (*P* value: 0.001) and fruit yield (*P* value: 0.001) were influenced by the application of the inducers to pineapple plants (Table 1). Activated carbon + ethylene induced greater flowering (98%) compared to the application of Ethephon (90%) and the control treatment (14%). In comparing Activated carbon + ethylene and control treatment, the plant flowering was seven times higher using flowering inducers. The fruit yield was almost four times higher on average only when one of the two inducers was applied (78 t ha^{-1}), compared to the control treatment (21 t ha^{-1}). The average weight of the crown (*P* value: 0.9469) and fruit (*P* value: 0.9939) was 175 g and 1.4 kg, respectively, regardless of whether the inducers were applied or not (Table 1).

Our results showed that applying activated carbon + ethylene to the pineapple crop increased the number of developed and viable flowers (Table 1). This result was also confirmed by the Pearson correlation (Table 3). On the one hand, the lack of ethylene in the pineapple causes low and heterogeneous flowering (Hotegni et al., 2014). On the other hand, using activated carbon enhances the effect of ethylene on pineapple flowering, causing it to be released more slowly and to remain in contact with the floral meristems for longer (Van de Poel et al., 2009). It can, therefore, be inferred that the inducer reached the apical meristems of the plants, contributing to greater flower production.

Although the application of inducers increased flowering in the pineapple, they did not affect the crown and fruit weights. In addition to its action on the floral meristem, thus guaranteeing the permanence and development of the flowers on the fruit, ethylene influences various biochemical and physiological processes during pineapple ripening. It regulates enzymes synthesizing starch into simple sugars, such as sucrose (Py et al., 1984; Taiz et al, 2017). However, the inducers did have a positive effect on fruit yield (t ha^{-1}), which would be beneficial for a pineapple producer. It is known that both Ethephon and ethylene associated with activated carbon can induce greater fruit production in pineapple plants (Van de Poel et al., 2009; Martínez et al., 2014).

While both inputs can induce flowering and increase fruit yield, due to ethylene application difficulty since it is a gas, we can suggest using Ethephon as an interesting flowering inducer in pineapple. In other crops, such as feijoa (*Acca sellowiana*), the application of Ethephon induces an increase in the weight and ripeness of the fruit, protecting them from cracks caused by rain (García et al., 2008). In any case, new experiments with other factors, such as doses for each inducer, must be carried out to elucidate better the influence of these products on the growth and development of fruit in the pineapple crop.

None of the inducers applied to pineapple plants had any effect on the increase in diameter (on average 12.2 cm), length (on average 15 cm), soluble solids (on average 14º Brix), and titratable acidity (on average 0.6 % citric acid) in the fruit (Table 2). It should be noted that the use of stimulants, whether associated with activated carbon or the chemical compound Ethephon, despite being involved in the physiological processes of flowering and, consequently, in increasing yields, did not influence fruit quality. Similar results were found in other research on pineapple (Chitarra and Chitarra, 2005; Caetano et al., 2015; Teixeira et al., 2001).

In the correlation analysis, only significant positive correlations were found between flowering and fruit yield (*P* value: $\leq$ 0.0001) and between crown weight and fruit length (*P* value: 0.0315) (Table 3). A positive correlation between flowering and fruit yield would indicate that pineapple plants with more flowers would produce a large quantity of fruit. This result also corroborates the importance of using flower inducers on pineapple plants. The correlation between crown weight and fruit length could be a fruit quality parameter. Other authors have also observed this correlation in other experimental conditions (Caetano et al., 2015; Lima et al., 2002). Both significant correlations can represent an estimate of production in the pineapple crop.

Table 1. Flowering (%), crown weight (g), fruit weight (kg), and fruit yield (t ha^{-1}) in MD-2 hybrid pineapple plants treated with the inducers activated carbon + ethylene and Ethephon. The untreated plants constituted the control treatment.

Treatments	Flowering (%)	Crown weight (g)	Fruit	
			Weight (kg)	Yield (t ha^{-1})
Activated carbon + ethylene	97.8 ± 1.3 a	167.5 ± 42.1 a	1.4 ± 0.0 a	75.4 ± 6.0 a*
Ethephon	90.2 ± 5.0 b	177.6 ± 69.3 a	1.4 ± 0.1 a	80.4 ± 7.3 a
Control	14.1 ± 2.3 c	180.1 ± 13.7 a	1.4 ± 0.0 a	21.1 ± 2.5 b
Average	67.4 ± 2.9	175.1 ± 41.7	1.4 ± 0.0	58.9 ± 5.3
P-value	0.0001	0.9469	0.9939	0.0001
CV (%)	5.13	31.53	10.15	9.99

*Means followed by equal letters in the columns do not differ significantly by the Tukey test ($P \leq 0.01$).

Table 2. Diameter, length, soluble solids, and titratable acidity in pineapple fruit from MD-2 hybrid treated with activated carbon + ethylene and Ethephon. The untreated plants constituted the control treatment.

Treatments	Fruit diameter (cm)	Fruit length (cm)	Soluble solids (ºBrix)	Titratable acidity (%citric acid)
Activated carbon + ethylene	12.4 ± 0.5 a	15.5 ± 0.5 a	13.8 ± 0.9 a	0.6 ± 0.1 a
Etephon	12.3 ± 0.4 a	15.2 ± 0.3 a	13.7 ± 0.5 a	0.7 ± 0.1 a
Control	12.0 ± 0.3 a	15.2 ± 0.5 a	14.0 ± 0.8 a	0.6 ± 0.1 a
Average	12.2 ± 0.4	15.3 ± 0.4	13.8 ± 0.7	0.6 ± 0.1
P value	0.1010	0.5786	0.8090	0.0868
CV (%)	2.60	3.15	4.74	6.71

* Means followed by equal letters in the columns do not differ significantly by the Tukey test Tukey ($P \leq 0.05$).

Table 3. Coefficients of Pearson correlation among quantitative and qualitative traits of MD-2 pineapple hybrid treated with activated carbon + ethylene and Ethephon. The untreated plants constituted the control treatment. The two values correspond to the correlation coefficient and the probability value. Significant correlations are highlighted in gray.

	Flowering	Crown weight	Fruit weight	Fruit yield	Fruit diameter	Fruit length	Soluble solids	pH
Flowering	-	-0.0204	-0.0011	0.9748	0.3681	0.124	-0.1099	-0.0984
	-	0.9300	0.9933	≤ 0.0001 **	0.1007	0.5923	0.6354	0.6712
Crown weight		-	-0.1192	-0.1099	-0.0425	0.4702	-0.1630	-0,3201
		-	0.6068	0.6355	0.8549	0.0315 *	0.4801	0.1571
Fruit weight			-	0.1487	-0.0137	-0.1312	0.1668	0.0831
			-	0.5200	0.9529	0.5708	0.4699	0.7202
Fruit yield				-	0.3568	0.1065	-0.0910	-0.0787
				-	0.1124	0.6459	0.6950	0.7346
Fruit diameter					-	0.1856	-0.5496	-0.0014
					-	0.4206	0,0099	0,9950
Fruit length						-	-0.3650	-0.1250
						-	0.1038	0.5892
Soluble solids							-	-0.3747
							-	0.0943
pH								-

The costs and benefits of each treatment is in the Table 4. The biggest difference occurs in the purchase and application of flowering inducers. Similarly, the profits resulting from productivity are also linked to the treatments with the inducers. For example, the control treatment had a reduction of 0.27 cents. The benefit-cost ratio indicates how many units of capital are received, with benefits obtained for each unit of capital invested (Newmann, 1988), and serves to verify the viability of a project. In terms of investment and financial return, there is a significant difference in costs and earnings between using or not using flowering inducers. Thus, using activated carbon + ethylene followed by Ethephon proved to be the most economically viable treatment.

Table 4. Cost-benefit analysis of pineapple fruit production of MD-2 hybrid treated with activated carbon + ethylene and Ethephon. The untreated plants constituted the control treatment.

Item	Treatment costs*		
	Ethephon	Activated carbon + ethylene	Control
Soil preparation			
Plowing	$ 80.00	$ 80.00	$ 80.00
Harrowing	$ 120.00	$ 120.00	$ 120.00
Agricultural inputs			
Seedling	$ 1,000.00	$ 1,000.00	$ 1,000.00
Fertilizers	$ 1,200.00	$ 1,200.00	$ 1,200.00
Agrochemicals	$ 2,100.00	$ 2,100.00	$ 2,100.00
Flowering inducers	$ 304.00	$ 432.00	$ 0.00
Labor			
Inducers application	$ 30.00	$ 43.20	$ 0.00
Fertilizers	$ 450.00	$ 450.00	$ 450.00
Agrochemicals	$ 650.00	$ 650.00	$ 650.00
Harvesting	$ 743.00	$ 800.00	$ 211.00
Cost ha^{-1}	$ 6,677.00	$ 6,875.20	$ 5,811.00
Fruit yield (T ha^{-1})	74.34	80.42	21.11
Price of the fruit (kg^{-1})	$ 0.20	$ 0.20	$ 0.20
Total revenue	$ 14,868.00	$ 16,084.00	$ 4,222.00
Net benefits	$ 8,191,00	$ 9,208.80	$ -1,589.00
Benefit-Cost ratio (BCR)	$ 1.23	$ 1.34	$ -0.27

*Prices expressed in US dollars ($)

4. Conclusions

The use of Ethephon and activated carbon associated with ethylene led to a higher flowering rate and fruit yield of pineapple. However, both inducers did not affect fruit quality.

Authors' Contribution

Freddy Agustín Sabando-Ávila and Felipe Rafael Garcés-Fiallos conceived and designed the research. Freddy Agustín Sabando-Ávila and Wellington Jean Pincay Ronquillo conducted the experiment and analysis. Felipe Rafael Garcés-Fiallos analyzed the data. Abimael Gomes da Silva and Felipe Rafael Garcés-Fiallos wrote the manuscript. All authors read and approved the manuscript.

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