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RESEARCH ARTICLE
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Modification of the flowering dynamics of pineapple (*Ananas comosus* L.) cv. 'MD2' using Aviglycine in the central jungle of Perú

Modificación de la dinámica de la flora ción en piña (*Ananas comosus* L.) cv. 'MD2' por la acción de la aviglicina en la selva central del Perú

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Abstract

Pineapple (*Ananas comosus*) is a widely cultivated fruit in tropical countries. However, its natural flowering (NF) is a physiological event that can make harvesting difficult, bringing with it financial problems. Therefore, this study aimed to determine the effect of Aviglycine (AVG) on the flowering of pineapple cv. 'MD2' in the central jungle of Peru. Three doses (150 mg/L, 250 mg/L, and 350 mg/L) of AVG (commercial product ReTain 15%) were studied with six and eleven applications. The results confirmed the appearance of NF under Satipo conditions. The high doses of AVG (250 mg/L and 350 mg/L) inhibited the appearance of inflorescences in almost all evaluations and particularly with eleven applications compared with the treatment without AVG and flower induction (NF). The NF presented three periods with different relative rates of inflorescence appearance (RRIA), where the first period had the highest RRIA and longest duration (42 d). In conclusion, the application of AVG had a significant effect in delaying the appearance of inflorescences; thus, its application in pineapple cultivation is recommended. However, more studies are needed to further deepen the knowledge on the management of this growth regulator.

Keywords: *Aviglycine, bloom retardant, growth regulators, natural bloom*

Resumen

La piña (*Ananas comosus*) es una especie muy cultivada en diferentes países tropicales. Sin embargo, su floración natural es un evento fisiológico que puede dificultar la labor de cosecha, trayendo consigo problemas económicos. En tal sentido, este trabajo tuvo como objetivo determinar el efecto de la Aviglicina sobre la floración de piña cv. 'MD2' en la selva central del Perú. Se estudiaron tres dosis (150 mg · L^{-1},

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250 mg · L^{-1} y 350 mg · L^{-1}) de Aviglicina (AVG) (producto comercial Retain 15 %), con 6 y 11 aplicaciones. En general, los resultados confirman la aparición de floración natural (FN) en condiciones de Satipo. Las altas dosis de AVG (250 mg · L^{-1} y 350 mg · L^{-1}) inhibieron la aparición de las inflorescencias durante casi todas las evaluaciones, especialmente con once aplicaciones comparadas con el tratamiento sin AVG ni TIF (Tratamiento de inducción floral) (FN). Asimismo, FN presentó tres periodos con tasas relativa de aparición de inflorescencias (TRAI) diferentes, siendo la primera la que tuvo mayor TRAI y mayor duración (42 días). Finalmente, se concluye que la aplicación de AVG tuvo un efecto significativo en el retardo de la aparición de las inflorescencias, motivo por el cual se sugiere su aplicación en el cultivo de piña. Sin embargo, son necesarios más estudios para seguir profundizando el conocimiento sobre el manejo de este regulador de crecimiento.

Palabras clave: *AVG, floración natural, reguladores de crecimiento, retardante de floración.*

Introduction

Pineapple (*Ananas comosus*) is the third most cultivated fruit globally and is native to tropical America (Centre for Agricultural Bioscience International [CABI], 2021). This crop plays a significant role in the economy of small farmers in tropical developing countries (Hossain, 2016; Rahim & Othman, 2019). In Peru, 15,901 ha of this tropical fruit are cultivated (Ministerio de Agricultura [MINAGRI], 2021). Although it does not represent a large extension, it has great potential due to its properties and nutritional content (Hossain, 2016) that could be exploited to increase the cultivated area and its export.

The 'MD2' stands out among other pineapple cultivars planted in Peru due to its high organoleptic quality compared with 'Cayena Lisa' (Neri et al., 2021). One of the critical factors in pineapple management is flowering, which is related to the environmental factors of the production site (Cunha, 2005; Food and Agriculture Organization [FAO], 2021). However, natural flowering (NF) is a major problem that occurs during some months of the year. It affects harvesting programs, decreases harvesting efficiency, increases costs, and decreases the price of the fruit, making it difficult to invest in controlling pests and diseases (Kuan et al., 2005; Martin-Prevel et al., 1993; Bello & Julca, 1994, 1995). Several environmental factors affect NF, such as decreased sunshine hours (short days), low temperatures (mainly at night), declined solar radiation due to high cloud cover, extreme relative humidity (low and high), and altitude (masl) (Gowing, 1961; Aubert et al., 1973; Friend & Lydon, 1979; Reinhardt et al., 1986; Bello, 1991; Cunha et al., 1999; Cunha, 2009; Maruthasalam et al., 2009; Bartholomew, 2014). Based on this evidence, NF is a "stress-induced flowering."

Ethylene (C_2H_4) is responsible for NF in pineapple, where its biosynthesis occurs in almost all plant tissues, particularly in the meristematic regions. Ethylene production also increases markedly in leaf abscission, fruit ripening, and senescence (Kende, 1993). In addition, some external stimuli such as drought, cold, and wounds can induce its synthesis (Ecker & Davis, 1987; Ohme-Takagi & Shinshi, 1995). Various strategies have been employed to reduce and avoid NF, such as the use of smaller planting material (Py, 1960; Bello & Julca 1994, 1995), to maintain adequate moisture in the soil (irrigation), ensure constant foliar fertilization with nitrogen, and apply chemical inhibitors of floral differentiation such as Aviglycine (AVG), which is a potent inhibitor of ethylene biosynthesis that hinders the conversion of S-adenosyl methionine to 1-aminocyclopropane-1-carboxylic acid (Yang & Hoffman, 1984). This compound is widely used pre-and postharvest to improve the quality attributes of climacteric fruits (Romani et al., 1983; Starrett & Laties, 1991; Ju et al., 1999; Manriquez et al., 1999; Shellie, 1999; Clayton et al., 2000; Amarante et al., 2002). Since 2005, several studies have been conduced that used AVG in pineapple (Kuang et al., 2005; Wang et al., 2007). However, its commercial use in pineapple is scant, specifically under Peruvian conditions whose climate particularities could affect the efficacy of this growth regulator. Thus, the objective of this study was to determine the effect of AVG on the dynamics of the flowering of pineapple (*Ananas comosus* cv. 'MD2') in the central jungle of Perú.

Materials and Methods

Plant materials and study area

Eight-month-old pineapple cultivar 'MD2' was employed in this study. The pineapples were planted in the district of Río Negro, Province of Satipo, Junín region, located at 720 masl (Fig. 1) with a plantation density of 50,000 plant per hectare. The climate in this region is characterized by a gradual increase in rainfall from September to March, whereas rainfall decreases significantly from April to August (Marca-Huamancha et al., 2018).

Pineapple suckers of 400 g were planted on September 20, 2017 (Fig. 2). The treatment was performed eight months after transplanting (May 5, 2018), and the plants were harvested from November 10 to 20, 2018. Experimental plots were fertilized with nitrogen, phosphorus, potassium, and magnesium in the concentrations of 10, 2, 12, and 1 g per plant, respectively.

Treatments

ReTain® 15 %, the active ingredient in AVG (150 g/kg), was used. Six treatments composed of various doses of ReTain® 15 % (150 mg/L, 250 mg/L, and 350 mg/L) were applied every 7 d

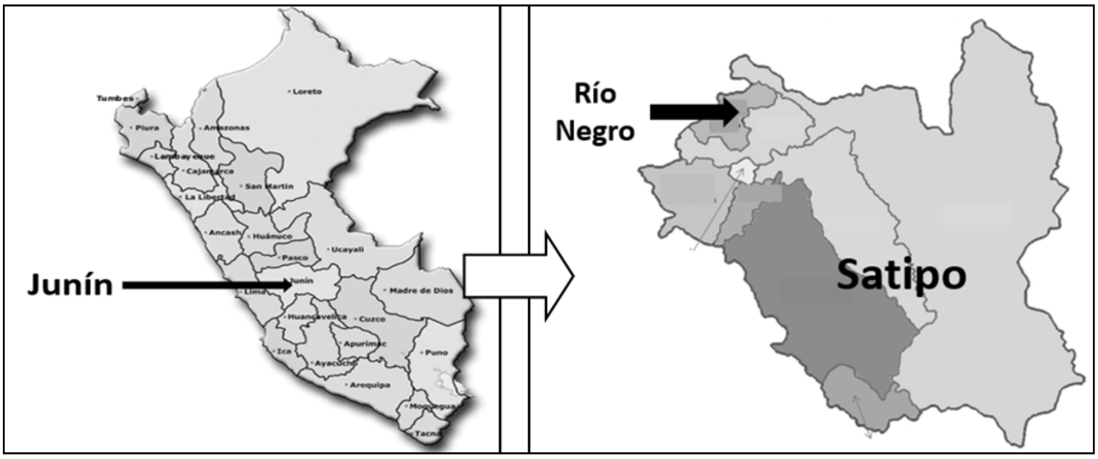

Figure 1. Location of the district of Río Negro in the province of Satipo in the department of Junín, Peru.

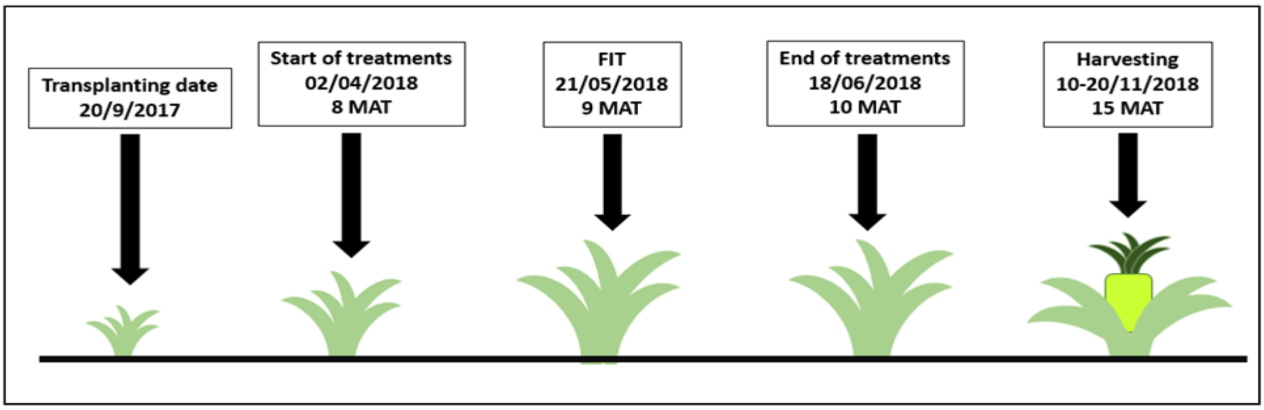

Figure 2. Key dates in the management of the MD2 pineapple experiment in Satipo.
MAT, months after transplant.

and 14 d, resulting in eleven and six applications, respectively. The AVG application was done in the morning (8 am – 10 am), and it was directed toward the heart of the plants (without adjuvant agrochemicals).

Two treatments without AVG were also included: with and without flower induction treatment (FIT) as controls. The applications were performed from April 2 to June 18, 2018 (Table 1). The FIT was prepared using calcium carbide and water (2.5 g/L). The FIT solution of 40 mL was applied at the heart of pineapple plants in the afternoon (from 4.30 pm).

Data collection

The number of inflorescences was counted at each sampling time. It is important to note that treatment one (T1) represented NF (Table 1). The data collected were used to construct inflorescence appearance curves with their respective equations (independent variable: days; dependent variable: number of inflorescences). The curves were divided into periods. In each period (based on the slope of the curve), the relative rates of inflorescence appearance (RRIA) were determined using the formula:

$$RRIA = (\ln ff - \ln fi)/(ti - tf),$$

where,

ln: natural logarithm, ff: number of inflorescences at the end of each period, fi: number of inflorescences at the beginning of each period, ti: initial time of each period, tf: final time of each period (Beadle, 1993).

Experimental design and data analysis

The experimental design used was a randomized complete block design with four replications. Each experimental unit consisted of 40 plants, with 25 central plants per replicate that were evaluated at harvest time. The data were analyzed using a two-way analysis of variance followed by the Tukey test ($p < 0.05$).

Results

Table 2 shows that the number of inflorescences increased over time. The appearance of inflorescences in plants treated with 0 mg AVG L^{-1} without and with the FIT (T1 and T8) was earlier than in the AVG-treated plants. In addition, both treatments resulted in more plants with inflorescence than others in almost all evaluations ($p \leq 0.05$). The plant treated with T8 showed a significantly higher number of inflorescences than T1 in all evaluations except for the last four. Besides that, the AVG-treated plant with six applications showed a higher number of inflorescences than eleven applications throughout sampling time ($p \leq 0.05$). In the final sampling, the T4-treated plants had the least inflorescence.

Flower appearance in pineapple cv. 'MD2' planted under Satipo's (Peru) conditions followed polynomial equations of the second, third, and fourth degree (Table 3) as a function of the treatment received. In the case of NF (0 mg AVG · L^{-1} without FIT; T1), flower emergence

Table 1. Treatments, doses, application frequency, and date of Aviglycine applications on pineapple cv. 'MD2'.

Treat.	AVG (mg/L)	Application frequency	Total number of applications	Start of application for all treatments	End of application
T1	0 (without FIT)	-----------	-------------	-----------	-----------
T2	150 (without FIT)	Every 7 d	11	April 2	June 18
T3	250 (without FIT)	Every 7 d	11	April 2	June 18
T4	350 (without FIT)	Every 7 d	11	April 2	June 18
T5	150 (without FIT)	Every 14 d	6	April 2	June 18
T6	250 (without FIT)	Every 14 d	6	April 2	June 18
T7	350 (without FIT)	Every 14 d	6	April 2	June 18
T8	0 (with FIT)	------------	1	May 21	May 21

Note: Treat., treatments; FIT, flower induction treatment; AVG, Aviglycine.

Table 2. Number of inflorescences observed in response to Aviglycine application on pineapple cv. 'MD2'.

T	AVG (mg/L)	Appl.	Number of inflorescences Sampling dates 6.25.18	7.9.18	7.23.18	8.6.18	8.20.18	9.3.18	9.17.18	10.1.18
T_1	0	−FIT	1.75 b	8.25 b	13.5 b	19.00 b	22.25 a	23.75 ab	25.00 a	25.00 a
T_2	150	11 – FIT	0.00 c	0.00 c	1.75 c	2.00 de	4.50 c	20.50 bc	22.50 b	24.25 a
T_3	250	11 – FIT	0.00 c	0.00 c	0.00 d	0.00 e	0.75 d	11.50 d	19.75 c	23.25 a
T_4	350	11 – FIT	0.00 c	0.00 c	0.25 d	0.00 e	0.00 d	3.00 e	10.50 d	20.00 b
T_5	150	6 – FIT	0.00 c	0.00 c	1.25 cd	3.50 d	11.00 b	18.75 c	19.25 c	22.75 a
T_6	250	6 – FIT	0.25 c	0.25 c	2.50 c	7.00 c	13.75 b	21.25 abc	24.25 ab	25.00 a
T_7	350	6 – FIT	0.75 bc	0.00 c	2.00 c	6.50 c	13.50 b	20.50 bc	23.50 ab	24.50 a
T_8	0	+FIT	3.75 a	25.00 a	25.00 a	25.00 a	25.00 a	25.00 a	25.00 a	25.00 a
	CV		56.17	9.2	9.73	11.17	13.25	9.1	4.5	4.1

Note: T, treatments; FIT, flower induction treatment; −FIT, without FIT; +FIT, with FIT; appl., number of applications. Different letters within each column indicate statistical differences using Tukey test at $p < 0.05$.

followed a second-degree polynomial equation. In comparison, the flower emergence followed a fourth-degree polynomial equation for the plants that received only FIT (0 mg AVG · L^{-1} with FIT; T8). In both cases, the slope was noticeable from the first evaluation. However, the FIT treatment had the greatest slope and reached stability in the shortest time (Fig. 3).

In the treatments where AVG was applied eleven times, it was observed that the dose used modified the degree of the polynomial equations (Table 3). Furthermore, in the high doses of 250 and 350 mg/L of AVG (T3 and T4), the slope was visible from the evaluation carried out on August 28/18 (Fig. 3). Those plants that received six applications of AVG (T5, T6, and T7) showed an increase in flowering by following a third-degree equation, and the slope was detected from the third or fourth evaluation (July 9–23/18) (Table 3, Fig. 3).

The inflorescence emergence curves generally had three periods, except in the T8, which had only two periods (Fig. 3). In addition, the duration of each period was related to the treatments applied (Table 4, Fig. 3). In the treatment with NF (T1), the first period was 42 d with an RRIA of 0.058 (day^{-1}), and the rate decreased in the second and third periods (both were 28 d). For the T8, the first period was 14 d with an RRIA of 0.137, stabilizing in the second period that lasted until the end of the experiment.

Table 3. Equations of the curves of inflorescence appearance in the experiment with pineapple cv. 'MD2' in Satipo.

Treatments			Equation	R^2
T_1	0	−FIT	$y = -0.003x^2 + 256.81x - 6*10^6$	0.9985
T_2	150	11/−FIT	$y = -3*10^{-6}x^4 + 0.5595x^3 - 36359x^2 + 10^9x - 10^{13}$	0.9606
T_3	250	11/−FIT	$y = 0.0044x^2 - 379.34x + 8*10^6$	0.950
T_4	350	11/−FIT	$y = 6*10^{-5}x^3 - 8.1594x^2 + 353319x - 5*10^9$	0.9961
T_5	150	6/−FIT	$y = -8*10^{-5}x^3 + 9.8097x^2 - 425066x + 6*10^9$	0.9807
T_6	250	6/−FIT	$y = -9*10^{-5}x^3 + 11.753x^2 - 509226x + 7*10^9$	0.9968
T_7	350	6/−FIT	$y = -9*10^{-5}x^3 + 12.172x^2 - 527381x + 8*10^9$	0.9977
T_8	0	+FIT	$y = -4*10^{-6}x^4 + 0.6356x^3 - 41314x^2 + 10^9x - 10^{13}$	0.9697

Note: FIT, flower induction treatment; −FIT, without FIT; +FIT, with FIT. Variable X = number of days.

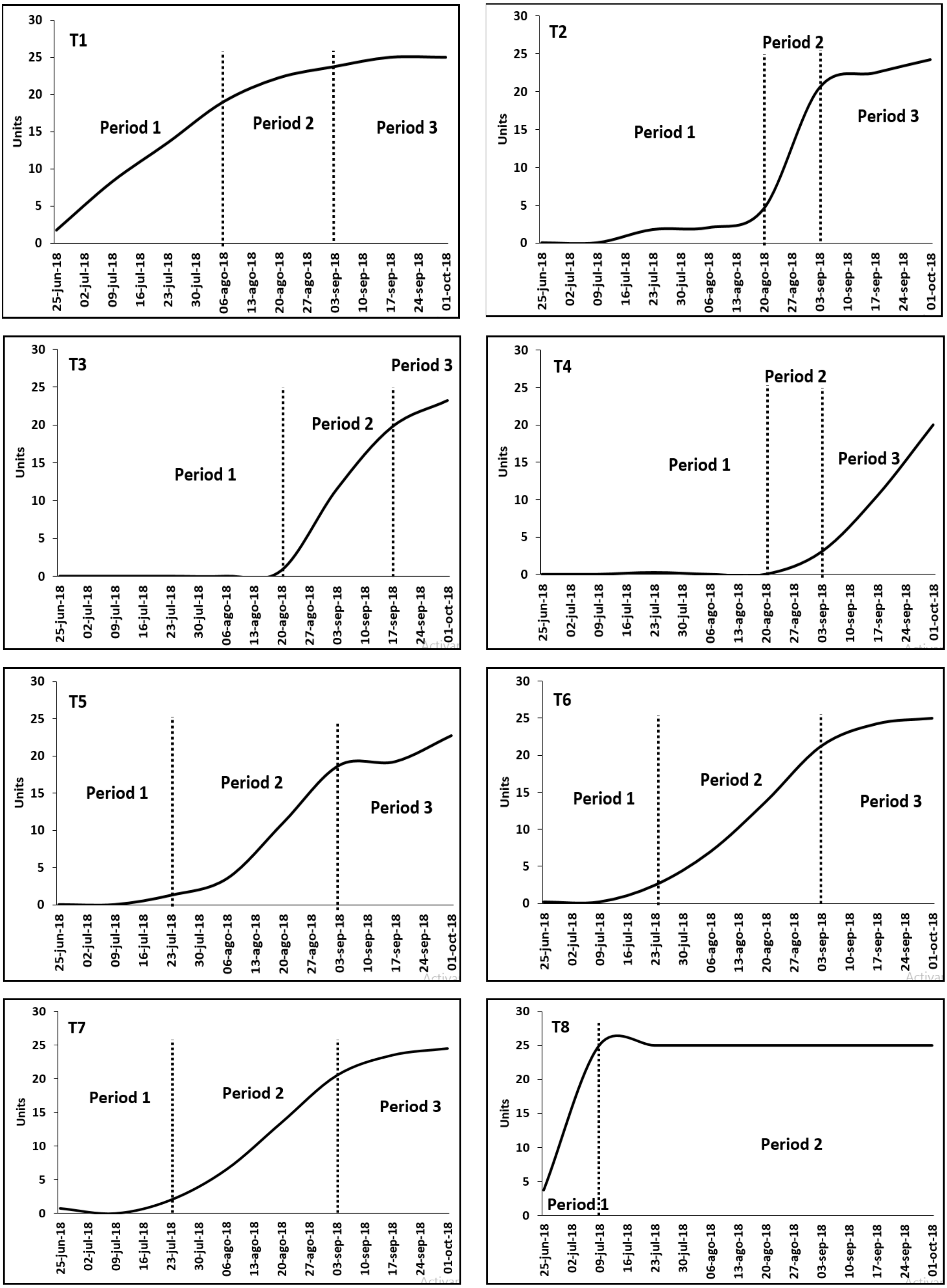

Figure 3. Curves of inflorescence number vs. time in the experiment with pineapple cv.'MD2' in Satipo. FIT, flower induction treatment; T1, AVG 0 mg/L and without FIT; T2, AVG 150 mg/L and without FIT (11 applications); T3, AVG 250 mg/L and without FIT (11 applications); T4, AVG 350 mg/L and without FIT (11 applications); T5, AVG 150 mg/L and without FIT (6 applications); T6, AVG 250 mg/L and without FIT (6 applications); T7, AVG 350 mg/L and without FIT (6 applications); T8, AVG 0 mg/L and with FIT.

The plants subjected to eleven applications of AVG (T2, T3, and T4) (Fig. 3, Table 4) exhibited a significant increase in the RRIA in the second period (compared with the first), followed by a significant decrease in the second or third period. For T2 and T4, the duration of the first, second, and third periods were 56, 14, and 28 d, respectively, whereas for T3, they were 56, 28, and 14 d, respectively. In the treatments with six applications of AVG (T5 and T6) (Fig. 3, Table 4), a high RRIA was observed in the first period (lasting 28 d), and it dropped in the second and third periods, which lasted for 42 and 28 d, respectively. In the first period, the plants with six applications had higher RRIA than those with eleven applications. On the contrary, in the second period, the plants with eleven applications showed higher values than those with six.

Discussion

The physiological phenomenon of NF affects pineapple production all over the world (Mendez, 2010), interrupting harvesting programs, decreasing harvesting efficiency, increasing costs, decreasing fruit prices, and making pest and disease control more difficult (Kuan et al., 2005; Martin-Prevel et al., 1993; Bello & Julca, 1994, 1995). In short, NP endangers the sustainability of the production of this crop. This study found that the emergence of inflorescences had gradually increased from the first to the last evaluation in treatment T1 (NF; 0 mg/L AVG without FIT) (Table 2), which is directly related to the climatic conditions of the area. Although we did not have the climactic data, Marca-Huamancha et al. (2018) reported that Satipo has low temperature and water deficit conditions,

Table 4. Relative rate and periods of inflorescence emergence in the pineapple cv. 'MD2' experiment in Satipo in 2018.

Treatment	AVG (mg/L)	Appl.	Period I	Period II	Period III
T1	0	−FIT	0.058* 25/6–06/8** (D = 42)	0.008 06/8–03/9 (D = 28)	0.002 03/9–01/10 (D = 28)
T2	150	11	0.067 25/6–20/8 (D = 56)	0.110 20/8–03/9 (D = 14)	0.007 03/9–01/10 (D = 28)
T3	250	11	0.031 25/6–20/8 (D = 56)	0.127 20/8–17/9 (D = 28)	0.012 17/9–01/10 (D = 14)
T4	350	11	0.000 25/6–20/8 (D = 56)	0.240 20/8–03/9 (D = 14)	0.069 03/9–01/10 (D = 28)
T5	150	6	0.088 25/6–23/7 (D = 28)	0.066 23/7–03/9 (D = 42)	0.007 03/9–01/10 (D = 28)
T6	250	6	0.094 25/6–23/7 (D = 28)	0.051 23/7–03/9 (D = 42)	0.006 03/9–01/10 (D = 28)
T7	350	6	0.043 25/6–23/7 (D = 28)	0.057 23/7–03/9 D = 42)	0.006 03/9–01/10 (D = 28)
T8	0	+FIT	0.137 25/6–09/7 (D = 14)	0.000 09/7–01/10 (D = 84)	---------------------------

Note: FIT, flower induction treatment; −FIT, without FIT; +FIT, with FIT; Appl., number of applications; D, number of days. Treatments 2–7 did not include FIT (−FIT).

*Relative rate of inflorescence appearance (RRIA). **Dates.

which stimulate NF (Cunha, 2005; FAO, 2021) by triggering the synthesis of ethylene.

The application of FIT, a common practice in pineapple-producing areas, was also evaluated (T8; 0 mg/L AVG with FIT). As expected, FIT significantly increased the number of inflorescences from the first evaluation, which was higher than the other treatments ($p \leq 0.05$) (Table 2). This practice stimulates flowering using growth regulators (Collazos et al., 2017) that favor ethylene synthesis. The practice seeks to homogenize flowering and harvest (FAO, 2021).

Likewise, the possible negative effects of NF have inspired research with the aim to delay the uncontrolled emergence of inflorescences without affecting yield. Among this group of trials are those aimed at reducing NF using ethylene synthesis inhibitors such as AVG (Kuan et al., 2005; Wang et al., 2007). Ethylene biosynthesis pathway is composed, essentially, of three phases, starting with the formation of S-adenosyl-L-methionine (SAM; phase 1), followed by the transformation of SAM into 1-aminocyclopropane-1-carboxylic acid (ACC; phase 2), which serves as a substrate for ethylene formation (phase 3) (Borjas-Ventura et al., 2020). The AVG inhibit the conversion of SAM into ACC in phase 2 (Khan Ali, 2018). Nevertheless, as expected, the effects of AVG depend on the dosage and its frequency, as well as on the cultivar under study (Arruda, 2017; Loría, 2016). In this study, the results showed that high doses of AVG (250 mg/L and 350 mg/L) with an application frequency of eleven times (T3 and T4) suppressed ($p \leq 0.05$) the inflorescences' emergence until almost the last evaluation compared with treatments that received only six applications (T5, T6, and T7) or without AVG (Table 2). Other researchers found that high doses of AVG inhibit the presence of inflorescences compared with low doses and a control (Kuan et al., 2005). Our results suggest that the activity of AVG is dose-dependent because of the slow penetration of this product into the plant (Kuan et al., 2005).

On the other hand, the dynamics of inflorescence emergence in pineapple cv 'MD2' have not been extensively studied. The patterns of inflorescence emergence changed depending on the treatments applied. Plants treated with T1 (NF) and T8 (0 mg/L AVG with FIT) showed different curves in inflorescence emergence compared with AVG treatments (Fig. 3). These results showed the plasticity of this pineapple cultivar in response to the imposed conditions (Dávila-Velderrain et al., 2016).

By evaluating the appearance of inflorescences over time, a series of data were obtained that allowed a functional analysis of the appearance of inflorescences. In this research, the equation that best represented inflorescence formation at T1 (NF; 0 mg/L AVG without FIT) was a second-degree polynomial equation, also known as a quadratic equation. In the remaining treatments, third and fourth-degree polynomial equations were obtained (Table 3). Similar equations have already been used to describe flowering in other species (Sun & Frelich, 2011; Chen et al., 2003).

Likewise, the curves of inflorescence appearance in the treatments had, in general, three periods, except for T8 (0 mg/L AVG with FIT) that showed only two (Fig. 3, Table 4), the first one being of short duration and with greater inflorescence appearance, whereas in the second period, there was no more inflorescence appearance. In addition, each period had a different duration and RRIA (Table 4).

For T1 (NF) (0 mg/L AVG without FIT) and the treatment with six applications of AVG, the first phase showed high RRIA; RRIA had dropped in the second period and stabilized in the third period. However, treatments that received eleven applications, particularly 250 and 350 mg/L AVG, showed a prolonged first phase (56 days) with low RRIA, followed by an increase and then a drastic drop in RRIA. These results indicated the strong inflorescence-suppressing capacity of AVG (Kuan et al., 2005; Wang et al., 2007).

Conclusions

Based on the results obtained, high AVG doses (at 250 mg/L and 350 mg/L AVG, eleven applications) inhibited NF in pineapple cv 'MD2'.

The treatment delayed or completely controlled early NF and losses due to excess fruit production at unscheduled times. In addition, this study has established NF under Satipo conditions, which has three periods with different appearance rates, where the first period was the longest (42 d). Further studies to evaluate AVG application in other cultivars and regions are required to deepen the knowledge on the management of this growth regulator.

Conflicts of interest

The signing authors of this research work declare that they have no potential conflict of personal or economic interest with other people or organizations that could unduly influence this manuscript.

Author contributions

Elaboration and execution, Development of methodology, Conception and design; Editing of articles and supervision of the study have involved all authors.

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