

Characterization of 'Gefner' atemoya seedless fruits with GA₃ application

Valéria de Oliveira Pinto¹, Marlon Cristian Toledo Pereira², Sílvia Nietsche³,
Débora Souza Mendes¹, Mauro Franco Castro Mota¹, Gisele Polete Mizobutsi²

¹ Universidade Estadual de Montes Claros, Programa de Pós-Graduação em Produção Vegetal no Semiárido, Janaúba, MG, Brasil. E-mail: valeriaagroolive@gmail.com (ORCID: 0000-0002-7538-9730); deborasouzamendes@yahoo.com.br (ORCID: 0000-0002-3100-5870); maurofrancocastro@yahoo.com.br (ORCID: 0000-0001-5184-2476)

² Universidade Estadual de Montes Claros, Centro de Ciências Exatas e Tecnológicas, Departamento de Ciências Agrárias, Montes Claros, MG, Brasil. E-mail: marlon.pereira@unimontes.br (ORCID: 0000-0003-1691-0466); gisele.mizobutsi@unimontes.br (ORCID: 0000-0001-6953-4332)

³ Universidade Federal de Minas Gerais, Instituto de Ciências Agrárias, Montes Claros, MG, Brasil. E-mail: silvia.nietsche@gmail.com (ORCID: 0000-0002-8188-3057)

ABSTRACT: The present study was carried out with the objective of evaluating the effect of artificial pollination and gibberellic acid (GA₃) in different doses and times of application in the fruit set, effective fruiting and the quality of 'Gefner' atemoya fruits. The experimental design was in randomized blocks, with thirteen treatments, four replicates and five plants per plot. The treatments applied were different doses of GA₃: 100, 150, 200, 250, 500 and 1000 mg L⁻¹ associated or not with artificial pollination. It was evaluated every seven days the fruit set, length and diameter of the fruits, and after the harvest the physical and chemical characteristics of the fruits. The growth rate of fruit length and diameter showed a sigmoid pattern with the highest growth peaks in all treatments at the 4th and 5th weeks after the anthesis. The application of 1000 mg L⁻¹ GA₃, without artificial pollination, divided in four times from the anthesis yielded seedless fruits with physical and chemical quality equivalent to the fruits of artificial pollination. The artificial pollination associated to two applications of 250 mg L⁻¹ of GA₃ showed high fruit set and fruits with greater length, diameter, mass of the fruits and reduction of the total fresh mass of the seeds.

Key words: *Annona squamosa* x *Annona cherimola*; gibberellic acid; growth regulator; parthenocarpy; pollination

Caracterização de frutos sem sementes de atemoieira 'Gefner' com aplicação de GA₃

RESUMO: O presente estudo foi realizado com objetivo de avaliar o efeito da polinização artificial e do ácido giberélico (GA₃) em diferentes doses e épocas de aplicação no pegamento, frutificação efetiva e na qualidade de frutos de atemoieira 'Gefner'. O delineamento experimental foi em blocos casualizados, com treze tratamentos, quatro repetições e cinco plantas por parcela. Os tratamentos aplicados foram diferentes doses de GA₃: 100, 150, 200, 250, 500 e 1000 mg L⁻¹ associados ou não com polinização artificial. Avaliou-se a cada sete dias o pegamento, comprimento e diâmetro dos frutos, e após a colheita as características físicas e químicas dos frutos. A taxa de crescimento do comprimento e diâmetro dos frutos apresentou em todos os tratamentos um padrão sigmoide com os maiores picos de crescimento na 4^a e 5^a semanas após a antese. A aplicação de 1000 mg L⁻¹ GA₃, sem polinização artificial, parcelada em quatro vezes a partir da antese originou frutos sem sementes, com qualidade físicas e químicas equivalente aos frutos de polinização artificial. A polinização artificial, associada a duas aplicações de 250 mg L⁻¹ de GA₃, apresentou elevado pegamento e frutos com maior comprimento, diâmetro, massa dos frutos e redução da massa fresca total das sementes.

Palavras-chave: *Annona squamosa* x *Annona cherimola*; ácido giberélico; regulador de crescimento; partenocarpia; polinização

Introduction

In the management of atemoya trees, which is the interspecific hybrid between the sugar apple (*Annona squamosa*) and cherimoya (*Annona cherimola*), artificial pollination is essential to obtain fruit sizes and shapes that are adequate for commercialization; this is therefore a technique widely adopted among producers (Pereira et al., 2011; Pereira & Kavati, 2011).

Seedless fruits are highly appreciated by consumers and producers. They have excellent sensory quality, facilitate consumption of fresh samples, and add value to the final product. Their production can be obtained through the use of gibberellins, auxins, cytokinins or the combination of these substances. The application of these phytohormones has been effective in the fruit setting and development of parthenocarpic fruits (Rademacher, 2015).

Recent studies indicate that among growth regulators, gibberellic acid is the most effective for fruiting, fruit size increase, and seedless fruit production of 'Gefner' atemoya trees. In the present study, it was observed that GA₃ doses between 1000 mg L⁻¹ and 1500 mg L⁻¹ applied in different moments in flowers and fruits promoted the production of seedless fruits with a pattern similar to artificially pollinated fruits (Pereira et al., 2014; Santos et al., 2016).

Results found in the literature leave no doubt about the efficiency of GA₃ for production of seedless fruits and of larger fruits with seeds of atemoya. However, the dosage and number of applications need to be adjusted to reduce shape irregularities and increase the fresh mass without affecting the other physical and chemical traits of the fruits.

Thus, the objective of this work was to evaluate the artificial pollination and the effect of GA₃ at different doses and times of application on the fruit setting, effective fruiting and quality of 'Gefner' atemoya fruits.

Material and Methods

The experiment was carried out from April to August 2015 in a commercial 'Gefner' atemoya orchard, Janaúba,

Minas Gerais (altitude of 472 m and geographic coordinates: 15°50'38" S, 43°19'23" W). The climate of the area is Aw (tropical humid with dry winter and rainy summer) according to Köppen's classification. Climatic data during the period of the experiment are described in Figure 1.

The orchard was composed of nine-year-old plants cultivated at 4.0 x 2.5 m spacing and the soil is of the type Eutrophic Red Latosol. A micro sprinkler system was used for irrigation. Twenty 'Gefner' atemoya plants were selected and received all the treatments.

A randomized block design with four replicates was adopted for the experiment; each replicate was composed of a plot with five plants. In each plant, 13 flowers were chosen for individual application of treatments. Artificial pollination was carried out through application of pollen from sugar apple at anthesis and GA₃ doses were applied in different moments from the anthesis onwards. Both management methods were evaluated in isolation and/or combined in the following detailed treatments (Table 1).

The commercial product used was Pro-Gibb®, composed of 10% gibberellic acid (GA₃), in the form of a soluble powder. The solution was prepared 24 hours prior to use with 500 mL

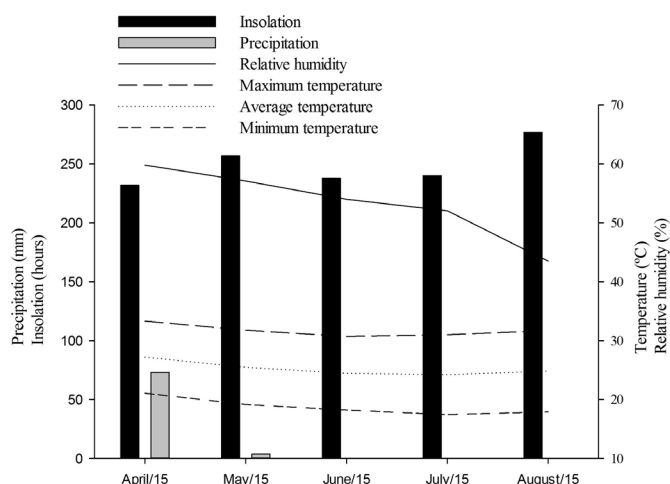


Figure 1. Insolation, precipitation, relative humidity, maximum, minimum and average monthly temperature in Janaúba, Minas Gerais, Brazil.

Table 1. Description of treatments of GA₃ application and artificial pollination in 'Gefner' atemoya flowers in northern Minas Gerais, Brazil.

Treatments	Description
1	Control - artificial pollination with sugar apple pollen (AP)
2	AP + 100 mg L ⁻¹ GA ₃ at the 1 st , 3 rd and 5 th week after anthesis (WAA)
3	AP + 100 mg L ⁻¹ GA ₃ at the 2 nd and 4 th WAA
4	AP + 150 mg L ⁻¹ GA ₃ at the 1 st , 3 rd and 5 th WAA
5	AP + 150 mg L ⁻¹ GA ₃ at the 2 nd and 4 th WAA
6	AP + 200 mg L ⁻¹ GA ₃ at the 1 st , 3 rd and 5 th WAA
7	AP + 200 mg L ⁻¹ GA ₃ at the 2 nd and 4 th WAA
8	AP + 250 mg L ⁻¹ GA ₃ at the 1 st , 3 rd and 5 th WAA
9	AP + 250 mg L ⁻¹ GA ₃ at the 2 nd and 4 th WAA
10	1,000 mg L ⁻¹ GA ₃ at anthesis and 500 mg L ⁻¹ GA ₃ at the 1 st , 3 rd and 5 th WAA
11	1,000 mg L ⁻¹ GA ₃ at anthesis, 1 st WAA + 500 mg L ⁻¹ GA ₃ at the 3 rd and 5 th WAA
12	1,000 mg L ⁻¹ GA ₃ at anthesis, 1 st and 3 rd WAA + 500 mg L ⁻¹ GA ₃ and 5 th WAA
13	1,000 mg L ⁻¹ GA ₃ at anthesis, 1 st , 3 rd and 5 th WAA

of distilled water solution, adding 0.1% nonionic adhesive spreader. The flowers, in functionally pistillate stage and with a length between 37 to 42 mm were duly selected and identified with colored wool ribbons. Gibberellic acid was applied on flowers using a spray bottle at the same time as the artificial pollination was carried out. Pollen from sugar apple flowers was used for artificial pollination, which was applied to the stigma of flowers at functionally pistillate stage with aid of a brush in the morning (7:00 a.m. to 9:00 p.m.) (Pereira et al., 2011).

From the first week after the anthesis onwards, after fruit setting, GA₃ applications were directed to the fruits, covering their entire surface. The solutions were applied at weekly basis, according to the intervals of each treatment. Each fruit received on average 2 mL of solution per application.

One week after the application of treatments, weekly evaluations of effective fruiting and fruit length and diameter were initiated. Fruit setting was evaluated in the second week after anthesis. The harvest took place on the 17th week after anthesis, on August 08, 2015.

The fruits harvested were duly identified, packed in paper bags, and then transported to the Post-Harvest Laboratory of Unimontes. When the fruits reached the point of consumption, the following characteristics were measured: fruit mass, weight loss, fresh pulp mass, number of seeds, seed mass, hardness, pH, soluble solids and titratable acidity.

The evaluated characteristics were submitted to analysis of variance and in case of significant results according to the F test were followed by comparisons of means by the Tukey test at 5% probability. Fruit setting and effective fruiting were analyzed weekly in a descriptive way; information on standard deviation was provided. The variables fruit length

and diameter were also analyzed weekly by adjusting the logistic model ($y=a/(1+be^{cx})$) and growth rates, obtained by the first derivative of the adjusted equation (Richards, 1969). Graphs were generated using the statistical software SigmaPlot (Scientific Data Analysis and Graphing Software).

Results and Discussion

The percentage of fruit setting in the second week after anthesis was 100% for all treatments. As for effective fruiting, the treatments with artificial pollination presented 95% of successful fruits until harvest regardless of application of GA₃ (Table 2). The percentage of effective fruiting from fruit treatments with GA₃ alone ranged from 55% to 85% of successful fruits until harvest (Table 2).

The high percentage of fruit setting and effective fruiting observed in the present study regardless of the fruiting management methods applied can be attributed to a number of factors, including climatic conditions. Studies on artificial pollination and/or application of growth regulators in flowers aiming at obtaining parthenocarpic fruits indicate that temperatures between 25 and 30°C and relative humidity above 50% are highly correlated with the viability of pollen grains and fruits, and are considered ideal conditions for the development of plants (Judd et al., 1999; Rodrigues et al., 2018).

Besides the effect of the environment, it is worth noting that the artificial pollination of the 'Gefner' atemoya using sugar apple pollen grains has already been reported in the literature as a highly efficient method. Some of the factors highlighted by authors are a large amount of pollen grains produced by sugar apple flowers, a higher percentage of pollen grains of the monad type, a longer flowering period

Table 2. Percentage of fruit setting in the second week after anthesis and effective fruiting of 'Gefner' atemoya submitted to treatments with artificial pollination and GA₃ application at 17 weeks after anthesis.

Weeks after anthesis	Treatments												
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13
1	100	100	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100	100	100	100	100	100	100
4	100	100	100	100	100	100	100	95	100	100	100	95	100
5	100	100	100	100	100	100	100	95	100	100	100	95	100
6	100	100	100	100	100	100	100	95	100	100	100	95	100
7	100	100	100	100	100	100	100	95	100	100	100	95	100
8	100	100	100	100	100	100	100	95	100	100	100	95	100
9	100	100	100	100	100	100	100	95	90	80	80	75	100
10	100	100	100	100	100	100	100	95	90	75	75	75	100
11	100	100	100	95	95	90	100	90	90	75	75	70	90
12	100	100	100	95	95	90	100	90	90	70	65	60	90
13	100	100	100	95	95	90	100	90	90	65	65	60	90
14	95	95	100	95	95	90	100	90	90	65	65	60	85
15	95	95	100	95	95	90	95	90	90	55	60	50	85
16	95	95	100	95	95	90	95	90	90	55	55	50	85
17	95	95	95	95	95	90	95	90	90	55	55	50	85

T1- artificial pollination (AP); T2-AP + 100 mg L⁻¹ GA₃ at the 1st, 3rd and 5th week after anthesis (WAA); T3 - AP + 100 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T4 - AP + 150 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T5 - AP + 150 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T6 - AP + 200 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T7 - AP + 200 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T8 - AP + 250 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T9 - AP + 250 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T10 - 1000 mg L⁻¹ GA₃ at anthesis and 500 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T11 - 1000 mg L⁻¹ GA₃ at anthesis and 1st WAA + 500 mg L⁻¹ GA₃ at the 3rd and 5th WAA; T12 - 1000 mg L⁻¹ GA₃ at anthesis, 1st and 3rd WAA + 500 mg L⁻¹ GA₃ and 5th WAA; T13 - 1000 mg L⁻¹ GA₃ at anthesis, 1st, 3rd and 5th WAA.

and the viability of the pollen grains of the sugar apple trees that is higher to that of atemoya (Nietsche et al., 2009; Rodrigues et al., 2016).

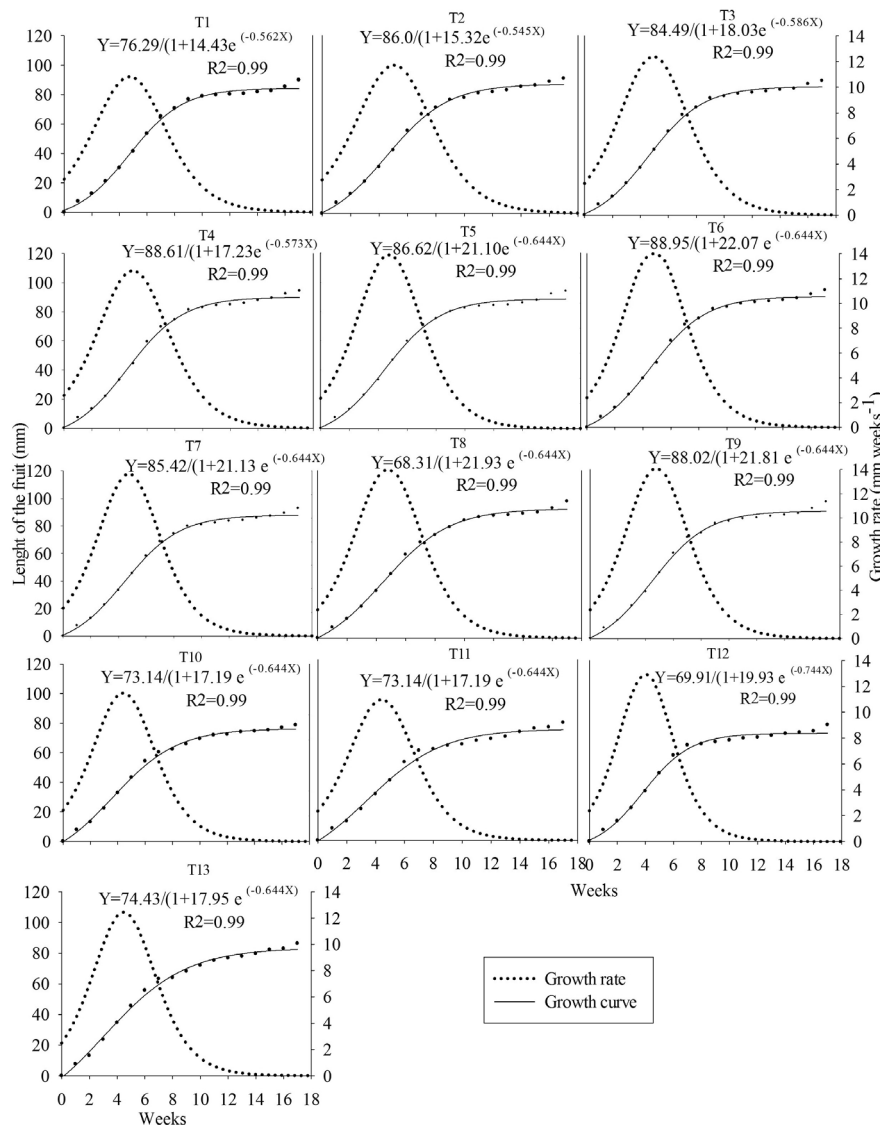
The application of 1000 mg L⁻¹ of GA₃ in four moments (at anthesis and 1st, 3rd and 5th weeks after anthesis) without artificial pollination promoted 85% of the fruit setting until the moment of harvest; there was also a fall at the 10th and 14th week after anthesis (Table 2).

Active gibberellins type GA₁ and GA₃ act directly on fruit setting and effective fruiting in several species (Sotelo-Silveira et al., 2014). In atemoya, the results of the most recent research indicate that GA₃ is, among regulators, the most efficient in the stages of fruit setting and effective fruiting. The studies suggest that exogenous application of GA₃ tends to promote an increase of the concentration of this regulator in the cells of fruit tissues. Pereira et al. (2014)

and Santos et al. (2016) evaluated different doses of GA₃ in 'Gefner' atemoya to observe the production of seedless fruits, increased effective fruiting and increased fruit growth at the dose of 1,000 mg L⁻¹ of GA₃.

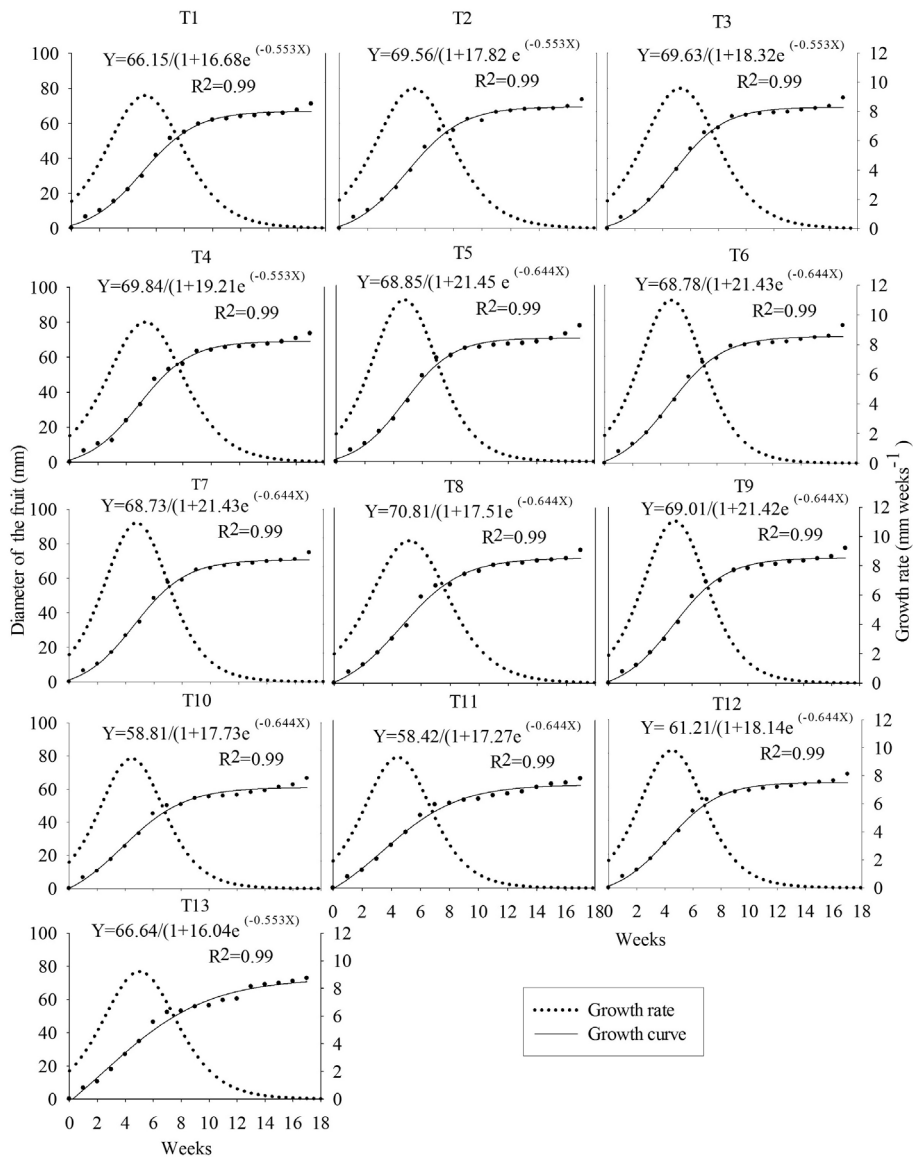
This increased intracellular concentration of GA₃ may also influence the synthesis of other hormones, including indoleacetic acid (AIA). Thus, fruits resulting from GA₃ application alone or combined with artificial pollination may present a higher concentration of phytohormones that allow increasing the stimuli associated with cell division and elongation.

Fruit length and diameter presented sigmoid curves adjusted to the logistic model. The rate of fruit length and diameter increase showed a constant development in all treatments, with a maximum growth point at the 4th and 5th weeks after anthesis (Figures 2 and 3).



T1- artificial pollination (AP); T2 - AP +100 mg L⁻¹ GA₃ at the 1st, 3rd and 5th week after anthesis (WAA); T3 - AP + 100 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T4 - AP + 150 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T5 - AP + 150 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T6 - AP + 200 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T7 - AP + 200 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T8 - AP + 250 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T9 - AP + 250 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T10 - 1.000 mg L⁻¹ GA₃ at anthesis and 500 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T11 - 1.000 mg L⁻¹ GA₃ at anthesis and at the 1st WAA + 500 mg L⁻¹ GA₃ at the 3rd and 5th WAA; T12 - 1.000 mg L⁻¹ GA₃ at anthesis, 1st and 3rd WAA + 500 mg L⁻¹ GA₃ and 5th WAA; T13 - 1.000 mg L⁻¹ GA₃ at anthesis, 1st, 3rd and 5th WAA.

Figure 2. Length and growth rate of 'Gefner' atemoya fruits submitted to treatments with artificial pollination and GA₃, at the 17th week after anthesis.



T1 - artificial pollination (AP); T2 - AP +100 mg L⁻¹ GA₃ at the 1st, 3rd and 5th week after anthesis (WAA); T3 - AP + 100 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T4 - AP + 150 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T5 - AP + 150 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T6 - AP + 200 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T7 - AP + 200 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T8 - AP + 250 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T9 - AP + 250 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T10 - 1.000 mg L⁻¹ GA₃ at anthesis and 500 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T11 - 1.000 mg L⁻¹ GA₃ at anthesis and 1st WAA + 500 mg L⁻¹ GA₃ at the 3rd and 5th WAA; T12 - 1.000 mg L⁻¹ GA₃ at anthesis, 1st and 3rd WAA + 500 mg L⁻¹ GA₃ and 5th WAA; T13 - 1.000 mg L⁻¹ GA₃ at anthesis, 1st, 3rd and 5th WAA.

Figure 3. Diameter and growth rate of 'Gefner' atemoya fruits submitted to treatments of artificial pollination and GA₃ application at the 17th week after anthesis.

The treatments with artificial pollination associated with two or three applications of GA₃ (100, 150, 200, and 250 mg L⁻¹) presented the highest growth peaks in relation to the non-pollinated treatments, with mean lengths of 12-14 mm/week and diameters of 9 to 11 mm/week (Figures 2 and 3).

In the present study we can consider that besides the supply of auxins and gibberellins by the plant itself, exogenous applications of GA₃ also contributed to increase the growth rates of fruits derived from artificial pollination associated with application of GA₃. Plackett & Wilson (2016) state that the embryo of fruits with seeds is responsible for supplying auxins during all stages of fruit development.

The fruits resulting from the application of 1000 mg L⁻¹ GA₃ alone at anthesis, followed by the dose variation between 500 mg L⁻¹ and 1000 mg L⁻¹ GA₃ at the 1st, 3rd and 5th

week after anthesis without pollination, presented a growth equivalent to fruits produced through artificial pollination, reaching lengths of 11.0; 11.7; 13.0; 12.7 mm/week and diameters of 9.4; 9.3; 10.0; 9.0 mm/week, respectively (Figures 2 and 3).

In general, an accelerated growth of length was observed until the 8th week after the anthesis, giving evidence of logarithmic and linear phases. After this period, there was a continuous decline in the growth rate, but the fruits continued to grow slowly in length and diameter until the harvest point (Figures 2 and 3).

The fruits resulting from artificial pollination associated with two and three applications of GA₃ with a dose of 250 mg L⁻¹ presented fruit length and diameter values superior to the control and other treatments (Table 3).

Table 3. Length and diameter of 'Gefner' atemoya fruits submitted to treatments of artificial pollination and GA₃ application at the 17th week after anthesis.

Treatments	Length (cm)	Diameter (cm)
1- artificial pollination (AP)	8.8 cd	7.1 bcde
2- AP + 100 mg L ⁻¹ GA ₃ at the 1 st , 3 rd and 5 th week after anthesis (WAA)	9.1 bc	7.3 abcde
3- AP + 100 mg L ⁻¹ GA ₃ at the 2 nd and 4 th WAA	9.2 bc	7.4 abcde
4- AP + 150 mg L ⁻¹ GA ₃ at the 1 st , 3 rd and 5 th WAA	9.3 bc	7.5 abcd
5- AP + 150 mg L ⁻¹ GA ₃ at the 2 nd and 4 th WAA	9.4 abc	7.6 abc
6- AP + 200 mg L ⁻¹ GA ₃ at the 1 st , 3 rd and 5 th WAA	9.4 abc	7.6 abc
7- AP + 200 mg L ⁻¹ GA ₃ at the 2 nd and 4 th WAA	9.4 abc	7.6 abc
8- AP + 250 mg L ⁻¹ GA ₃ at the 1 st , 3 rd and 5 th WAA	10.2 ab	7.8 ab
9- AP + 250 mg L ⁻¹ GA ₃ at the 2 nd and 4 th WAA	10.5 a	8.1 a
10- 1,000 mg L ⁻¹ GA ₃ at anthesis and 500 mg L ⁻¹ GA ₃ at the 1 st , 3 rd and 5 th WAA	7.8 d	6.6 de
11- 1,000 mg L ⁻¹ GA ₃ at anthesis, 1 st WAA + 500 mg L ⁻¹ GA ₃ at the 3 rd and 5 th WAA	7.9 d	6.6 e
12- 1,000 mg L ⁻¹ GA ₃ at anthesis, 1 st and 3 rd WAA + 500 mg L ⁻¹ GA ₃ and 5 th WAA	7.9 d	6.8 cde
13- 1,000 mg L ⁻¹ GA ₃ at anthesis, 1 st , 3 rd and 5 th WAA	8.7 cd	7.3 abcde
CV (%)	6.36	6.98

Means followed by the same lowercase letter in the column do not differ statistically ($P \leq 0.05$) according to Tukey test.

The results described above suggest that increasing GA₃ doses and the number of applications were directly proportional in both characteristics. Srivastava & Handa (2005) confirm that artificial pollination and exogenous application of growth regulators increase the concentration of gibberellins and auxins in fruits.

The application of 1000 mg L⁻¹ of GA₃ in four doses produced fruits with mean length of 8.6 cm and mean diameter of 7.3 cm, similar to the control treatment (Table 3). This result indicates that the application of 1000 mg L⁻¹ of GA₃ can be used instead of artificial pollinating in 'Gefner' atemoya, with the main benefit of production of parthenocarpic fruits.

The fruits resulting from artificial pollination with 250 mg L⁻¹ of GA₃ in two or three moments resulted in a greater increase of fresh mass, with a mean value higher than 30% in relation to the control treatment (Table 4).

The fruits obtained from artificial pollination followed by application of 150 and 200 mg L⁻¹ GA₃ in two and three

moments did not present differences but were superior to the control treatment, presenting an average increase of 13%.

Fruits produced in the treatments with GA₃ (T10, T11 and T12) presented the lowest mean values in relation to the other treatments. The significant reduction observed in practically all the physical characteristics evaluated is most probably due to the absence of the seeds, and consequently lower level of hormones associated with fruit growth.

We can infer that the exogenous application of gibberellic acid at anthesis had a similar effect to bioactive gibberellin resulting from pollination and fertilization. Moreover, during the fruit growth phase (1st, 3rd and 5th week after anthesis), gibberellins participated in the processes of cell division and expansion. According to Taiz & Zeiger (2013), this hormone is associated with increasing size of existing or newly divided cells, indicating that gibberellins act both in cell expansion and cell division. Although the results are promising, the

Table 4. Total fresh mass (TFM), fresh peel mass (FPM), fresh pulp mass (FPM), total seed mass (TSM), number of seeds (NSE) and hardness (HAR) of 'Gefner' atemoya fruits subjected to treatments of artificial pollination and GA₃ application.

Treatments	TFM	FPM	FPM	TSM	NSE (un)	HAR (N)
	(g)					
T1	264.9 d	53.9 bcd	178.5 cd	32.5 c	68.1 bc	7.06 a
T2	289.5 d	67.1 ab	194.2 bc	28.2 bc	72.4 bc	5.97 a
T3	288 d	61.1 abcd	179.2 cd	27.7 bc	69.0 bc	6.21 a
T4	293.8 bc	64.3 abc	202.9 b	27.4 b	66.3 b	6.69 a
T5	292.2 bc	71.8 a	190.4 bc	29.9 bc	73.0 bc	6.27 a
T6	305.3 b	69.0 ab	207.0 b	29.2 bc	73.8 bc	6.65 a
T7	301.5 bc	67.6 ab	203.9 b	30.1 bc	73.7 bc	6.81 a
T8	344.4 a	67.8 ab	247.1 a	29.5 bc	81.7 c	6.91 a
T9	347.4 a	62.9 abc	257.7 a	26.9 b	62.3 b	6.31 a
T10	208.6 f	45.2 d	163.4 d	0.0 a	0.0 a	3.24 b
T11	213.8 ef	48.3 cd	165.5 d	0.0 a	0.0 a	3.21 b
T12	224.5 e	47.9 cd	176.7 cd	0.0 a	0.0 a	3.36 b
T13	260.2 d	52.4 bcd	207.7 b	0.0 a	0.0 a	3.50 b
CV (%)	6.48	11.23	6.40	9.84	10.95	9.18

Means followed by the same lowercase letter in the column do not differ statistically ($P \leq 0.05$) according to Tukey test. T1 - artificial pollination (AP); T2 - AP + 100 mg L⁻¹ GA₃ at the 1st, 3rd and 5th week after anthesis (WAA); T3 - AP + 100 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T4 - AP + 150 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T5 - AP + 150 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T6 - AP + 200 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T7 - AP + 200 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T8 - AP + 250 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T9 - AP + 250 mg L⁻¹ GA₃ at the 2nd and 4th WAA; T10 - 1.000 mg L⁻¹ GA₃ at anthesis and 500 mg L⁻¹ GA₃ at the 1st, 3rd and 5th WAA; T11 - 1.000 mg L⁻¹ GA₃ at anthesis and 1st WAA + 500 mg L⁻¹ GA₃ at the 3rd and 5th WAA; T12 - 1.000 mg L⁻¹ GA₃ at anthesis, 1st and 3rd WAA + 500 mg L⁻¹ GA₃ and 5th WAA; T13 - 1.000 mg L⁻¹ GA₃ at anthesis, 1st, 3rd and 5th WAA.

physical dimensions of the parthenocarpic fruits were still lower than those of pollinated fruits, indicating that further applications of gibberellins could be evaluated after the fifth week, because the fruits were still in active growth.

The overall mean of fresh weight loss was 13.82% over a five-day period, from the harvest to the point of consumption; no differences were found between treatments. The fresh pulp mass of the fruits showed a greater increase in the treatments of artificial pollination and GA₃ application, with an increase of 41% of pulp in relation to the control group. Fresh peel mass presented a similar behavior to that of the total mass, again pointing to the highest mean values of the treatments T8 and T9 (Table 4).

The control group had higher total seed mass than the other treatments (Table 4). Fruits in all treatments using GA₃ alone were seedless (Figure 4).

The pulp hardness of fruits produced through artificial pollination was statistically higher than that of fruits treated with GA₃ alone. Studies have shown that the absence of

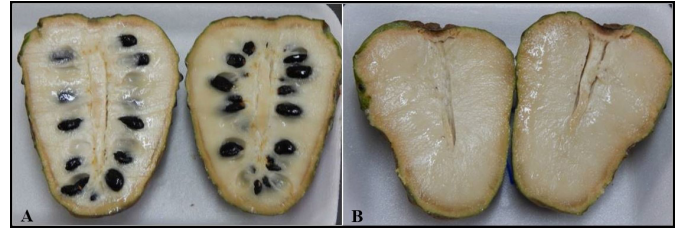
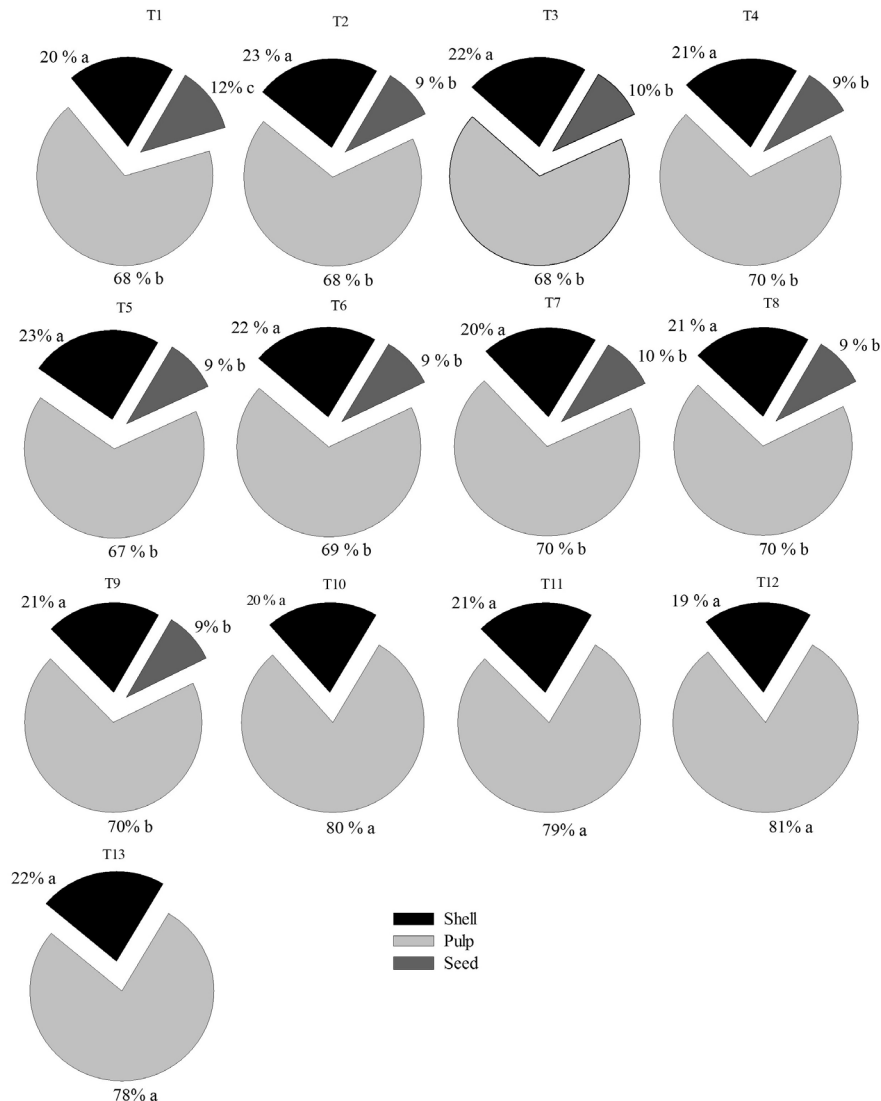


Figure 4. 'Gefner' atemoya fruits. A: fruit artificially pollinated (with seeds); B: fruit treated with GA₃ alone (seedless).

seeds reduces the concentration of calcium in the middle lamella, leading cell walls to tend to become softer. Hudson & Buescher (1985) reported that calcium reduces tissue breakdown by protecting pectin macromolecules from demethylation. Changes in the cell wall structure by means of protopectin degradation in the middle lamella and the primary cell wall lead to increased soluble pectin concentration and loss of non-cellulose neutral sugars during fruit maturation (Hocking et al., 2016).



Means followed by the same letter do not differ statistically ($P \leq 0.05$) according to Tukey test.

Figure 5. Percentage of the fresh pulp mass, peel + stem and seed of 'Gefner' atemoya fruits submitted to treatments of artificial pollination and GA₃ application.

The post-harvest quality variables did not show significant differences between treatments, with a mean of 26° Brix, pH 4.27, 0.45% titratable acidity and 62.27 ratio, evidencing fruits of excellent chemical quality, regardless of the treatment applied.

The fruits resulting from the GA₃ alone showed a higher percentage of pulp (80%) than the other fruits with artificial pollination alone or combined with GA₃, with a mean of 69% (Figure 5).

Considering that the mesocarp (pulp) represents proportionally the largest volume of the fruit and probably constitutes the part with the largest number of cells, we can suggest that the effect of exogenous application of GA₃ was more evident in this group of tissues than in the epicarp and endocarp regions. It is important to highlight the high permeability of the cell walls and membranes in the application of growth regulators, which are polar molecules of low molecular weight.

The characteristic of high percentage of pulp is of paramount importance to the market because the pulp is the main part of the fruit consumed in natural samples. The percentage of peel varied from 19 to 23%. Fruits produced with artificial pollination alone (control) presented higher percentage of seeds in relation to the treatments with two and three applications of GA₃ (Figure 5).

Fruits treated with GA₃ alone did not present seeds. It was observed that the seedless fruits presented some deformities when compared to the fruits produced through artificial pollination (Figure 4). Pereira et al. (2014) and Santos et al. (2016) who worked with production of parthenocarpic fruits of atemoya observed the same irregularity in the shape of fruits.

In general, the results of the present study demonstrated that GA₃ can be applied with the objective of increasing the quality of fruits with seeds, as well as producing parthenocarpic fruits in atemoya without altering the chemical characteristics of the fruits. Among the challenges of the application of this new technology we emphasize the need for a better understanding of the effects of exogenous application of GA₃ on the processes of fruit growth and development and the creation of strategies for dissemination and commercialization of seedless fruits, a product totally unknown in the national and international markets.

Conclusions

Artificial pollination associated with two applications of 250 mg L⁻¹ of GA₃ in the 2nd and 4th weeks after anthesis provides high fruit setting, effective fruiting and fruits with greater length, diameter, fruit mass and reduction of total fresh mass of fruit seeds.

The application of 1000 mg L⁻¹ of GA₃ in four moments from the anthesis results in seedless fruits with physical and chemical quality equivalent to the fruits produced through artificial pollination.

Acknowledgements

To the Foundation for Research Support of the State of Minas Gerais - FAPEMIG, the CNPq, and the CAPES for financial support, scholarships and research grants.

Literature Cited

- Hocking, B.; Tyerman, S. D.; Burton, R.A.; Gilliam, M. Fruit calcium: transport and physiology. *Frontiers in Plant Science*, v.7, article 569, 2016. <https://doi.org/10.3389/fpls.2016.00569>.
- Hudson, J.M.; Buescher, R.W. Pectic substances and firmness of cucumber pickles as influenced by CaCl₂, NaCl and brine storage. *Journal of Food Biochemistry*, v.9, n.3, p.211-229, 1985. <https://doi.org/10.1111/j.1745-4514.1985.tb00350.x>.
- Judd, W.S.; Campbell, P.S.; Qellogg, E.A.; Stevens, P.S. *Plant systematics: a phylogenetic approach*. 4. ed. Massachusetts: Sinauer, 1999. 464 p.
- Nietsche, S.; Pereira, M.C.T.; Oliveira, C.; Dias, M.M.; Reis, S.T. Viabilidade dos grãos de pólen de flores de pinheira (*Annona squamosa*) em diferentes horários. *Ciência e Agrotecnologia*, v. 33, n. 2, p. 527-531, 2009. <https://doi.org/10.1590/S1413-70542009000200026>.
- Pereira, F.M.; Kavati, R. Contribuição da pesquisa científica brasileira no desenvolvimento de algumas frutíferas de clima subtropical. *Revista Brasileira de Fruticultura*, v. 33, n. spe1, p. 92-108, 2011. <https://doi.org/10.1590/S0100-29452011000500013>.
- Pereira, H. S.; Delgado, M.; Avó, A.P.; Barão, A.; Serrano, I.; Viegas, W. Pollen grain development is highly sensitive to temperature stress in *Vitis vinifera*. *Australian Journal of Grape and Wine Research*, v. 20, n.3, p.474-484, 2014. <https://doi.org/10.1111/ajgw.12105>.
- Pereira, M.C.T.; Crane, J.H.; Nietsche, S.; Montas, W.; Santos, M.A. Reguladores de crescimento na frutificação efetiva e qualidade de frutos partenocárpicos de atemoia 'Gefner'. *Pesquisa Agropecuária Brasileira*, v.49, n.4, p.281-289, 2014. <https://doi.org/10.1590/S0100-204X2014000400006>.
- Pereira, M.C.T.; Nietsche, S.; Costa, M.R.; Crane, J.H.; Corsato, C.D.A.; Mizobutsi, E.H. Anonaceas: pinha, atemoia e graviola. **Informe Agropecuário**, v. 32, n. 264, p. 26-34, 2011. <http://www.epamig.br/download/informe-agropecuario-264-cultivo-tropical-de-fruteiras-2011>. 22 Jun. 2017.
- Plackett, A. R. G.; Wilson, Z. A. Gibberellins and plant reproduction. In: Hedden, P.; Thomas, S. G. (Eds.). *The gibberellins*. West Sussex: Wiley Blackwell, 2016. Chap 11, p.323-358. (Annual Plant Reviews book series, v. 49). <https://doi.org/10.1002/9781119210436.ch11>.
- Rademacher, W. Plant growth regulators: backgrounds and uses in plant production. *Journal of Plant Growth Regulators*, v.34, n. 4, p.845-872, 2015. <https://doi.org/10.1007/s00344-015-9541-6>.
- Richards, F.C. The quantitative analysis of plant growth. In: Steward, F.C. (Ed.). *Plant physiology: a treatise*. New York: Academic Press, 1969. p.3-76.
- Rodrigues, B.R.A.; Nietsche, S.; Mercadante-Simões, M.O.; Pereira, M.C.T.; Ribeiro, L.M. Climatic seasonality influences the development of pollen grains and fruiting in *Annona squamosa*. *Environmental and Experimental Botany*, v. 150, p. 240-248, 2018. <https://doi.org/10.1016/j.envexpbot.2018.03.025>.

- Rodrigues, B.R.A.; Santos, R.C.; Nietsche, S.; Mercadante-Simões, M.O.; Cunha, I.R.G.; Pereira, M.C.T. Determination of cardinal temperatures for sugar apple (*Annona squamosa* L.). *Ciência e Agrotecnologia*, v. 40, n. 2, p.145-154, 2016. <https://doi.org/10.1590/1413-70542016402039115>.
- Santos, R. C.; Pereira, M.C.T.; Mendes, D.S.; Sobral, R.R.S.; Nietsche, S.; Mizobutsi, G.P.; Santos, B.H.C. Gibberellic acid induces parthenocarpy and increase fruit size in 'Gefner' custard apple (*A. cherimola* x *A. squamosa*). *Australian Journal of Crop Science*, v.10, n.3, p. 314-321, 2016. <https://doi.org/10.21475/ajcs.2016.10.03.p6911>.
- Sotelo-Silveira, M.; Marsch-Martinez, N.; Folter, S. Unraveling the signal scenario of fruit set. *Planta*, v.239, n. 6, p.1147-1158, 2014. <https://doi.org/10.1007/s00425-014-2057-7>.
- Srivastava, A.; Handa, A. K. Hormonal Regulation of Tomato Fruit Development: A Molecular Perspective. *Journal of Plant Growth Regulators*, v. 24, n.2, p. 67-82, 2005. <http://doi.org/10.1007/s00344-005-0015-0>.
- Taiz, L.; Zeiger, E. *Fisiologia vegetal*. 5.ed. Porto Alegre: Artmed, 2013. 820 p.