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Optimized cutting of yellow passion fruit and its potential for unstaked or trellised cultivation

Carlos Augusto Santos de Jesus[1], Lucas Kennedy Silva Lima[2], Everton Vieira de Carvalho[1], Raul Castro Carriello Rosa[3], Onildo Nunes de Jesus[2 ✉] and Eduardo Augusto Girardi[2]

[1] Universidade Federal do Recôncavo da Bahia, Centro de Ciências Agrárias, Ambientais e Biológicas, Rua Rui Barbosa, nº 710, Centro, CEP 44380-000 Cruz das Almas, BA, Brazil. E-mail: gutoufrb@gmail.com, evieira.c@gmail.com

[2] Embrapa Mandioca e Fruticultura, Rua Embrapa, s/nº, Caixa Postal 007, CEP 44380-000 Cruz das Almas, BA, Brazil. E-mail: lucas18kennedy@gmail.com, onildo.nunes@embrapa.br, eduardo.girardi@embrapa.br

[3] Embrapa Agrobiologia, Rodovia BR-465, Km 7, Ecologia, CEP 23891-000 Seropédica, RJ, Brazil. E-mail: raul.rosa@embrapa.br

✉ Corresponding author

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Abstract – The objective of this work was to evaluate types of cuttings, indole-3-butyric acid (IBA) concentrations, and potting media on the rooting of passion fruit (*Passiflora edulis*) cultivars, and to compare the initial performance of flowering-competent cuttings cultivated in a trellising system or in a nonstaking method on ground covered with plastic mulch. The passion fruit cultivars evaluated were BRS Gigante Amarelo, Isla Redondo Amarelo, and FB 200 Yellow Master were evaluated. The assessed treatments were: softwood or semi-hardwood cuttings; five concentrations of IBA (0, 500, 1,000, 2,000, and 4,000 mg L^{-1}); and the pine bark or phenolic foam potting media. Initial growth, fruit yield, and bacteriosis severity were evaluated in the field in flowering-competent cuttings and seedlings, both in the trellising system and in the nonstaking method on mulched ground. For the evaluated cultivars, a high rooting rate (>90%) was observed for both softwood and semi-hardwood cuttings grown in phenolic foam or decomposed pine bark for potting media, regardless of the IBA concentration. In the espalier system, 14 months after transplanting, fruit yield was 45% higher for cuttings than for seedlings. Unstaked plants had a low number of flowers and fruit set, and a great damage by bacteriosis according to the used cultivar. The evaluated cultivars can be propagated either by softwood or semi-hardwood cuttings, in phenolic foam or decomposed pine bark, without IBA application. Flowering-competent cuttings have the potential to anticipate the production in the trellised cultivation of yellow passion fruit.

Index terms: *Passiflora edulis*, flowering competence, indole-3-butyric acid, phenolic foam, rooting, training system.

Otimização da estaquia do maracujá-amarelo e seu potencial para o cultivo rasteiro ou tutorado

Resumo – O objetivo deste trabalho foi avaliar tipos de estacas, concentrações de ácido indolbutírico (AIB) e substratos de cultivo, no enraizamento de cultivares de maracujá (*Passiflora edulis*), e comparar o desempenho inicial de estacas floríferas conduzidas em sistema de espaldeira ou no método de cultivo rasteiro em solo protegido com cobertura de plástico. Avaliaram-se as cultivares de maracujá BRS Gigante Amarelo, Isla Redondo Amarelo e FB 200 Yellow Master. Os tratamentos avaliados foram: estacas herbácea ou lenhosa, cinco concentrações de AIB (0, 500, 1.000, 2.000 e 4.000 mg L^{-1}); e os substratos de cultivo casca de pinheiro ou espuma fenólica. Em campo, o crescimento inicial, a produção de frutos e a severidade da bacteriose foram avaliados em plantas de estacas competentes para florescer e em mudas, tanto no sistema em espaldeira como no método rasteiro em solo com cobertura de plástico. Para as cultivares avaliadas, observou-se alta taxa de enraizamento (>90%) tanto para as estacas herbáceas como para as semilenhosas, em substrato de espuma fenólica ou casca decomposta de pinheiro, independentemente da concentração de AIB. No sistema de espaldeira, após 14 meses de cultivo, a produção foi 45% maior para plantas obtidas de estacas que para mudas. As plantas rasteiras apresentaram baixo número de flores e frutos e grande severidade de bacteriose conforme a cultivar utilizada. As cultivares avaliadas podem ser propagadas por estaquia herbácea ou semilenhosa, em espuma fenólica ou em casca de pinheiro decomposta, sem aplicação de AIB. As estacas floríferas apresentam potencial para antecipar a produção em cultivo de maracujá-amarelo em espaldeira.

Termos para indexação: *Passiflora edulis*, competência para florescimento, ácido indolbutírico, espuma fenólica, enraizamento, tutoramento de planta.

Introduction

Brazil is the leading producer and consumer of yellow passion fruit (*Passiflora edulis* Sims) in the world, with a total production of 602,651 tonnes obtained in 42,731 hectares in 2019. The tropical semiarid Northeastern is responsible for 62.31% of the national production, and Bahia state alone stands for 26.7% (IBGE, 2019). This fruit is mainly cultivated in family farming system in areas ranging from three to five hectares. As an early bearing cash crop that requires much labor, yellow passion fruit has a major importance for employment and income generation (Jesus et al., 2018).

Yellow passion fruit is commercially propagated by seed, since it is a practical and cheap method (Roncatto et al., 2008a; Faleiro et al., 2019). However, since seedlings have segregation due to sexual auto-incompatibility, the use of local varieties leads to a wide variation for fruit yield and size, as well as to irregular vineyard shape, and higher susceptibility to pests and diseases (Albuquerque Junior et al., 2013).

The asexual propagation of selected genotypes could fix desirable traits as high yield of fruit with superior quality (Faleiro et al., 2019). Despite the cutting investigations for *Passiflora* spp. (Albuquerque Junior et al., 2013; Alexandre et al., 2014), this method has not been commercially used for most of the species in a massive way. Cutting methods are very expensive and highly complex (Faleiro et al., 2019); moreover, there is a lack of information on the most adequate types of cutting and potting media, and on the use of plant growth regulators for rooting.

Investment costs are elevated for yellow passion fruit cultivation, not only for the nursery stocks, but also for the trellising supports necessary to train the vines, which is frequently the single-wire espalier (Agrianual…, 2020). Diseases caused by *Cowpea aphid-borne mosaic virus*, and the *Fusarium* wilt aggravates the situation, reducing the lifespan to less than a year, which results in increasing production costs and economical losses to the growers because there are no resistant varieties (Viana et al., 2014). This context demands new cultivation strategies to increase yield in a shorter period, and the optimal propagation of elite cultivars by cutting may be an alternative for trained orchards (Faleiro et al., 2019). However, the unstaked cultivation could represent a more substantial way to reduce expenses and facilitate some practices, such as the mechanical harvesting, taking as example from other vine crops like tomatoes, grapes, and pumpkins (Almeida, 1960; Azevedo et al., 2010; Ramos et al., 2010). Despite the potential of this technique, there is no report on it for passion fruit, to the best of our knowledge.

The objective of this work was to evaluate types of cuttings, indole-3-butyric acid (IBA) concentrations, and potting media on the rooting of passion fruit cultivars, and to compare the initial performance of flowering-competent cuttings cultivated in a trellising system or in a nonstaking method on ground covered with plastic mulch.

Materials and Methods

Four experiments were carried out in the municipality of Bebedouro, in the state of São Paulo, Brazil (20°53'16"S, 48°28'11"W, at 601 m altitude). The local climate is typical Aw, according to the Köppen-Geiger's classification (Rolim et al., 2007), with 17.5°C, 31°C, and 1,440 mm for annual means of minimum and maximum air temperatures and rainfall, respectively. Cuttings were collected from mother plants of three market cultivars of yellow passion fruit *Passiflora edulis* Sims (BRS Gigante Amarelo, Isla Redondo Amarelo, and FB 200 Yellow Master) that were grown in an anti-aphid greenhouse.

Mother plants were obtained from commercial seed that were sown in November 2014 in polystyrene trays with 32 cells (12 cm deep and 120 cm^3) filled with commercial potting media Tropstrato (Vida Verde, Mogi Mirim, SP, Brazil). Thirty days after emergence, five seedlings of each cultivar were transplanted into 18 L plastic pots, using one plant per pot. The plant treatments were daily irrigation, and fertigation three times a week with 1.5 L per plant of a nourishing solution comprised of 18 g calcium nitrate, 9 g potassium nitrate, 9 g monoamonic phosphate, 6.75 g Fe-EDDHA, and 0.45 g of a nutrient cocktail (15% Mg, 10% S, 2% B, 5% Mn, 0.5% Mo, and 6% Zn) in 22.5 L of water.

Mother plants were trained on vertical stakes with single-stem growth and removal of lateral sprouts. Every time the vines were too long to be trained on the stake, they were wrapped around the pot, and the shoot tip was trained again on the stake. This procedure was repeated several times until the plants initiated flowering, when the vines were pruned to allow of lateral shooting. Flowering shoots were used to collect the cuttings.

In the first experiment, softwood and semi-hardwood cuttings were evaluated. The experimental design was a 3 x 2 factorial arrangement (yellow passion fruit cultivars x types of cutting) in completely randomized blocks, with five replicates, and eight cuttings in the plot, with the 240 cuttings.

Flowering-competent shoots with 200 cm length were collected from the mother plants in the morning. From these shoots, 10–15 cm long softwood cuttings (only green young tissue) were cut from the shoot tip, and 15–20 cm long semi-hardwood cuttings (mature tissue with partial lignification) were collected from 120 to 200 cm to the base of the shoot. All cuttings had two nodes with two leaves cut in half and the base cut in a bevel. Shoot tips in softwood cuttings was not pruned. After collecting, the cuttings undergone treatment with captan (2.5 g L^{-1}) (Adama Brasil S/A, Londrina, PR, Brazil). Cuttings were individually planted into cell trays, as described for the mother plants. Inside the anti-aphid greenhouse, the meteorological variables during the evaluation period (August to September 2015) were 30, 22, and 14°C (averages for maximum, mean, and minimum daily air temperatures, respectively), and 49% mean relative air humidity of. A misting-irrigation system was turned on for 5 s every 5 min.

Forty-seven days after cutting, the following variables were evaluated: percentage of cuttings with rooting (PR), number of sprouts per cutting (NS), length of the longest sprout per cutting (LS), length of the longest root per cutting (LR), and number of roots per cutting (NR). Values of PR, LS and NR were transformed with arcsine $\sqrt{(x+1)/100}$, to attend to the normality and variance homoscedasticity assumptions. Data were subjected to the analysis of variance, and the means were compared by the Tukey's test, at 1% and 5% probability, using the Sisvar software (Ferreira, 2019).

In the second experiment, five concentrations of indole-3-butyric acid (IBA) were evaluated on the rooting of the yellow passion fruit cuttings. The experimental design was a 3 x 5 + 3 factorial arrangement (softwood cuttings of the three yellow passion fruit cultivars x five concentrations of IBA + three additional treatments of semi-hardwood cuttings of the three cultivars without IBA), in completely randomized blocks, with five replicates, and five cuttings in the plot, with the total of 450 cuttings. Only softwood cuttings were treated with IBA because they had a lower percentage of rooting, in the first experiment, and our major interest was for this propagule due of the highest and fastest way to obtain it. However, since it was interesting to compare with the standard easy-to-root semi-hardwood cuttings, three additional treatments were added to the statistical scheme following the recommendations of Barbosa & Maldonado Júnior (2015).

The same cuttings as described for the first experiment were used. After the cut in a bevel, the cutting base (2 cm) was immersed for 10 s in a 30% hydroalcoholic solution at 0, 500, 1,000, 2,000, and 4,000 mg L^{-1} of 99% purity IBA (Dinâmica, Química Contemporânea LTDA., Indaiatuba, SP, Brazil). The cuttings were then planted in two stacked cubes (2 cm side each) of phenolic foam (Green-Up, Floral Atlanta, São Bernardo dos Campos, SP, Brazil) that were washed before use. The two cubes with a single cutting each were transferred to 200 mL plastic cups. A 2 cm layer of water was continuously kept at the bottom of the cup. From 15 to 30 days after cutting, some rooting was observed, and the plants started to be fertigated (50 mL per plant) three times a week with the afore mentioned nourishing solution. Inside the anti-aphid greenhouse, meteorological mean variables during the evaluation period (November to December 2015) were 43, 32, and 21°C (averages for maximum, mean, and minimum daily air temperatures, respectively), and 39% mean relative air humidity.

Thirty days after cutting, the same variables as described for the first experiment were evaluated. Later, the cuttings were transplanted to 15 x 30 cm plastic bags. The same decomposed pine bark potting media was used, and, 35 days after transplanting, a 22-04-08 N-P_2O_5-K_2O control release fertilizer (Osmocote, Forth Cote, Cerquilho, SP, Brazil) was applied at 5 g per plant. Sixty-two days after transplanting to the bags, plants were trained on 80 cm long wires with a 3.5 mm gauge, and the following variables were evaluated: plant height (PH), stem diameter at 5 cm above the collar end (SD), and the number of flower buds per plant (NB). Data were analyzed as described for the first experiment, except for the effect of IBA concentration, for which the regression analyses considered the significance of the tested model, using the Sisvar software (Ferreira, 2019).

In the third experiment, the use of phenolic foam or water was compared on the rooting of the yellow passion fruit softwood cuttings. The experimental design was carried out in completely randomized blocks, in 3 x 2 factorial arrangement (yellow passion fruit cultivars x phenolic foam or water, without IBA), with five replicates and six cuttings in the plot. Data were collected and analyzed as described for the previous experiments.

Softwood cuttings were obtained and, after the cut in a bevel, the cuttings were planted as described before. The same procedures were followed for rooting of the softwood cuttings directly in the water, without phenolic foam. IBA was not used. The plastic cups containing the cuttings were put inside the cells of the trays that were placed on concrete benches. Inside the antiaphid-mesh greenhouse, meteorological mean variables during the evaluation period (November to December 2016) were 42, 31, and 20°C (averages for maximum, mean, and minimum daily air temperatures, respectively), and 35% mean relative air humidity.

In the fourth experiment, the initial performance of cutting and seedling-derived plants in unstaked and trellised cultivation was evaluated in the field. Meteorological variables during the evaluation period (November 2015 to April 2017) were 30, 24, and 17°C (averages for maximum, mean, and minimum daily air temperatures, respectively), 73% mean relative air humidity, and 1,318 mm annual rainfall. The soil in the experimental area is a dystrophic red udox oxisol (Buol et al., 2011), with a moderate to average texture, and the following chemical properties before planting (at 0–20 cm soil depths): pH ($CaCl_2$), 5.9; Ca, 40 $mmol_c$ dm^{-3}; Mg, 15 $mmol_c$ dm^{-3}; K, 2 $mmol_c$ dm^{-3}; H + Al, 18 $mmol_c$ dm^{-3}; and CEC (T), 75 $mmol_c$ dm^{-3}; base saturation (V), 76%; OM, 22 g dm^{-3}; P, 48 mg dm^{-3}; Fe, 130 mg dm^{-3}; Cu, 6.6 mg dm^{-3}; Zn, 6.6 mg dm^{-3}; Mn, 1.8 mg dm^{-3}; B, 0.2 mg dm^{-3}; and S, 9 mg dm^{-3}.

An experimental design in completely randomized blocks was carried out in a 3 x 2 x 2 factorial arrangement (cultivars x type of propagule x training system), with five replicates and four plants in the plot, totaling 240 plants. In November 2015, softwood cuttings of the three *P. edulis* cultivars (BRS Gigante Amarelo, Isla Redondo Amarelo, and FB 200 Yellow Master) were obtained, as previously described in the first experiment, treated with IBA, and seed from commercial mother plants were sown. All plants (cuttings and seedlings) were grown in anti-aphid mesh greenhouse in 2 L plastic bags filled with decomposed pine bark potting media. Ninety days later, uniform and vigorous plants (60 and 80 cm height for cuttings and seedlings, respectively) were selected and transplanted in the field.

Two training systems were evaluated: unstaked cultivation with plants growing directly on the ground, and trellised cultivation. For both systems, beds (1 m width x 48 m length, and 1 m between-beds) were set with hoe and covered with black/silver (bottom/up) plastic mulching, and the between-beds corridor was bare ground. Planting was performed before mulching for which holes were set corresponding to plants' pit position.

Plant spacing was 2 m (between-rows) x 1 m (in-rows) totaling 5,000 plants ha^{-1}. For the unstaked cultivation, shoot tips of the plants were constantly pruned to stimulate lateral branching, and the plants were manually trained to grown only on the mulched bed. For the trellising system, wood espaliers were set at 6 m intervals in the row, using a single stand of flat galvanized wire with 2.77 mm of gauge at 1.8 m above the ground level. Plants were trained on the espalier with a single-stem until they reached the wire, then the tips were pruned, and two lateral shoots were trained on the opposite directions on the wire. Tips of secondary shoots were pruned once they touched the following plant to stimulate the lateral curtain.

Drip irrigation was applied daily, for 1 hour, at 4 L per hour. Before transplanting, pits (40 x 40 x 40 cm) were fertilized with 50 g of thermic phosphate Yoorin Master (17.5% total P_2O_5; 1:100 citric acid – 16% P_2O_5; 18% Ca; 7% Mg; 0.10% B; 0.05% Cu; 0.30% Mn; 0.10% Si; and 0.55% Zn), and 50 g of dolomitic limestone

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[70% effective calcium carbonate equivalent (ECCE)]. After transplanting, cover fertilization was manually performed every 45 days, using potassium chloride (10 g per plant) and calcium nitrate (50 g per plant). Starting from five months of age, fertilization was performed with calcium nitrate (30 g per plant), monoamonic phosphate (4 g per plant), and Krista-K (12% N, 46% K_2O, and 1.6% S, 20 g per plant) (Yara Brasil S.A., Porto Alegre, RS, Brazil). In this period, due to the overgrowth of unstaked plants, the vines were erected, and the amount of fertilizer per plant was diluted in 400 mL solution that was manually applied into the hole, on the mulching, where the plant was grown. Pollination was natural by carpenter bees (*Xilocopa* spp.). Whenever necessary, weeding was done with a hoe, and pests were controlled with delthametrin (5 mL 10 L^{-1}). Every 20 days, copper hydroxide (2.5 g L^{-1}) was preventively sprayed on plants with a 20 L costal sprayer to control bacteriosis (*Xanthomonas axonopodis* pv. *passiflorae*). The mean number of fruit per plant (NF) and the length of the lateral shoot or curtain (CR) were assessed weekly from the first flowering, until 14 months after transplanting.

Mature fruit that have dropped on the ground in the plot were counted and weighted. The cumulative productivity (Prod) was estimated by Prod = total NF x PD x FW (Mg ha^{-1}), in which PD is the planting density (5,000 plants ha^{-1}), and FW is the mean fruit weight (g). Fruit were weighted weekly on a scale, and the FW was calculated at the end of the evaluation period. In two producing periods (November 2015 and March 2016), the number of flower buds (NB), number of opened flowers (NFlo), and the bacteriosis severity (BS) were evaluated within a 0.5 x 0.5 m square frame made of ½" PVC tubes. In the trellising system, the frame was set at ≈ 1.5 m above the ground level, in the middle of the plot, vertically on both sides of the plant or espalier. In the unstaked system, the frame was set horizontally on the plants on the ground, at two equidistant points within each plot. In both systems, the average values of the two frames per plot and periods were calculated. BS was evaluated first due to the evident incidence of the disease, especially on the unstaked system, although the use of chemical control and typical bacteriosis symptoms were in accordance to Ishida & Halfeld-Vieira (2009) and Machado et al. (2017). BS was assessed using a grading scale, proposed by Viana et al. (2014) and Ferreira & Tebaldi (2019), with modifications, which facilitated the evaluation in the field, as follows: 0, for symptomless plants; 1, for up to 25% of leaf area within the frame covered by bacteriosis spots; 2, for 25–50% of leaf area with bacteriosis spots; 3, for 50–75% of leaf area with bacteriosis spots; and 4, for more than 75% of leaf area with bacteriosis spots, severe leaf drop, and shoot dieback. The area within a given frame was completely covered by the leaves of yellow passion fruit, that is the reason why it was assumed as 100% of leaf area, and the number of leaves was not counted. Then, the BS was evaluated by three independent inspectors, whom visually attributed grades according to the scale, considering the approximated percentage of symptomatic leaf area within the frame, and the average grades were calculated. CR and NF means were transformed with arcsine $\sqrt{(x+1)/100}$ to attend to the normality and variance homoscedasticity assumptions. Data were analyzed as described for the previous experiments using the Sisvar software (Ferreira, 2019). BS was analyzed by the nonparametric test of Friedman using the Action software (Equipe Estatcamp, 2014).

Results and Discussion

Semi-hardwood cuttings displayed overall better adventitious rooting than softwood cuttings because of their higher percentage of rooting (PR), mean number of sprouts per cutting (NS), length of the longest sprout (LS), root system length (LR), and two-fold higher mean number of roots per cutting (NR) (Table 1). Softwood cuttings of *P. actinia* Hook did not root, whereas semi-hardwood resulted in 75% of rooting at 90 days after cutting (Albuquerque Junior et al., 2013).

Yellows passion fruit FB 200 and BRS Gigante Amarelo cultivars showed similar PR, which was higher than that of Isla Redondo cultivar. The same behavior was observed for NS and LR, but NR of FB 200 cultivar was about 20% higher than that of the other cultivars (Table 1). The differentiated performance of cutting propagation of these cultivars is reported for the first time in the present work, and may be related to physiological traits and hormonal content during callogenesis and root emission (Araújo et al., 2010), and to genetic constitution which is highly variable (Castro et al., 2016; Faleiro et al., 2019; Viana et al., 2019). For wild passion fruit species such as *P. amethystine* J.C. Mikan, *P. odontophylla* Harms ex

Glaziou and *P. laurifolia* L., the rooting variation of different accessions was also reported (Viana et al., 2019). Nevertheless, in the present work, rooting was at least 70% for all yellow passion fruit cultivars, which is encouraging for marketing, besides being higher than rooting described in previous studies (Roncatto et al., 2008a; Santos et al., 2012; Viana et al., 2019).

In the second experiment, FB 200 cultivar cuttings resulted in lower LS, LR, and plant height (PH), even though its number of flower buds per plant (NB) was 48% and 56% higher than those of BRS Gigante Amarelo and Isla Redondo cultivars, respectively, 60 days after transplanting (Table 2). In the comparison between IBA-treated softwood and nontreated semi-hardwood cuttings, the later induced a lower number of longer roots, but growth was similar after transplanting. There was an effect of IBA only on NR and LS. For NR, all cultivars showed a linear response to the evaluated concentrations, and Isla Redondo was the most responsive cultivar (Figure 1 A). Regardless of the cultivar, the LS had a quadratic response that was estimated as the highest (4.8 cm per plant) at 1,500 mg L^{-1} IBA (Figure 1 B). Therefore, a competition between the canopy and root partitioning was suggested. Responses of passion fruit cuttings to IBA are highly variable and rely on the species, and on environmental and cultivation conditions, from which *P. edulis* usually shows none or low effects (Roncatto et al., 2008a; Araújo et al., 2010; Sabião et al., 2011; Mayer et al., 2017; Tomazzoli et al., 2019). In this species, the endogenous levels of auxins are probably sufficient to stimulate rooting (Moreira et al., 2015; Viana et al., 2019). Results in the present work confirm a low response to IBA, whose higher concentrations could even damage the cutting development, as reported for *P. nitida* Kunth. by Sabião et al. (2011). Since the rooting percentage and number of roots were high, even without IBA application, there was no clear benefice from its use.

However, any attempt to establish cutting-based orchards of yellow passion fruit will depend on the availability of commercially prone propagation systems. A high percentage of rooting was observed in high-quality cuttings that can be obtained for commercial cultivars of yellow passion fruit, in a fast and reproducible system under protected nursery. There was no need for the IBA application, which could be explained by the maintenance of leaves on the cuttings (Kasahara, 2016) that, in turn, lead to a high level of endogenous auxins in yellow passion fruit (Roncatto et al., 2008a), while rooting of other wild species of *Passiflora* frequently responds more to IBA (Alexandre et al., 2014).

In the third experiment, cutting propagation directly in water was clearly detrimental to yellow passion fruit because PR in water decreased to less than 50% for Isla Redondo and BRS Gigante Amarelo cultivars; still, FB 200 cultivar showed a mean 95% PR regardless of the

Table 1. Biometric variables of three cultivars of yellow passion fruit (*Passiflora edulis*) propagated by softwood and semi-hardwood cuttings in decomposed pine bark for potting media, 47 days after cutting(1).

Treatment	PR (%)	NS (per plant)	LS	LR	NR (per plant)
			(cm)	(cm)	
Cutting type (T)					
Softwood	71.67b	0.84b	4.18b	6.84b	16.32b
Semi-hardwood	94.17a	1.79a	7.14a	10.10a	38.44a
Cultivar (C)					
Isla Redondo	70.00b	1.25b	5.64	8.19b	29.49b
BRS Gigante Amarelo	90.00a	1.67a	7.33	9.80a	31.12b
FB 200	88.75a	1.74a	6.25	9.88a	38.14a
p-value					
Cultivar (C)	0.001**	0.001**	0.422ns	0.018*	0.014*
Cutting type (T)	0.000**	0.000**	0.028*	0.000**	0.000**
C x T	0.495ns	0.124ns	0.767ns	0.091ns	0.433ns
Coefficient of variation (%)	8.15	16.41	24.3	20.32	14.20

(1)Means followed by equal letters, in the columns, do not differ by the Tukey's test, at 5% probability (*) or 1% (**) of probability. (ns)Nonsignificant. Percentage of cuttings with rooting (PR), number of sprouts per cutting (NS), length of the longest sprout per cutting (LS), length of the longest root per cutting (LR), and number of roots per cutting (NR).

media (Table 3). This same cultivar did not vary for NS and LR, which were reduced, in turn, by 47% and 87%, respectively, in water, in comparison to phenolic foam for the other cultivars. The direct rooting in water probably resulted in hypoxia, which facilitates the proliferation of anaerobic microorganisms that degrade the cuttings before root emission (Lattuada et al., 2011), especially for BRS Gigante Amarelo and Isla Redondo cultivars.

Decomposed pine bark for potting media is highly available for commercial propagation in Brazil and, from our results, it can be used for the production of semi-hardwood cutting-derived nursery plants of yellow passion fruit, in greenhouse conditions. Phenolic foam led to almost 100% of rooting for all evaluated cultivars and cutting types. Therefore, it is an alternative potting media for yellow passion fruit propagation, without the need for IBA application. Rooting directly in water was unsuccessful.

In the fourth experiment that was carried out in field conditions, the variation between the cultivation methods occurred in all evaluated variables, but triple interaction was significant only for the number of flowers (Nflo) (Table 4). Trellised plants had length of the lateral shoots, number of flower buds, and number of opened flowers 39, 45, and 30% higher than those of unstaked plants, respectively. Moreover, the bacteriosis severity was 36% higher in unstaked plants, which is probably a result of shorter shoots, lower flowering, and more severe bacteriosis symptoms; consequently, fruit production and yield in the unstaked system was none.

In the trellising system, the propagation method influenced the results of cuttings, leading to earlier flowering, which resulted in 45% higher production than the propagation with seedlings (Table 4). BRS Gigante Amarelo cultivar showed the lowest-bacteriosis severity index (1.65), but this resistance was not related to a higher-fruit number and yield, which were attained by FB 200 cultivar with 8.17 fruit per plant and 6.74 Mg ha^{-1}.

The sexual propagation of yellow passion fruit is a cheap method, and currently available selected cultivars and hybrids represent an advance for growers (Cruz Neto et al., 2016; Faleiro et al., 2019). However, the use of asexual propagation could significantly improve

Table 2. Biometric variables of cuttings of three cultivars of yellow passion fruit (*Passiflora edulis*) treated or not with five concentrations of indole-3-butyric acid (IBA) in greenhouse conditions(1).

Treatment	PR (%)	NS (per plant)	LS	LR	NR	NB	PH	SD
			----------- (cm) -----------		--------- (per plant) ---------		----------- (cm) -----------	
Softwood cuttings (SW)								
Isla Redondo	98.00	1.10	4.86a	5.36a	26.72a	0.71b	59.76a	3.46
BRS Gigante Amarelo	100.00	1.06	4.71a	5.06a	21.44c	0.85b	55.86a	3.67
FB 200	99.00	1.03	3.17b	4.34b	23.98b	1.63a	48.03b	3.76
Semi-hardwood cuttings (HW)								
Isla Redondo	95.00	1.75	6.15a	6.23	25.20a	0.50	72.00	3.93
BRS Gigante Amarelo	95.00	1.63	1.35b	5.30	19.58b	0.70	55.90	4.38
FB 200	100.00	1.85	2.84b	5.10	20.00ab	0.90	56.28	3.99
SW x HW								
Softwood	99.00	1.06	4.25	4.91b	24.04a	1.06	54.56	3.69
Semi-hardwood	96.67	1.74	3.45	5.55a	21.08b	0.70	61.39	4.10
p-value								
Softwood cuttings (SW)	0.440ns	0.299ns	0.001**	0.001**	0.000**	0.000**	0.004*	0.549ns
Concentration of IBA	0.362ns	0.134ns	0.009**	0.440ns	0.000**	0.289ns	0.264ns	0.132ns
SW x IBA	0.171ns	0.800ns	0.123ns	0.081ns	0.000**	0.609ns	0.987ns	0.355ns
Semi-hardwood cuttings (HW)	0.259ns	0.151ns	0.000**	0.116ns	0.037*	0.367ns	0.070ns	0.746ns
SW x HW	0.138ns	0.379ns	0.107ns	0.014*	0.023*	0.061ns	0.056ns	0.101ns
Coefficient of variation (%)	4.98	12.46	37.34	15.84	14.12	49.85	19.74	24.15

(1)Means followed by equal letters, in the columns, do not differ by the Tukey's test, at 5% (*) or 1% (**) of probability. (ns)Nonsignificant. Evaluation 30 days after cutting: percentage of cuttings with rooting (PR), number of sprouts per cutting (NS), length of the longest sprout per cutting (LS), length of the longest root per cutting (LR), and number of roots per cutting (NR). Evaluation 62 days after transplanting of the cuttings: number of flower buds per plant (NB), plant height (PH), and stem diameter (SD) at 5 cm above the collar end.

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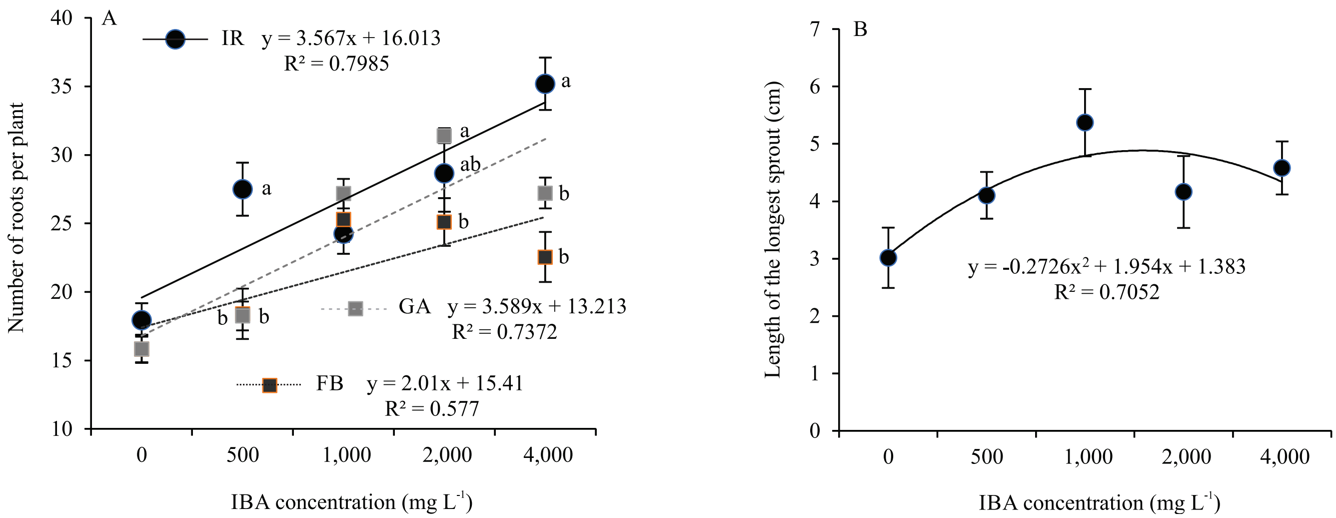

Figure 1. Effect of the concentration of indole-3-butyric acid (IBA) on the number of roots per cutting (A) and length of the longest sprout per cutting (B) of three cultivars of yellow passion fruit (*Passiflora edulis*), 30 days after propagation by softwood cuttings in greenhouse. Cultivars in figure A were: IR, Isla Redondo; GA, BRS Gigante Amarelo; and FB, FB 200 Yellow Master. The mean of the three evaluated cultivars are in figure B. Lowercase letters in figure A compare the means between the three cultivars respectively within each IBA concentration.

Table 3. Biometric variables of three passion fruit (*Passiflora edulis*) cultivars propagated by softwood cutting in water and phenolic foam, 30 days after cutting in greenhouse[(1)].

Treatment	PR (%)	NS (per plant)	LS	LR	NR (per plant)
			---------------------- (cm)	----------------------	
Cultivar (C)					
Isla Redondo	68.32b	1.07b	1.37b	2.94b	6.08b
BRS Gigante Amarelo	61.66b	1.25b	1.39b	2.74b	4.70b
FB 200	94.99a	1.60a	2.42a	4.45a	10.87a
Potting media (P)					
Phenolic foam	94.44a	1.61a	2.26a	4.58a	11.01a
Water	55.55b	1.00b	1.19b	2.16b	3.42b
p-value					
Cultivar (C)	0.000**	0.002**	0.000**	0.011*	0.000**
Potting media (P)	0.000**	0.000**	0.000**	0.000**	0.000**
C x P	0.007**	0.021*	0.304ns	0.001**	0.146ns
Coefficient of variation (%)	21.36	25.47	35.04	38.52	23.43
[(2)]PR (%)		Isla Redondo	BRS Gigante Amarelo	FB 200	
Phenolic foam		93.32aA	90.00aA	100.0aA	
Water		43.33bB	33.33bB	89.99aA	
[(2)]NS (number per plant)		Isla Redondo	BRS Gigante Amarelo	FB 200	
Phenolic foam		1.53aA	1.63aA	1.67aA	
Water		0.60bB	0.86bB	1.53aA	
[(2)]LR (cm)		Isla Redondo	BRS Gigante Amarelo	FB 200	
Phenolic foam		4.78aA	4.48aA	4.50aA	
Water		1.11bB	0.99bB	4.40aA	

[(1)]Means followed by equal letters, in the columns, do not differ by the Tukey's test, at 5% (*) or 1% (**) of probability. [(ns)]Nonsignificant. Percentage of cuttings with rooting (PR), number of sprouts per cutting (NS), length of the longest sprout per cutting (LS), length of the longest root per cutting (LR), and number of roots per cutting (NR). [(2)]Within interactions, lowercase letters compare means between potting media within each cultivar; and uppercase letters compare means among cultivars within each potting media.

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Table 4. Biometric variables of three cultivars of yellow passion fruit (*Passiflora edulis*) propagated by cuttings and seedlings, and cultivated in unstaked and trellised cultivation(1).

Treatment	CR (cm)	NB	NFlo	BS(2) (grade)	NF (per plant)	Prod. (Mg ha^{-1})
		--------------- (per plant) ---------------				
Cultivation (C)						
Trellised	170.55a	12.65a	13.56a	1.60b	6.02a	4.74a
Unstaked	103.05b	6.91b	9.51b	2.50a	0.00b	0.00b
Propagation (P)						
Seedling	141.25	8.86b	9.75b	2.10	2.13b	1.69b
Cutting	132.36	10.69a	13.33a	2.00	3.89a	3.04a
Cultivar (V)						
Isla Redondo	131.25	9.04	10.28	2.25a	2.60b	1.73b
BRS Gigante Amarelo	138.75	10.55	12.50	1.65b	2.34b	2.02b
FB 200	140.42	9.75	11.85	2.25a	4.09a	3.37a
p-value						
Cultivation (C)	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
Propagation (P)	0.277^{ns}	0.006**	0.000**	0.414^{ns}	0.000**	0.000**
Cultivar (V)	0.614^{ns}	0.147^{ns}	0.086^{ns}	0.003**	0.007**	0.001**
C x P	0.731^{ns}	0.462^{ns}	0.002**	0.0001**	0.000**	0.000**
C x V	0.643^{ns}	0.382^{ns}	0.615^{ns}	0.0002**	0.007**	0.001**
P x V	0.397^{ns}	0.086^{ns}	0.081^{ns}	0.0023**	0.091^{ns}	0.101^{ns}
C x P x V	0.631^{ns}	0.715^{ns}	0.006**	0.410^{ns}	0.091^{ns}	0.527^{ns}
Coefficient of variation (%)	17.15	18.50	14.36	30.28	16.53	15.23

Number of fruit per plant

C x P(3)	Cutting	Seedling	C x V(4)	Unstaked	Trellised
Unstaked	0.00bA	0.00aA	Isla Redondo	0.00aB	5.22bA
Trellis	7.78aA	4.26aB	BRS Gigante Amarelo	0.00aB	4.68bA
-	-	-	FB 200	0.00aB	8.17aA

Fruit yield (Mg ha^{-1})

C x P(3)	Cutting	Seedling	C x V(4)	Unstaked	Trellised
Unstaked	0.0bA	0.0bA	Isla Redondo	0.00aB	3.45bA
Trellis	6.09aA	3.39aB	BRS Gigante Amarelo	0.00aB	4.04bA
-	-	-	FB 200	0.00aB	6.74aA

BS C x P(2)			BS C x R(2)			BS P x V(2)		
Trellised	Seedling	1.70b	Trellised	Isla Redondo	1.75bc	Seedling	Isla Redondo	2.10abc
	Cutting	1.50b		BRS Gigante Amarelo	1.20c		BRS Gigante Amarelo	1.60d
Unstaked	Seedling	2.50a		FB 200	1.85b		FB 200	2.60a
	Cutting	2.50a	Unstaked	Isla Redondo	2.75a	Cutting	Isla Redondo	2.40ab
-	-	-		BRS Gigante Amarelo	2.10b		BRS Gigante Amarelo	1.70cd
-	-	-		FB 200	2.65a		FB 200	1.90bcd

Number of flowers per plant(4)	Unstaked			Trellised		
	Isla Redondo	BRS Gigante Amarelo	FB 200	Isla Redondo	BRS Gigante Amarelo	FB 200
Seedling	6.80aA*	5.70bA*	6.70bA*	11.00aB*	17.50aA*	10.80bB*
Cutting	10.30aA	14.10aA	13.50aA	13.00aA	12.70bA	16.40aA

(1)Means followed by equal letters, in the columns, do not differ by Tukey's test, at 5% (*) or 1% (**) of probability. (ns)Nonsignificant. CR, length of the lateral shoots or curtain; NB, number of flower buds, NFlo, number of opened flower; BS, severity of bacteriosis, using grades 0 (none) to 4 (100%); NF, number of fruit per plant; and Prod: cumulative productivity until 14 months after transplanting. (2)p-value and mean comparisons with the nonparametric Friedman test. (3)Lowercase letters in the columns and uppercase letters in the lines, compare means between cultivation methods within each propagation method and the inverse comparison, respectively. (4)Lowercase and uppercase letters in columns and lines, respectively, compare means between cultivars in each cultivation method and the inverse comparison, respectively. (5)Lowercase and uppercase letters in columns and lines, respectively, compare means between propagation methods within each cultivation method and the inverse comparison, respectively. *Significant difference between cultivation methods within each propagation method and cultivar.

the fruit yield and quality and, notably, anticipate the bearing, as already observed for *P. alata* Curtis and *P. edulis* (Roncatto et al., 2008b). The results of the present work corroborate, since the yield of flowering-competent cuttings on espalier was almost 50% higher than those of seedlings, just 14 months after transplanting in the field. However, the average fruit yield was lower than that of the genetic potential of the crop (50 Mg ha^{-1}) or than that of the Brazilian mean productivity, which is 14.1 Mg ha^{-1} (IBGE, 2019). This is probably a result of the natural pollination, which usually leads to decreased fruit set of *P. edulis* in comparison with artificial manual pollination (Rendón et al., 2013). In addition, the experimental area was surrounded by a commercial cultivation of other crops subjected to the use of insecticides, which could have impaired the pollinators at some extent. It must be also underlined that, in the present work, the results of only one production cycle are reported because the unstaked plants did not produce and the experiment ended, whereas the fruit yield is normally calculated for three cycles.

Despite the fact that collecting cuttings from a few mother plants may result in low yield due to the sexual auto-incompatibility of yellow passion fruit (Madureira et al., 2014), and a larger number of mother plants should be evaluated, the higher production of trellised cuttings than seedlings suggest this was not a major issue under the evaluated conditions. The evaluated cuttings were obtained from disease-free mother plants grown from seed in anti-aphid greenhouse, and the cuttings were planted in plots at random in the field, which improves the cross-pollination, and there were favorable edaphoclimatic and management conditions for the crop at the locality (Jesus et al., 2018).

Cutting-propagated FB 200 and BRS Gigante Amarelo cultivars had more flowers than their counterpart seedlings in unstaked cultivation (Table 4). Similar results were observed for both types of propagation for FB 200 cultivar in trellised cultivation, but BRS Gigante Amarelo cultivar showed an opposite behavior, since its seedlings had 27% more flowers on the espaliers. Overall, seedlings of the three cultivars had more flowering in the trellising system than unstaked plants that were damaged by the severity of bacteriosis.

The attempt for the unstaked cultivation has failed, even though this training system could allow of lower-investment and production costs. The vines were constantly trained on the mulched bed, but the overgrowth could have increased shading; however, yellow passion fruit fecundity is highly responsive to the sun irradiance (Cavichioli et al., 2008). The use of flowering-competent cuttings anticipated flowering, as expected, but fruit set was none in unstaked cultivation. A lower-plant density that could allow of a better distribution of vines on the ground might be useful to improve the sunlight interception, but the overgrowth may have influenced the severity of bacteriosis as well. Nevertheless, to date, this is the first report on unstaked cultivation of yellow passion fruit, which is still a challenge for horticulturists. The evaluation of disease-resistant varieties or species of passion fruit, preferably propagated by cuttings or presenting earlier flowering (shorter juvenile period), and the cultivation in drier climates, or more adequate disease and pollinators management, may make this practice feasible in the future, as it has happened for other fruit and vegetable crops. Intermediate solutions, for instance caged system, or natural trellising on inter-planted crops, may increase light interception and, consequently, improve the yield, while reducing investment costs, which may overall benefit both family farming and the processing yellow passion fruit.

Conclusions

1. Semi-hardwood or softwood cuttings can be used for the efficient rooting of the passion fruit (*Passiflora edulis*) BRS Gigante Amarelo, Isla Redondo Amarelo, and FB 200 Yellow Master cultivars.
2. Pine bark substrate or phenolic foam are recommended for the cutting propagation of these three cultivars of yellow passion fruit, without the need of indole-3-butyric acid application.
3. The cultivation of flowering-competent cuttings has the potential to anticipate the production in the trellising system, whereas the unstaked cultivation is not suitable for yellow passion fruit.

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