

Vegetative development and production of ‘Tahiti’ acid lime clone selections grafted on different rootstocks

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Abstract- Brazil accounts for a large percentage of the world’s citrus production, with ‘Tahiti’ acid lime tree standing out among several cultivated species. However, its cultivation is supported by a very narrow genetic base, being composed of few scion and rootstock options. In this way, the aim of this study was to evaluate the vegetative development and production of twelve ‘Tahiti’ acid lime clones on two rootstocks. The experiment was carried out at Fazenda José Guarete, municipality of São Mateus – ES. A randomized block design was used in the split plot scheme, with plot consisting of two rootstocks and subplot of the twelve ‘Tahiti’ acid lime clones. Traits evaluated were: vegetative development, production and productive efficiency, internal and external quality of fruits. Bello Fruit, Iconha, BRS Passos, Itarana, Persian 58, CNPMF 5059 and Elédio clones were superior in terms of production, vegetative traits and fruit quality. ‘Swingle’ citrumelo rootstock showed higher values for vegetative traits compared to ‘Riverside’ citrandarin. The clone and rootstock combinations that provided better agronomic performance in this study were BRS Passos, Bello Fruit, Elédio and Iconha grafted on ‘Swingle’ citrumelo and CNPMF 5059, Iconha and Elédio grafted on ‘Riverside’ citrandarin.

Index terms: *Citrus latifolia* Tanaka, fruit quality, citriculture.

Desenvolvimento vegetativo e produção de seleções de limeira ácida ‘Tahiti’ enxertadas em diferentes porta-enxertos

Resumo- O Brasil representa em grande percentual a produção mundial de citros, destacando dentre várias espécies cultivadas, a limeira ácida ‘Tahiti’. No entanto, seu cultivo é sustentado por uma base genética muito estreita, sendo composto por poucas opções de copa e porta-enxerto. Deste modo, objetivou-se avaliar o desenvolvimento vegetativo e a produção de doze clones de limeira ácida ‘Tahiti’ sobre dois porta-enxertos. O experimento foi conduzido na Fazenda José Guarete, no município de São Mateus – ES. Utilizou-se o delineamento experimental de blocos ao acaso, no esquema de parcelas subdivididas, com a parcela sendo constituída por dois porta-enxertos e a subparcela, os doze clones de limeira ácida ‘Tahiti’. Foram avaliadas as características: desenvolvimento vegetativo, produção e eficiência produtiva, qualidade interna e externa dos frutos. Os clones Bello Fruit, Iconha, BRS Passos, Itarana, Persian 58, CNPMF 5059 e Elédio foram superiores nas características produtivas, vegetativas e na qualidade do fruto. O porta-enxerto citrumelo ‘Swingle’ apresentou valores referentes a características vegetativas superiores ao citrandarin ‘Riverside’. As combinações de clone e porta-enxerto que proporcionaram melhor desempenho agrônômico neste estudo foram BRS Passos, Bello Fruit, Elédio e Iconha enxertadas no citrumelo ‘Swingle’ e CNPMF 5059, Iconha e Elédio sobre o citrandarin ‘Riverside’.

Termos para indexação: *Citrus latifolia* Tanaka, qualidade de frutos, citricultura.

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Introduction

Brazil has an area of approximately 5 million hectares with citrus cultivation, distributed among orange, mandarin, lemon and lime fruits. ‘Tahiti’ acid lime accounts for an area of 48 thousand hectares (IBGE, 2018), making citrus growing among the main activities of Brazilian agribusiness (PORTELLA et al., 2015; STUCHI et al., 2009).

Due to the growing demand in the citrus market, especially for ‘Tahiti’ lemon (as it is popularly known), which serves both internal and external fresh fruit market, alternatives to increase production are essential. In the current scenario, there is little diversity of genetic material to be used, being predominantly restricted to ‘IAC 5’ and ‘quebra-galho’ cultivars. ‘Rangpur’ lime (*Citrus Limonia* Osbeck) rootstock has been used from the middle of the last century to present day, which has been considered one of the most apparent causes of phytosanitary problems in the crop, causing production loss and increased costs (AGUILERA 2016; CARVALHO et al., 2016).

Due to the problems presented by ‘Rangpur’ lime such as susceptibility to gummosis caused by *Phytophthora* spp., which reduces plant longevity, the use of new rootstocks has been studied, highlighting that the selection of scion and rootstock for ‘Tahiti’ acid lime is among the factors that most influence quality and production of fruits and orchard management (STUCHI et al., 2009). Resistance to biotic and abiotic factors, plant size and compatibility are the main attributes that are taken into account in rootstock selection (SOUZA et al. 2017, BOWMAN; JOUBERT, 2020).

Therefore, adequate combination of scion and rootstock is of utmost importance, as the interaction between them will determine traits essential to the culture, such as nutritional needs, canopy size, resistance to some diseases, fruit quality and production (CERQUEIRA et al., 2004; SCHÄFER et al, 2001; SOARES et al., 2015). Thus, the aim was to evaluate the vegetative development and production of twelve ‘Tahiti’ acid lime clones on two rootstocks, defining the best planting combinations.

Material and methods

The experiment was carried out at “Fazenda José Guarete”, belonging to the Bello Fruit company, located in the municipality of São Mateus - ES, Rodovia BR 101, Km 77. The experimental area has approximately 5000 m², with spacing of 6.00 m x 3.00 m (six meters between rows and three meters between plants). The nutritional management of plants followed recommendation of Prezotti et al. (2013), via fertigation through microsprinkler system (BERNARDO et al., 2006).

According to the Koppen classification, the local climate is tropical hot and humid (AW), with rainy season in summer and dry in winter (ALVARES et al., 2013). The average temperature during the experimental period was 25°C and the average precipitation was 140 mm (Figure 1).

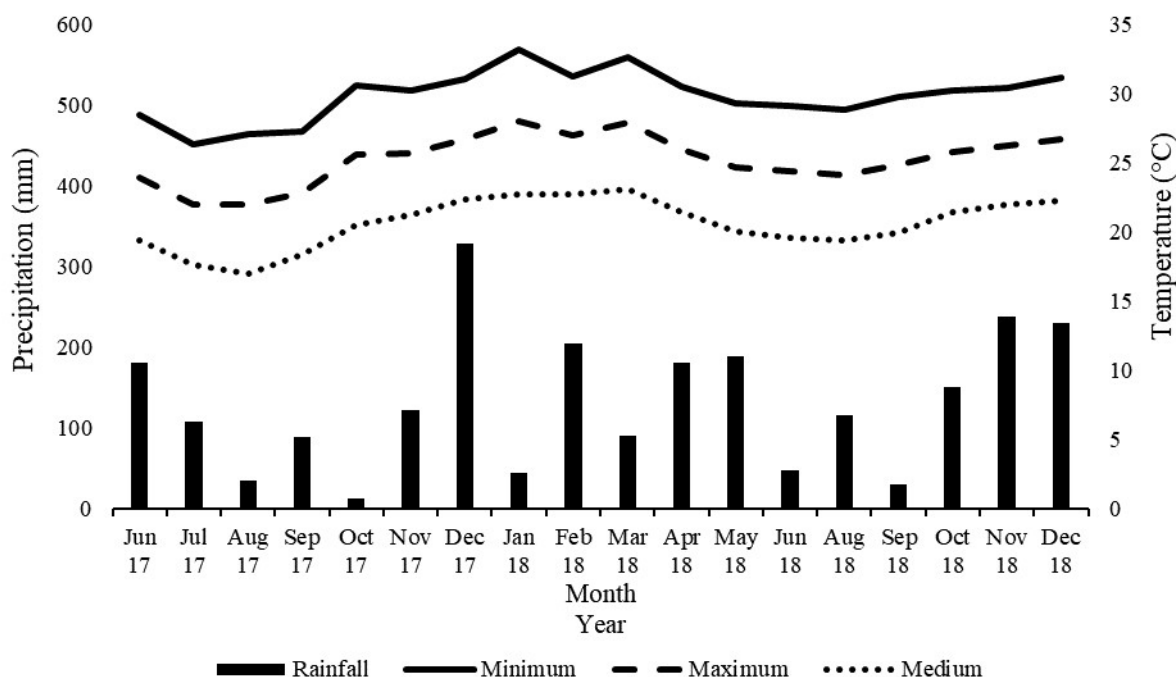


Figure 1. Climatic data from São Mateus, ES, Brazil, location of the experiment, with temperature and rainfall information from June 2017 to December 2018. Source: INMET

The experimental design used was randomized blocks with four replicates in a split plot scheme, where plot was composed of 'Swingle' citrumelo and 'Riverside' citrandarin rootstocks and subplot was composed of one among 12 clones that are usually the most widely used and marketed: Bello Fruit, Elédio, Iconha, Itarana, Santa Rosa, Bearss Lime, BRS Passos, Persian 58, CNPMF 01, CNPMF 02, CNPMF 2001 and CNPMF 5059. Each experimental unit consisted of three useful plants, totaling 288 plants. The border was composed of 'Tahiti' acid lime plants on 'Flying Dragon' rootstock.

Vegetative development

The vegetative development of plants was evaluated at 36 months of age, measuring scion stem diameter (SSD), and rootstock stem diameter (RSD), plant height (PH), diameter of canopy projection on the row (DCR) and diameter of canopy projection on the planting spacing (DCS). From these data, the following parameters were determined: canopy coverage rate on the row (CCR), canopy coverage rate on the planting spacing (CCS) and canopy volume (CV).

To measure plant height (PH), a measuring tape graduated in meters was used, measuring from the ground up to canopy formation. Canopy diameter was measured using a measuring tape expressed in meters, measuring from one end to the other end of the plant, in the direction of the planting row (DCR), and perpendicular to the planting row (DCS). Scion stem diameter and rootstock stem diameter were measured five centimeters above (SSD) and below (RSD) the grafting point and expressed in millimeters.

The canopy coverage rate on the row (CCR) was calculated using the following formula: $CCR = DCR / E \times 100$ where, DCR = diameter of canopy projection on the row and E = spacing used in the planting row, expressed as a percentage.

Canopy coverage rate on the planting spacing (CCS) was calculated using the following formula: $CCS = (DCS / E) \times 100$ where, DCS = diameter of canopy projection on the planting spacing and E = spacing used between the planting rows expressed as a percentage.

Canopy volume was calculated using the formula proposed by Zekri (2000): $CV = (\pi / 6) \times PH \times DCR \times DCS$ where, PH: plant height (m); DCR: diameter of canopy projection on the row; DCS: diameter of canopy projection on the planting spacing (m).

Productive traits

To assess production, total production and productive efficiency, eight harvests were carried out, three in 2017, between June and October and five in 2018, between January and December. Fruits were harvested when reaching minimum diameter of approximately

47 mm (HORTIBRASIL, 2000), where shell is rough with dark to light green color. As 'Tahiti' acid lime presents flowering multiplicity, harvests were performed throughout the year, with results of production per plant being added up over the period.

After harvested, fruits were placed in plastic boxes with size of 31 cm x 34 cm x 55 cm and maximum capacity of 30 kg; then, mass and number of fruits were evaluated for each scion / rootstock combination. Total annual and accumulated production were calculated. Production data were used to calculate productive efficiency, obtained by the relationship between fruit production ($\text{kg} \cdot \text{plant}^{-1}$) and canopy volume ($\text{m}^3 \cdot \text{plant}^{-1}$). All fruits from plants that were at the point of harvest were randomly harvested. Subsequently, a sample of 10 fruits from each experimental plot was collected to determine the qualitative traits of fruits.

Internal and external quality of fruits

Fruit samples were taken to the Laboratory of Plant Breeding at the University Center - Federal University of Espírito Santo (Ceunes / Ufes) to determine qualitative traits. The following physical attributes were analyzed: longitudinal fruit diameter (LFD), transversal fruit diameter (TFD), performed using a digital caliper and expressed in mm, shell thickness (ST), cutting fruits in half and shell being measured using a digital caliper expressed in mm, juice yield (JY), calculated from the relationship between weight of fruits and weight of fruit pomace, expressed as percentage. As for the assessments of chemical attributes, the soluble solids content (SS) was determined, verified with ATAGO portable Palette PR–refractometer with automatic temperature compensation, expressed in °Brix.

Statistical analysis

Data were analyzed regarding the assumptions of independence, normality and homogeneity of residues to perform the analysis of variance. Then, the significance of the difference among treatments was verified through analysis of variance with F test. In case of significant, the Scott Knott test at 5% probability was performed using the Sisvar software (FERREIRA, 2011).

Results and discussion

Vegetative development

RDS, SSD, DCR, DCS, CCR, CCS and CV vegetative traits had significant interaction between clones and rootstocks in 2018, except for PH, which showed significance only for the scion factor.

Rootstock diameter showed variation, especially when using *Poncirus trifoliata* and its hybrids (SCHÄFER et al., 2001). As this study used two *Poncirus trifoliata*

hybrid rootstocks, it was observed that the diameter (DRS) of 'Swingle' citrumelo rootstock combined with Bello Fruit and BRS Passos clones presented 100.04 and 96.63 mm respectively (Table 1). When 'Riverside' citrandarin rootstock was used, the combinations that presented higher averages were CNPMF 02 and Persian 58, obtaining values of 87.64 and 89.38 mm, respectively.

Scion stem diameter (SSD) also varied. It was observed that Bello Fruit clone on 'Swingle' rootstock with value of 78.45 mm presented higher average compared to the others. When 'Riverside' rootstock was used, CNPMF 02, Persian 58, BRS Passos and Iconha clones stood out among the others, with values from 78.71 to 80.53 mm (Table 1).

Table 1. Mean values of the rootstock stem diameter (RSD) and scion stem diameter (SSD) traits of 'Tahiti' acid lime clones grafted on two rootstocks

Clones	Traits ⁽¹⁾			
	RSD (mm)		SSD (mm)	
	'Swingle' ⁽²⁾	'Riverside' ⁽²⁾	'Swingle'	'Riverside'
	Year 2018			
Bello Fruit	100,04 aA	80,01 bB	78,45 aA	71,71 aB
Elédio	84,30 aB	71,46 bC	62,67 aC	66,36 aB
Iconha	81,73 aC	80,01 aB	61,29 bC	77,04 aA
Itarana	89,44 aB	69,97 bC	71,00 aB	63,83 bB
Santa Rosa	77,10 aC	70,19 aC	57,56 bC	68,76 aB
Bearss Lime	86,14 aB	74,39 bC	69,40 aB	69,15 aB
CNPMF01	87,32 aB	79,91 aB	70,27 aB	73,08 aB
CNPMF02	89,56 aB	87,64 aA	67,99 bB	80,53 aA
CNPMF2001	89,13 aB	76,83 bC	68,72 aB	72,25 aB
CNPMF5059	86,89 aB	80,34 aB	65,97 aB	71,40 aB
BRS Passos	96,63 aA	82,44 bB	70,12 bB	78,71 aA
Persian 58	87,25 aB	89,38 aA	77,76 bB	80,36 aA

⁽¹⁾ In the columns, values followed by the same capital letter do not differ statistically, by the Scott-Knott test at 5% significance; in the rows, values followed by the same lowercase letter do not differ significantly, by the 5% F-test. ⁽²⁾ Abbreviation for the 'Swingle' citrumelo and 'Riverside' citrandarin rootstocks.

Comparing different clones on the two rootstocks (Table 1), variation in sizes for both RSD and CDS was observed. Among clones that stood out, Bello Fruit and CNPMF 02 were superior to the others for both rootstocks. Stem diameter is an important parameter in citrus, because the larger the diameter, the greater the reserve substances in the stem, the canopy size and its productive capacity. In contrast, there is a need for greater spacing and fewer numbers of plants per hectare. However, larger plants tend to hinder cultural treatments, especially harvest (TAZIMA et al., 2013).

Lower RDS values were obtained by Iconha (81.73 mm) and Santa Rosa (77.10 mm) clones on 'Swingle' citrumelo rootstock. However, when 'Riverside' citrandarin rootstock is used, other clones showed lower values, such as Elédio, Itarana, Bearss Lime and CNPMF 2001, in addition to Santa Rosa (Table 1). In general, it was possible to observe that the rootstock diameter is greater than the graft diameter for both 'Swingle' citrumelo and 'Riverside' citrandarin. In citrus, the rootstock has a notable influence on attributes in the scion variety, such as production, tree size, fruit quality and response to abiotic and biotic stressors (SCHÄFER et al., 2001)

Carvalho et al. (2016) studied the agronomic performance of 'Piemonte' mandarin grafted on several rootstocks in Coastal Tablelands, including the two rootstocks evaluated in this work and found higher values for rootstock diameter, contributing to greater vegetative vigor of the plant.

For variable diameter of canopy projection on the row (DCR) and of canopy projection on the planting spacing (DCS), clones that obtained the greatest growth when grafted on 'Swingle' rootstock were Itarana with 2.63 and 2.73 m, Bello Fruit with 2.62 and 2.67 m, CNPMF01 with 2.46 and 2.63 m and BRS Passos with 2.56 and 2.72 m (Table 2). When grafted on 'Riverside' rootstock, clones showed no significant difference for DCR trait. As for DCS trait, clones that stood out on the same rootstock were Persian 58 with 2.59 m, Iconha with 2.48 m, CNPMF 5059 with 2.47 m, CNPMF 01 with 2.42 m and BRS Passos with 2.38 m.

Santa Rosa clone showed the lowest value for both DCR and DCS (Table 2). Thus, it is suggested that this variety may be an option for use in smaller spacing, and thus, the adoption of greater number of plants per hectare is possible.

Table 2. Mean values of diameter of canopy projection on the row (DCR), diameter of canopy projection on the planting spacing (DCS) and plant height (PH) traits of ‘Tahiti’ acid lime clones grafted on two rootstocks.

Clones	Traits ⁽¹⁾				PH (m) ⁽³⁾
	DCR (m)		DCS (m)		
	‘Swingle’ ⁽²⁾	‘Riverside’ ⁽²⁾	‘Swingle’	‘Riverside’	
	Year 2018				
Bello Fruit	2,62 aA	2,28 aA	2,67 aA	2,34 bB	2,08 a
Elédio	2,30 aB	2,12 aA	2,36 aB	2,22 aB	1,64 c
Iconha	2,26 aB	2,44 aA	2,28 aB	2,48 aA	1,96 a
Itarana	2,63 aA	2,08 bA	2,73 aA	2,24 bB	1,76 b
Santa Rosa	1,90 bC	2,26 aA	2,06 aC	2,23 aB	1,62 c
Bearss Lime	2,37 aB	2,20 aA	2,43 aB	2,18 aB	1,85 b
CNPMF01	2,46 aA	2,40 aA	2,63 aA	2,42 aA	1,96 a
CNPMF02	2,32 aB	2,25 aA	2,37 aB	2,43 aA	1,94 a
CNPMF2001	2,32 aB	2,31 aA	2,40 aB	2,31 aB	1,82 a
CNPMF5059	2,48 aA	2,26 aA	2,50 aB	2,47 aA	1,92 a
BRS Passos	2,56 aA	2,27 bA	2,72 aA	2,38 bA	2,04 a
Persian 58	2,42 aB	2,38 aA	2,45 aB	2,59 aA	1,99 a

⁽¹⁾ In the columns, values followed by the same capital letter do not differ statistically, by the Scott-Knott test at 5% significance; in the rows, values followed by the same lowercase letter do not differ significantly, by the 5% F-test. ⁽²⁾ Abbreviation for the ‘Swingle’ citrumelo and ‘Riverside’ citrandarin rootstocks.

⁽³⁾ The trait did not show significant interaction between clones and rootstock.

As for plant height (PH), clones that achieved greater growth compared to the others were Bello Fruit with 2.08 m and BRS Passos with 2.04 m when grafted in ‘Swingle’ rootstock. When grafted on ‘Riverside’ rootstock, Iconha and Persian 58 clones stood out with 1.96 and 1.99 m, respectively (Table 2).

Similarly to the other plant traits, height has strong influence on orchard management, where higher plants can hinder harvesting and cultural treatments. Variations in vegetative development traits can be influenced by intrinsic factors of each material, but also by external factors. As an example, we can suggest the presence of different viral loads, which can induce different types of symptoms in citrus, such as changes in plant shape and size, generally presenting short internodes and, as a consequence, lower structure (FLORES and DURAN-VILA, 1996; EIRAS et al., 2009). Santa Rosa (1.62 m), Elédio (1.64 m) and Itarana (1.76 m) clones presented lower height values in relation to the other clones. Therefore, as there is a trend in interest by researchers and producers in plants with lower height, these clones can be indicated. Usually, such selection was justified to facilitate harvest and cultural treatments, leading to cost reduction (MACHADO et al., 2017). With smaller plant size, densification can be done, increasing the plant stand, and as a consequence, greater yield, especially in the first years (DONADIO and STUCHI, 2001).

When comparing rootstocks, ‘Swingle’ citrumelo showed higher averages for DCR and DCS traits, with significant interaction (Table 2). For PH, ‘Swingle’ citrumelo presented values of 1.89 m and ‘Riverside’ citrandelo of 1.87 m, being statistically different

(coefficient of variation of 1.76%); however, the comparison did not consider scion, because the interaction is not significant. Pompeu Junior and Blumer (2011) evaluated different rootstocks and obtained similar results, in which ‘Swingle’ citrumelo showed superiority among the others for plant height.

Bello Fruit, CNPMF 01, CNPMF 5059, Itarana and BRS Passos clones were those that obtained the highest canopy coverage rate on the row (CCR) and canopy coverage rate on the planting spacing (CCS), with approximately 30% growth when grafted on ‘Swingle’ rootstock (Table 3). When grafted on ‘Riverside’ rootstock, clones showed no significant difference for CCR. For the CCS trait in the same rootstock, clones that obtained the highest coverage rate were Iconha, CNPMF 01, CNPMF 02, CNPMF 5059, BRS Passos and Persian 58, with about 10% growth in relation to the others. Growth in CCR was superior to CCS for all clones in both rootstocks.

Table 3. Mean values of Canopy coverage rate on the row (CCR), in percentage, canopy coverage rate on the planting spacing (CCS), in percentage, and canopy volume (CV), in m³, traits of ‘Tahiti’ acid lime clones grafted on two rootstocks

Clones	Traits ⁽¹⁾					
	CCR (%)		CCS (%)		CV (m ³)	
	‘Swingle’ ⁽²⁾	‘Riverside’ ⁽²⁾	‘Swingle’	‘Riverside’	‘Swingle’	‘Riverside’
Year 2018						
Bello Fruit	87,45 aA	76,23 bA	44,65 aA	39,15 bB	8,01 aA	5,59 bA
Elédio	76,61 aB	70,79 aA	39,37 aB	37,01 aB	4,71 aC	4,16 aB
Iconha	75,47 aB	81,49 aA	37,98 aC	41,31 aA	5,01 bC	6,62 aA
Itarana	87,89 aA	69,36 bA	45,44 aA	37,27 bB	6,86 aB	4,16 bB
Santa Rosa	63,47 bC	75,48 aA	34,37 aC	37,12 aB	3,47 aD	4,22 aB
Bearss Lime	78,91 aB	73,54 bA	40,58 aB	36,44 aB	5,66 aC	4,75 aB
CNPMF01	82,23 aA	79,93 aA	43,85 aA	40,47 aA	6,76 aB	6,02 aA
CNPMF02	77,49 aB	74,99 aA	39,58 aB	40,59 aA	5,55 aC	5,61 aA
CNPMF2001	77,25 aB	77,03 aA	39,98 aB	38,53 aB	5,47 aC	5,00 aB
CNPMF5059	82,66 aA	75,49 aA	41,75 aB	41,12 aA	6,27 aB	5,70 aA
BRS Passos	85,59 aA	75,01 bA	45,35 aA	39,63 bA	7,74 aA	5,52 bA
Persian 58	80,81 aB	79,43 aA	40,82 aB	43,18 aA	6,16 aB	6,58 aA

⁽¹⁾ In the columns, values followed by the same capital letter do not differ statistically, by the Scott-Knott test at 5% significance; in the rows, values followed by the same lowercase letter do not differ significantly, by the 5% F-test

⁽²⁾ Abbreviation for the ‘Swingle’ citrumelo and ‘Riverside’ citrandarin rootstocks.

Therefore, for mechanized plantations, there must be a concern to maintain greater space between rows for the circulation of machines (CARVALHO, 2017). It is worth mentioning that ‘Tahiti’ acid lime clones, when compared with other citrus, have the highest CCR values, demonstrating that the variety is quite vigorous, regardless of rootstock used (PORTELLA et al., 2015; CARVALHO et al., 2016).

Plants with higher canopy volumes tend to have greater productive potential, since citrus blooms in the branch of the year. Bello Fruit and BRS Passos varieties, with 8.01 m³ and 7.74 m³, grafted on ‘Swingle’ citrumelo had the highest canopy volume values. When ‘Riverside’ rootstock was used, clones that showed higher averages were Bello Fruit, Iconha, CNPMF 01, CNPMF 02 and CNPMF 5059, BRS Passos and Persian 58 with values ranging from 5.52 to 6.62 m³ (Table 3).

The lowest CV values were observed for Elédio, Santa Rosa and Bearss Lime clones, regardless of rootstock used. Plants with smaller canopy volumes are considered more suitable for forming high-density orchards combined with rootstocks that induce more vigorous clones, obtaining high fruit production (DONADIO and STUCHI, 2001; BASTOS et al., 2014). Bastos et al. (2017) evaluated the initial development of ‘Tahiti’ acid lime on various rootstocks and observed that ‘Riverside’ rootstock obtained the highest canopy volume values, unlike results observed in this study, where ‘Riverside’ rootstock induced the lowest CV values.

Productive traits

Production data (kg.plant⁻¹) and number of fruits per plant showed significant interaction between rootstocks and the different ‘Tahiti’ lime clones in the 2017 and 2018 harvests. For the productive efficiency trait (kg .m⁻³), the interaction was significant in 2018.

Clones that were the most productive when grafted on ‘Swingle’ citrumelo rootstock were Itarana (46.98 kg.plant⁻¹), BRS Passos (40.05 kg.plant⁻¹), Bello Fruit (37.47 kg.plant⁻¹) and Iconha (37.31 kg.plant⁻¹). Likewise, Iconha, with value of 46.24 kg.plant⁻¹ and CNPMF 5059, with 43.03 kg.plant⁻¹ were more productive when grafted on ‘Riverside’ rootstock (Table 4).

For the total accumulated production in the two harvests, the best clones on ‘Swingle’ rootstock were Itarana (56.73 kg.plant⁻¹), BRS Passos (47.85 kg.plant⁻¹) and Iconha (46.87 kg .plant⁻¹). When grafted on ‘Riverside’ rootstock, Iconha (56.61 kg.plant⁻¹), CNPMF 5059 (50.08 kg.plant⁻¹) and BRS Passos (46.87 kg.plant⁻¹) clones stood out.

Based on production per plant and number of plants per hectare, estimated productions of Itarana, CNPMF 5059, BRS Passos and Iconha clones were 26.099 kg.ha⁻¹, 23.905 kg.ha⁻¹, 22.249 kg.ha⁻¹ and 20.727 kg.ha⁻¹, respectively. When comparing the average production in the state of Espírito Santo, which is 20.951 kg.ha⁻¹ (IBGE 2018), productivity was relevant. It is worth mentioning that plants in this study are in the third and fourth year of production, which allows for greater productivity in the following years.

For most clones, the 'Riverside' rootstock was statistically superior when compared to 'Swingle' rootstock (Table 4). Similar results were found by Rodrigues et al. (2018), who evaluated the agronomic

performance of rootstocks for 'Tahiti' acid lime and observed that 'Riverside' rootstock obtained the highest production values, remaining more productive when compared to other rootstocks.

Table 4. Mean value of yield (YL), in kg .plant⁻¹, trait of 'Tahiti' acid lime clones grafted on two rootstocks, evaluated in 2017 and 2018, and the sum of these two years (TOTAL)

Clones	Yield (kg .plant ⁻¹) ⁽¹⁾					
	2017		2018		TOTAL	
	'Swingle' ⁽²⁾	'Riverside' ⁽²⁾	'Swingle'	'Riverside'	'Swingle'	'Riverside'
Bello Fruit	8,53 aA	6,51 aB	37,47 aA	31,12 aB	46,01 aA	37,61 aB
Elédio	7,28 aA	5,58 aC	36,11 aA	35,48 aB	43,40 aA	41,07 aB
Iconha	9,65 aA	10,37 aA	37,31 aA	46,24 aA	46,97 aA	56,61 aA
Itarana	9,75 aA	4,98 bC	46,98 aA	33,65 bB	56,73 aA	38,63 bB
Santa Rosa	4,04 aB	4,57 aC	15,77 aB	22,41 aC	19,81 aB	26,98 aC
Bearss Lime	5,89 aA	8,90 aA	17,36 bB	34,80 aB	23,25 bB	43,70 aB
CNPMF01	4,32 aB	6,34 aB	31,20 aA	33,85 aB	35,52 aA	40,19 aB
CNPMF02	2,38 aB	2,10 aD	13,53 aB	15,51 aC	15,92 aB	17,62 aC
CNPMF2001	0,49 aC	0,60 aD	2,54 aC	3,01 aD	3,03 aC	3,62 aD
CNPMF5059	3,36 bB	7,04 aB	21,88 bB	43,03 aA	25,25 bB	50,08 aA
BRS Passos	7,79 aA	9,35 aA	40,05 aA	37,51 aB	47,85 aA	46,87 aA
Persian 58	2,29 aB	3,15 aD	15,40 aB	22,54 aC	17,69 aB	25,69 aC

⁽¹⁾ In the columns, values followed by the same capital letter do not differ statistically, by the Scott-Knott test at 5% significance; in the rows, values followed by the same lowercase letter do not differ significantly, by the 5% F-test ⁽²⁾ Abbreviation for the 'Swingle' citrumelo and 'Riverside' citrandarin rootstocks.

On the other hand, there are reports that 'Swingle' citrumelo rootstock is commonly used by citrus growers due to its several distinguished traits (GIRARDI et al., 2017; MACHADO et al., 2017; STUCHI et al., 2008) and played an important role in this experiment, where different clones grafted on it obtained higher production values. It is worth mentioning that both rootstocks are resistant to gummosis and that "Tahiti" acid lime is highly susceptible, which makes them excellent options for citrus growers.

Regarding productive efficiency, no significant interaction among factors in the 2017 harvest was observed, with emphasis on the Iconha clone, which reached the highest production efficiency, with 6.09 kg m⁻³ (Table 5). When grafted on 'Swingle' rootstock, clones that showed the highest production efficiency in 2018 were Itarana with 6.33 kg.m⁻³, BRS Passos with 5.20 kg m⁻³, Bello Fruit with 5.13 kg m⁻³ and Iconha with 5.05 kg m⁻³. For the 'Riverside' rootstock, CNPMF 5059 with 6.05 kg m⁻³, Iconha with 5.88 kg m⁻³ and BRS Passos with 5.27 kg m⁻³ stood out.

Table 5. Mean values of productive efficiency (PE), in kg.m⁻³, trait of 'Tahiti' acid lime clones grafted on two rootstocks, evaluated in 2017 and 2018

Clones	Productive Efficiency (kg.m ⁻³) ⁽¹⁾		
	2017 ⁽²⁾	2018	
		'Swingle' ⁽³⁾	'Riverside' ⁽³⁾
Bello Fruit	3,17 c	5,13 aA	3,99 aB
Elédio	4,31 b	4,91 aA	4,53 aB
Iconha	6,09 a	5,05 aA	5,88 aA
Itarana	4,12 b	6,33 aA	4,25 bB
Santa Rosa	4,62 b	2,11 aB	2,82 aC
Bearss Lime	4,32 b	2,31 bB	4,48 aB
CNPMF01	2,57 c	4,13 aA	4,76 aB
CNPMF02	1,15 d	1,78 aB	2,18 aC
CNPMF2001	0,38 d	0,33 aC	0,42 aD
CNPMF5059	2,61 c	2,85 bB	6,05 aA
BRS Passos	2,96 c	5,20 aA	5,27 aA
Persian 58	1,31 d	1,99 aB	3,16 aC

⁽¹⁾ In the columns, values followed by the same capital letter do not differ statistically, by the Scott-Knott test at 5% significance; in the rows, values followed by the same lowercase letter do not differ significantly, by the 5% F-test ⁽²⁾ In 2017, the trait did not show significant interaction. ⁽³⁾ Abbreviation for the 'Swingle' citrumelo and 'Riverside' citrandarin rootstocks.

High productive efficiency for combinations involving rootstocks used in this work was also verified by Machado (2014), Portella et al. (2015) and Carvalho (2017). Clones with high productive efficiency are considered relevant, since they contribute to the formation of denser plants and higher production in smaller area (DONADIO et al., 1995; SANTOS et al., 2016).

The number of fruits per plant is a considerable trait with regard to the quality of clones and rootstocks used. Clones that obtained the highest number of fruits were Itarana with 503.29 fruits.plant⁻¹, BRS Passos with 439.58 fruits.plant⁻¹, and Bello Fruit with 422.08 fruits.plant⁻¹, when grafted on ‘Swingle’ rootstock (Table 6). For ‘Riverside’ rootstock, those with the highest fruit production were Iconha with 499.62 fruits.plant⁻¹, CNPMF 5059 with 482.99 fruits.plant⁻¹, and BRS Passos with 414.37 fruits.plant⁻¹ (2018 harvest). However, it should be emphasized that fruits should have size pattern, since very small or very large fruits have no preference for marketing.

Table 6. Mean values of the number of fruits (NF) trait of ‘Tahiti’ lime clones grafted on two rootstocks, evaluated in 2017 and 2018

Clones	Number of fruits ⁽¹⁾			
	2017		2018	
	‘Swingle’ ⁽²⁾	‘Riverside’ ⁽²⁾	‘Swingle’	‘Riverside’
Bello Fruit	106,50 aA	77,83 aB	422,08 aA	322,02 aB
Elédio	83,00 aA	62,33 aC	350,54 aB	363,41 aB
Iconha	127,37 aA	121,95 aA	375,33 bB	499,62 aA
Itarana	109,67 aA	57,91 bC	503,29 aA	359,12 bB
Santa Rosa	46,87 aB	51,75 aC	173,37 aC	257,29 aC
Bearss Lime	66,79 aB	98,04 aA	181,67 bC	362,04 aB
CNPMF01	47,91 aB	72,08 aB	322,50 aB	379,29 aB
CNPMF02	30,08 aB	22,87 aD	151,75 aC	188,62 aC
CNPMF2001	5,50 aB	3,91 aD	29,33 aD	35,70 aD
CNPMF5059	41,00 bB	82,91 aB	261,08 bC	482,99 aA
BRS Passos	83,41 aA	114,83 aA	439,58 aA	414,37 aB
Persian 58	28,33 aB	33,25 aD	177,66 aC	242,62 aC

⁽¹⁾ In the columns, values followed by the same capital letter do not differ statistically, by the Scott-Knott test at 5% significance; in the rows, values followed by the same lowercase letter do not differ significantly, by the 5% F-test ⁽²⁾ In 2017, the trait did not showed significant interaction. ⁽³⁾ Abbreviation for the ‘Swingle’ citrumelo e ‘Riverside’ citrandarin rootstocks.

The high fruit production of these clone varieties is a trait required for a possible increase in production, since ‘Tahiti’ acid lime produces flowers and fruits in new growing branches, thus, productive development is associated with the vegetative development of plants, which has to be sufficient to form standard sized fruits (STUCHI et al., 2009). For Elédio, CNPMF 01, BRS Passos and Persian 58 clones, the number of fruits was similar for both rootstocks, showing similar productive performance. Rodrigues et al. (2018) evaluated the agronomic performance of ‘Tahiti’ acid lime in the state of Acre and observed that among rootstocks evaluated, ‘Riverside’ was the one that most induced number of fruits.

Internal and external quality of fruits

Longitudinal and transversal fruit diameter (LFD and TFD), shell thickness (ST) and juice yield (JY) traits had no significant interaction between scion and rootstock in the 2017 and 2018 harvests. Regarding the soluble solids content (SS), no statistically significant difference between treatments was observed.

Fruit diameter is a trait that has great commercial appeal, especially when the objective is the external market. CNPMF 02 and BRS Passos clones showed the lowest LFD values, ranging from 55.12 to 57.18 mm. The other clones obtained, on average, values between 60.05 to 59.54 mm, not differing from each other. For TFD, BRS Passos, CNPMF 5059 and Persian 58 clones showed lower values, ranging from 51.34 to 54.43 mm (Table 7). According to classification suggested by Bleinroth (1995), ‘Tahiti’ fruits can be grouped into five categories according to their size as follows: 1- diameter 47-50 mm; 2- diameter 50-53 mm; 3- diameter 53-56 mm; 4- diameter 56-60 mm and 5 - diameter above 60 mm. Fruits from the different clones can be classified into caliber 2 and 3 for clones with lower values and 4 and 5 for higher values, meeting requirements of the foreign market, which require fruits with longitudinal diameter between 47 and 60 mm (CASTRICINI et al. , 2017).

Table 7. Mean values of longitudinal fruit diameter (LFD), in mm, and transversal fruit diameter (TFD), in mm, traits of 'Tahiti' lime clones grafted on two rootstocks, evaluated in 2017 and 2018

Clones	Fruit diameter (mm) ⁽¹⁾			
	2017		2018	
	Longitudinal	Transversal	Longitudinal	Transversal
Bello Fruit	57,26 a	53,22 a	59,06 a	54,12 b
Elédio	57,13 a	54,13 a	59,27 a	56,18 a
Iconha	56,89 a	53,82 a	58,40 a	55,24 a
Itarana	57,48 a	53,64 a	58,75 a	55,42 a
Santa Rosa	56,40 a	54,14 a	58,54 a	55,35 a
Bearss Lime	57,10 a	54,57 a	59,23 a	55,47 a
CNPMF01	56,09 a	53,45 a	59,54 a	56,02 a
CNPMF02	55,12 b	53,67 a	57,18 b	54,00 b
CNPMF2001	53,19 b	53,81 b	59,39 a	55,24 a
CNPMF5059	56,99 a	52,62 b	58,88 a	54,43 b
BRS Passos	55,30 b	53,11 a	55,80 c	52,78 c
Persian 58	56,99 a	51,34 b	60,05 a	53,94 b

⁽¹⁾ Means followed by the same lower case letters, in the columns, do not differ statistically by the Scott Knott test at 5% significance.

When the objective is the internal market, small fruits are those that have values less than 48 mm, intermediate with 48 to 56 mm and large above 56 mm (HORTIBRASIL, 2000). Thus, most fruits were classified

as large, with emphasis on Persian 58 with 60.05 mm, Bearss Lime with 59.23 mm and Elédio with 59.27 mm, values referring to the 2018 harvest (Table 8).

Table 8. Mean values of shell thickness (ST), in mm, and juice yield (JY), in percentage, traits of 'Tahiti' lime clones grafted on two rootstocks, evaluated in 2018.

Clones	Traits ⁽¹⁾	
	Shell thickness (mm)	Juice yield (%)
Bello Fruit	2,84 b	44,89 a
Elédio	3,15 a	40,79 b
Iconha	2,90 b	42,98 a
Itarana	2,94 b	42,60 a
Santa Rosa	3,22 a	35,69 b
Bearss Lime	6,12 a	38,87 b
CNPMF01	3,23 a	40,74 b
CNPMF02	3,27 a	39,15 b
CNPMF2001	2,93 b	42,47 a
CNPMF5059	2,95 b	43,73 a
BRS Passos	3,14 a	37,38 b
Persian 58	3,06 a	40,14 b

⁽¹⁾ Means followed by the same lower case letters, in the columns, do not differ statistically by the Scott Knott test at 5% significance.

As for shell thickness, the clone that obtained the highest value was Bearss Lime with 6.12 mm, while Bello Fruit with 2.84 mm and Iconha with 2.90 mm showed the lowest shell thickness values. Very thick shells reduce juice yield, as was observed for Bearss Lime (Table 8). According to Junqueira (2009), shell thickness is related to the maturation period of fruits, in which fruits harvested green, or which have not yet reached the point

of physiological development, present thicker shell and lower juice yield. However, fruits were harvested at the correct maturation point, indicating that other factors can also influence shell thickness. In the domestic market, there is preference for thin-shelled and juicier fruits, while the external market prefers fruits with intense green and slightly thicker shell (GAYET; SALVA FILHO, 2003; SANTOS et al., 2016).

Clones that obtained the highest juice yield were Bello Fruit with 44.89%, followed by CNPMF 5059 with 43.73%, Iconha, Itarana and CNPMF 2001. However, it was observed that only five clones had juice yield above 42%, which is the minimum juice content required for fruits intended for export. Juice yield is an important trait for marketing purposes, especially when the objective is the export of juice.

Conclusions

Clones that induced the greatest vegetative vigor were Bello Fruit, BRS Passos and Itarana grafted on ‘Swingle’ citrumelo rootstock. For clones grafted on ‘Riverside’ citrandarin, those with the greatest vegetative vigor were CNPMF 5059, Persian 58 and Iconha. Regarding rootstock, ‘Swingle’ citrumelo induced greater vegetative vigor in clones. For production, total production, productive efficiency and number of fruits, Itarana, BRS Passos, Bello Fruit, Elédio and Iconha clones grafted on ‘Swingle’ citrumelo were superior. For ‘Riverside’ citrandarin rootstock, Iconha, CNPMF 5059, Elédio and BRS Passos clones were superior. ‘Riverside’ rootstock outperformed ‘Swingle’ citrumelo for productive traits. Regarding internal and external quality, CNPMF 02, CNPMF 5059, Persian 58, Iconha and Bello Fruit clones showed higher quality. Santa Rosa and CNPMF 2001 clones were those that obtained the lowest values for all traits.

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