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# Vegetative growth and fruit quality of 'Tahiti' acid lime grafted onto different rootstocks

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**Abstract**

The production of 'Tahiti' acid lime in Brazil is currently limited to the northeastern and southeastern regions and research is required to identify compatible rootstocks in order to potentiate other producing areas and to meet the needs of the consumer and industrial markets. The aim of this study was to evaluate the physical characteristics during vegetative growth and the physicochemical attributes and quality of fruit produced by 'Tahiti CNPMF-02' acid lime grafted onto the twelve rootstocks 'Cravo LCRSC' and 'LCR-03' lime, citrandarins 'CTRI' and 'CTRSD', citrumelo 'CTSW', 'Pear HTR-069' orange, 'Volkamer LVK×LCR- 038' lemon, and 'Sunki TSKC×CTSW-028', 'TSKC×CTSW-041', 'TSKC×(LCR×TR)-059', 'TSKC×TRFD-003' and 'TSKT' tangerine. The randomized experimental design included 12 treatments with four repetitions and five plants per plot. The characteristics of the grafted plants were evaluated during vegetative growth at 3.5, 4.0 and 4.5 years of age, while fruit quality was assessed at maturity. All tested rootstocks were compatible with the scion 'Tahiti CNPMF 02' acid lime cultivated under the climate and soil conditions in the north of Mato Grosso state. The rootstocks 'LCR-003', 'CTRI', 'CTRSD', 'CTSW' and 'TSKC×CTSW-028' induced the greatest vertical growth, trunk diameter, crown volume and vigor in the grafted plants. The physicochemical characteristics and quality of the fruit produced by grafted plants of 'Tahiti CNPMF 02' acid lime met market expectations, except for the parameter total titratable acidity. The fruits produced by 'Tahiti CNPMF 02' acid lime grafted onto 'CTRSD', 'TSKC×(LCR×TR)-059', 'LCR-003', 'TSKC×CTSW-041', 'TSKC×TRFD-003', 'LVK×LCR-038' and 'CTRI' were the largest in terms of length and mass.

**Keywords:** *Citrus latifolia, Citrus sunki*, fruit attributes, *Poncirus trifoliata*

## Introduction

Brazil is the fifth largest producer of limes and lemons worldwide and 'Tahiti' acid lime is among the ten most important fruit varieties produced in the country (Food and Agriculture Organization, 2024). 'Tahiti' acid lime, popularly known as 'Tahiti' lime, is a hybrid variety of citrus [*Citrus latifolia* (Yu. Tanaka) Tanaka] deriving from a cross between 'Sicilian' lemon and 'Persian' lime (Rossi & Pandolfi, 2019).

Commercial orchards of 'Tahiti' lime incorporate grafted plants that comprise a rootstock, which provides support and nutrition, joined vegetatively to a scion, which is responsible for forming the crown and producing the fruit (Siqueira & Salomão, 2017). The rootstock influences a number of characteristics of the grafted plant such as growth, production precocity, productivity and tolerance to abiotic and biotic factors, as well as parameters of fruit quality including size, shape, weight, maturation time, yield of juice, color of skin and juice, sugar content and acidity (Siqueira & Salomão, 2017). For this reason, it is important to select rootstocks that are best suited to the specific production system, with particular consideration being given to the climate and soil conditions of the region.

Various rootstocks are available for use in citriculture including the commercial varieties 'Rangpur' lime ('Cravo' lime) and 'Sunki' tangerine, plants of which exhibit high vigor and growth height, resistance to water stress, tolerance to the citrus tristeza virus and early fruit production. In addition, there are trifoliate hybrids such as 'Swingle' citrumelo [*Citrus paradisi* Macfad. × *Poncirus trifoliata* (L.) Raf.] (Carvalho et al., 2019, Costa et al., 2020a, b, Costa et al., 2021) and 'Indio' and 'San Diego' citrandarins (*Citrus sunki* (Hayata) hort. ex Tanaka × *P. trifoliata*) (Rodrigues et al., 2018) that yield greater quantities of fruit per cubic meter of canopy


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and increased overall productivity by virtue of the larger number of plants that can be cultivated per unit area (Mademba-Sy et al., 2012).

While the production of 'Tahiti' lime is gaining greater importance within the Brazilian citrus market, its cultivation is presently limited to northeastern and southeastern regions of the country. Hence, research is required to identify rootstocks that are compatible with 'Tahiti' lime in order to attend to the requirements of other potential producing regions and to meet the needs of the consumer and industrial markets. In light of the above, the aim of this study was to evaluate the vegetative growth of 'Tahiti' lime grafted onto different rootstocks and to assess the physicochemical characteristics and quality of the fruit.

**Materials and methods**

The experimental orchards were implemented on 6th December 2016 in an area of the Instituto Federal de Mato Grosso (IFMT) located in Sorriso, MT, Brazil (12°32'42"S, 55°42'39"W; altitude 450 m). According to the Köppen classification system, the climate of the region is tropical hot and wet (Awi) with a mean temperature of 24°C (minimum 17°C; maximum 34°C), an annual average rainfall of 2,200 mm and mean relative humidity of 80 % during the rainy season and 30 % during the dry season. The soil in the area is categorized as dystrophic red-yellow latosol (LVd) with composition as shown in **Table 1**.

The soil was prepared in the conventional manner by plowing and grading, and was subsequently corrected to raise the base saturation to 65% in the 0 - 20 cm layer. Pits for the grafted plants were opened using a 12 " drill attached to a tractor. Fertilization and correction was performed by mixing the 0 – 20 cm soil layer removed from the pits with 250 g of dolomitic limestone, 150 g of simple superphosphate, 10 g of slow release NPK fertilizer 22-04-08, 50 g of FTE BR 12 and 5 g of boric acid.

The experiment involved 'Tahiti' acid lime as scion grafted onto 12 different types of rootstocks as described in **Table 2**, and was of randomized block design with four repetitions per treatment and five plants per plot. The 'Tahiti CNPMF-02' acid lime clone employed was produced by the Citrus Genetic Improvement Program (PMG Citros) of Embrapa Mandioca e Fruticultura Tropical (Cruz da Almas, BA, Brazil) and released in 2009. This variety produces tall plants with medium-size fruits weighing about 130 g and shows a productivity of 40 t $ha^{-1}$ when grafted onto 'Cravo LCRSC' lime (employed as control in this study). Certified citrus budwood was obtained from the nursery of Empresa Mato-Grossense de Pesquisa, Assistência Técnica e Extensão Rural (Empaer, Sinop, MT, Brazil), while seeds of the rootstocks originated from genotypes produced or introduced by PMG Citros.

Grafted plants were produced in the research facilities of Embrapa Agrossilvipastoril (Sinop, MT, Brazil) and cultivated in 2.6 L plastic bags filled with Tecnomax Citros® substrate enriched with thermophosphate (7 kg $m^{-3}$) and slow release NPK fertilizer (22-04-08 + micronutrient; 2.7 kg $m^{-3}$). Grafted plants received the recommended cultural treatment and were grown on for 1.5 years prior to planting in the field.

Grafted plants were spaced 3.0 m apart with 6.0 m between the rows (513 plants $ha^{-1}$) and irrigated during the dry season. Weed management was performed by application of herbicide in the planted rows and tractor mowing between the rows. Chemical control of citrus leafminer larvae (*Phyllocnistis citrella*) was performed periodically during the first and second year after planting. Development fertilizers were applied according to analysis of the soil and the requirements of 'Tahiti' lime, while other cultural practices were performed according to the technical recommendations for the culture.

The physical characteristics of the grafted plants were evaluated during the vegetative phase at 3.5, 4.0 and 4.5 years after planting. Plant height (PH; cm) was measured from the surface of the soil to the highest point of the plant using a graduated ruler. Trunk diameter (TD; mm) was measured with a caliper at 10 cm below the grafting line for the rootstock portion (TD1) and at 10 cm above the grafting line for the scion portion (TD2), while graft compatibility (GC) was determined as the quotient of TD2 divided by TD1. Crown diameter (CD; cm) was calculated as the average of two equatorial CD values measured at perpendicular directions to the planting line using a measuring tape. The crown volume (CV; $m^3$) was estimated using Eq. 1:

$$CV = \frac{2}{3} \times \left[ \left( \pi \times \frac{CD}{4} \right) \right] \times PH \quad (1)$$

in which CD is the mean crown diameter (m) and PH is plant height (m).

The vegetative vigor index (VVI) was determined according to Eq. 2 as described by Bordignon et al. (2003):

$$VVI = \frac{PH + CD\ (TD1 \times 10)}{100} \quad (2)$$

in which PH is plant height (cm), CD is the mean crown diameter (taken as 9 cm) and TD1 is the trunk diameter of the rootstock portion (cm).

The physicochemical characteristics and quality of fruit produced by the grafted plants were evaluated during the first production cycle by sampling 10 mature

**Table 1.** Physicochemical properties of the soil (0 - 20 cm layer) in the experimental area at the Instituto Federal de Mato Grosso prior to implementation of 'Tahiti' acid lime orchards in 2016.

| pH $H_2O$ | $Ca^{2+}$ | $Mg^{2+}$ | $K^+$ | H+Al | CEC | BS | P | OM | Sand | Silt | Clay |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ..... ($cmol_c$ $dm^{-3}$)..... | | | | % | (mg $dm^{-3}$) | (g $dm^{-3}$) | .....(g $kg^{-1}$)..... | | |
| 5.4 | 0.84 | 0.53 | 0.09 | 3.80 | 5.3 | 27.8 | 3.4 | 16.7 | 672 | 58 | 270 |

CEC, cation exchange capacity; OM, organic matter, BS, base saturation

**Table 2.** Varieties of citrus used as rootstocks with 'Tahiti CNPMF 02' acid lime as scion.

| Rootstock | Code | Parents (species/cultivars) | Scientific names |
|---|---|---|---|
| 'Cravo' lime (control) | 'LCRSC' | 'Cravo Santa Cruz' | *Citrus* × *limonia* Osbeck |
| Citrandarins | 'CTRI' | 'Indio' | *Citrus sunki* (Hayata) hort ex Tanaka × *Poncirus trifoliata* (L.) Raf. 'English' |
| | 'CTRSD' | 'San Diego' | *Citrus sunki* × *Poncirus trifoliata* 'Swingle' |
| Citrumelo | 'CTSW' | 'Swingle' | *Citrus paradisi* Macfad. × *Poncirus trifoliata* |
| 'Pear' orange | 'HTR-069' | 'Pear' orange × 'Rusk' or 'Yuma' citrange | *Citrus* × *sinensis* (L.) Osbeck × (*Citrus* × *sinensis* × *Poncirus trifoliata*) |
| 'Cravo' lime | 'LCR-003' | 'Cravo CNPMF-03' lime | Citrus × paradisi × Poncirus trifoliata |
| 'Volkamer' lemon | 'LVK×LCR-038' | 'Volkamer' lemon ×'Cravo' lime | *Citrus* × *volkameriana* (Risso) V. Ten. & Pasq. × *Citrus* × *limonia* |
| 'Sunki' tangerine | 'TSKC×CTSW-028' | Common 'Sunki' tangerine × 'Swingle' citrumelo | *Citrus sunki* × (*Citrus* × *paradisi* × *Poncirus trifoliata*) |
| | 'TSKC×CTSW-041' | Common 'Sunki' tangerine × 'Swingle' citrumelo | *Citrus sunki* × (*Citrus* × *paradisi* × *Poncirus trifoliata*) |
| | 'TSKC×(LCR×TR)-059' | Common 'Sunki' tangerine × citrimonia | *Citrus sunki* × (*Citrus* × *limonia* × *Poncirus trifoliata*) |
| | 'TSKC×TRFD-003' | Common 'Sunki' tangerine × 'Flying Dragon' trifoliate orange | *Citrus sunki* × *Poncirus trifoliata* |
| 'Sunki Tropical' tangerine | 'TSKT' | 'Sunki Tropical' tangerine | Citrus sunki |

fruits per plot on 26th January 2021. Fruit length (FL; mm) and fruit diameter (FD; mm) were measured using a digital caliper, while fruit mass (FM; g) was determined using a digital scale. With regard to the expressed fruit juice, total soluble solids (TSS) were determined by direct reading with a portable digital refractometer, total titratable acidity (TTA) was established by titration with 0.1 mol $L^{-1}$ NaOH, vitamin C (VIT C; mg 100 $mL^{-1}$) content was quantified by potentiometric titration with 0.001 mol $L^{-1}$ $KIO_3$ and juice yield (JY; %) was established as the quotient of juice mass divided by total fruit mass.

Data were tested for normality of distribution using the Kolmogorov-Smirnov test and subsequently submitted to analysis of variance (ANOVA) and the F test. Mean values of variables were compared using the Scott-Knott test with the significance level set at 5%. All statistical analyses were performed using SISVAR software (Ferreira, 2011).

**Results and Discussion**

The results of the analysis of vegetative growth of 'Tahiti CNPMF-02' acid lime grafted onto 12 different types of rootstocks are presented in **Table 3**.

with respect to all vegetative variables assessed, demonstrating that the rootstocks exerted a direct influence on the characteristics of the scion 'Tahiti CNPMF-02' acid lime during growth and development. Similar findings concerning the influence of rootstocks on grafted plants of 'Tahiti CNPMF-02' acid lime have been reported previously (Bremer Neto et al., 2013, Machado et al., 2017, Rodrigues et al., 2018).

At the 3.5 year evaluation, grafts with rootstocks 'LCR-003', 'TSKC×CTSW-028', 'CTRI', 'CTRSD', 'CTSW' and 'TSKT' presented the highest values of PH, which ranged between 317.1 and 345.0 cm and were similar to that of the 'LCRSC' control. However, in 4.0-year-old grafted plants, only those with 'LCR-003' and 'CTSW' rootstocks exhibited PH values that were similar to the control with mean heights above 334 cm. The PH values of 4.5-year-old grafted plants involving 'CTSW', 'CTRSD', 'LCR-003', 'CTRI' and 'TSKC×CTSW-028' rootstocks were similar to that of the control with mean height of 352.54 cm. In general, 'Tahiti CNPMF-02' acid lime grafted onto 'Cravo LCR-003' lime, citrandarins ('CTRI' and 'CTRSD'), citrumelo ('CTSW') and 'Sunki TSKC×CTSW-028' tangerine exhibited the highest vertical growth.

Our results corroborate those of Rodrigues et al. (2018) who found that the rootstocks 'Cravo Santa Cruz' ('LCRSC') lime and the citrandarins 'Riverside' and 'San Diego' induced maximum growth in 'Tahiti' acid lime. Bremer Neto et al. (2013) observed that the growth of 'Tahiti' lime grafted onto five different rootstocks varied from 210 to 270 cm in 3-year-old plants and from 290 to 350 cm in 6-year-old plants. In our study, the lowest growth was observed when the scion was grafted onto trifoliate hybrids of 'Sunki' tangerine, most especially the variety 'TSKC×(LCR×TR)-059' the grafts of which showed a reduction of 12.29% in PH in comparison with the 'LCRSC'

**Table 3.** Physical characteristics during vegetative growth of 'Tahiti CNPMF-02' acid lime grafted onto various rootstocks.

| Rootstocks | PH (cm) | TD1 (mm) | TD2 (mm) | GC | CD (cm) | CV ($m^3$) | VVI |
|---|---|---|---|---|---|---|---|
| 3.5-year-old plants | | | | | | | |
| LCRSC (control) | 345.0 a | 106.6 a | 104.2 a | 1.03 c | 333.5 a | 20.15 a | 7.85 a |
| CTRI | 335.0 a | 103.2 b | 101.4 a | 1.02 c | 332.3 a | 19.48 a | 7.70 a |
| CTRSD | 330.5 a | 105.9 a | 101.2 a | 1.05 c | 344.0 a | 20.53 a | 7.80 a |
| CTSW | 325.0 a | 111.1 a | 96.3 b | 1.16 a | 323.8 a | 17.88 b | 7.60 a |
| HTR- 069 | 294.6 b | 100.7 c | 92.7 b | 1.09 b | 305.8 b | 14.49 c | 7.01 b |
| LCR-003 | 338.4 a | 107.4 a | 104.6 a | 1.03 c | 332.9 a | 19.74 a | 7.79 a |
| LVK×LCR-038 | 280.3 b | 96.2 c | 96.4 b | 1.00 c | 311.9 b | 14.33 c | 6.88 b |
| TSKC×CTSW-028 | 338.1 a | 108.4 a | 104.3 a | 1.04 c | 328.3 a | 19.18 a | 7.75 a |
| TSKC×CTSW-041 | 302.8 b | 102.8 b | 98.1 b | 1.05 c | 310.6 b | 15.53 c | 7.16 b |
| TSKC×(LCR×TR)-059 | 277.7 b | 97.3 c | 95.5 b | 1.03 c | 333.1 a | 16.26 c | 7.08 b |
| TSKC×TRFD-003 | 290.0 b | 94.0 c | 83.8 c | 1.13 a | 311.0 b | 14.84 c | 6.95 b |
| TSKT | 317.1 a | 108.9 a | 108.4 a | 1.01 c | 322.9 a | 17.49 b | 7.49 a |
| CV (%) | 9.78 | 7.61 | 7.77 | 7.54 | 6.45 | 17.26 | 5.96 |
| 4.0-year-old plants | | | | | | | |
| LCRSC (control) | 339.6 a | 111.5 b | 111.6 b | 1.00 c | 385.4 a | 26.49 a | 8.36 a |
| CTRI | 324.1 b | 110.0 b | 110.5 b | 0.99 c | 386.4 a | 25.59 a | 8.20 a |
| CTRSD | 326.6 b | 114.6 a | 113.3 a | 1.01 c | 389.7 a | 26.06 a | 8.31 a |
| CTSW | 334.7 a | 118.3 a | 107.5 b | 1.10 a | 391.9 a | 27.00 a | 8.45 a |
| HTR-069 | 319.6 b | 108.3 b | 100.0 c | 1.08 a | 367.3 b | 22.72 b | 7.95 b |
| LCR-003 | 336.9 a | 112.4 b | 112.1 b | 1.00 c | 405.9 a | 29.16 a | 8.55 a |
| LVK×LCR-038 | 307.3 c | 102.4 c | 104.7 c | 0.98 d | 381.9 a | 23.52 b | 7.91 b |
| TSKC×CTSW-028 | 330.4 b | 112.7 b | 115.0 a | 0.97 d | 387.3 a | 26.07 a | 8.30 a |
| TSKC×CTSW-041 | 315.7 c | 104.9 c | 108.3 b | 0.97 d | 375.5 b | 23.39 b | 7.96 b |
| TSKC×(LCR×TR)-059 | 292.1 d | 100.0 c | 102.7 c | 0.97 d | 379.8 a | 22.35 b | 7.71 b |
| TSKC×TRFD-003 | 309.4 c | 100.1 c | 95.7 d | 1.05 b | 360.0 b | 21.18 b | 7.69 b |
| TSKT | 326.3 b | 112.3 b | 118.5 a | 0.95 d | 385.5 a | 25.46 a | 8.24 a |
| CV (%) | 6.30 | 6.97 | 6.78 | 4.34 | 6.46 | 15.89 | 5.02 |
| 4.5-year-old plants | | | | | | | |
| LCRSC (control) | 362.2 a | 125.9 b | 127.1 b | 0.99 c | 417.5 a | 33.23 a | 9.06 a |
| CTRI | 349.5 a | 123.9 c | 125.2 b | 0.99 c | 422.5 a | 32.90 a | 8.96 a |
| CTRSD | 354.8 a | 127.8 b | 123.2 b | 1.04 c | 419.7 a | 32.76 a | 9.02 a |
| CTSW | 358.2 a | 138.1 a | 124.1 b | 1.11 a | 420.5 a | 33.38 a | 9.17 a |
| HTR-069 | 333.2 b | 118.1 d | 106.7 d | 1.11 a | 387.4 b | 26.49 b | 8.39 b |
| LCR-003 | 353.4 a | 126.6 b | 125.7 b | 1.01 c | 429.6 a | 34.56 a | 9.10 a |
| LVK×LCR-038 | 332.4 b | 118.7 d | 120.3 b | 0.99 c | 397.4 b | 27.62 b | 8.48 b |
| TSKC×CTSW-028 | 346.8 a | 131.2 b | 129.0 a | 1.02 c | 414.4 a | 31.33 a | 8.92 a |
| TSKC×CTSW-041 | 337.8 b | 122.8 c | 122.5 b | 1.01 c | 399.7 b | 28.44 b | 8.60 b |
| TSKC×(LCR×TR)-059 | 317.7 c | 116.2 d | 114.5 c | 1.02 c | 409.6 a | 28.51 b | 8.43 b |
| TSKC×TRFD-003 | 337.2 b | 113.7 d | 107.1 d | 1.06 b | 387.0 b | 26.68 b | 8.38 b |
| TSKT | 342.9 b | 131.8 b | 135.1 a | 0.98 c | 405.0 b | 29.69 b | 8.80 a |
| CV (%) | 6.31 | 8.37 | 8.21 | 6.27 | 6.92 | 16.64 | 5.47 |

PH, plant height; TD1, trunk diameter measured 10 cm below the grafting line; TD2, trunk diameter measured 10 cm above the grafting line; GC, graft compatibility (TD1/TD2); CD, crown diameter; CV, crown volume; VVI, vegetative vigor index; CV, coefficient of variation.

In each column, mean values followed by dissimilar letters are significantly different at 5% probability according to Scott-Knot test.

control. In this context, Machado et al. (2017) reported a 38.6% reduction in the height of 'Tahiti' acid lime when trifoliate 'Limeira' was used as rootstock (average height 2.90 m) in comparison with 'Volkamer' lemon , which induced the highest average height of 4.72 m in 5-year-old plants. Moreover, Rodrigues et al. (2019a, b) reported reduced plant height when 'Valência' sweet orange was grafted onto 'Sunki TSKFL×CTC- 25-002' tangerine. Apparently, trifoliate hybrids contain a semi-dwarfing gene from *Poncirus trifoliata* that reduces the overall size of the plant compared with other rootstocks (Rosa et al., 2001). According to these authors, the interest in dwarfing rootstocks is on the rise because they reduce harvesting costs, facilitate pest and disease management and increase productivity.

The highest TD1 values (with mean of 108.34 mm) were observed in 3.5-year-old plants of 'Tahiti' acid lime grafted onto 'CTSW', 'TSKT', 'TSKC×CTSW-028', 'LCR-003' and 'CTRSD' rootstocks, although there were no significant differences in comparison with the 'LCRSC' control. At the 4.0 year evaluation, grafted plants involving 'CTSW' and 'CTRSD' presented TD1 values that were significantly higher than the control, while at 4.5 years of age, only plants with 'CTSW' rootstock were significantly superior

to the control. Regarding TD2, the highest values (with mean of 103.98 mm) were observed in 3.5-year-old plants involving 'TSKT', 'LCR-003', 'TSKC×CTSW-028', 'CTRI' and 'CTRSD' rootstocks, although there were no significant differences in comparison with the control. At the 4.0 and 4.5 year evaluations, grafted plants with 'TSKC×CTSW-028' and 'TSKT' rootstocks presented significantly higher TD2 values compared with the 'LCRSC' control.

The lowest values of TD1 and TD2 were observed at all three evaluations when 'Sunki TSKC×TRFD-003' tangerine was employed as rootstock. It is important to note that grafted plants with short stature rootstocks also presented smaller trunk diameters both above and below the grafting line, indicating a possible correlation of PH with TD1 and TD2, an observation reported previously by Bordignon et al. (2003) following the evaluation of 'Valência' sweet orange grafted onto trifoliate hybrids.

All of the studied rootstock-scion combinations presented GC values close to 1.0 indicating that 'Tahiti CNPMF-02' acid lime was genetically compatible with the rootstocks. In a study performed by Rodrigues et al. in 2018, the compatibilities of the tested rootstocks with 'Tahiti' acid lime were found to be higher than 0.80, i.e. close to full compatibility and indicative of good affinity between rootstocks and scion. In the selection of an appropriate rootstock, compatibility with the scion is a factor that is of equivalent importance to the agronomic characteristics and resistance to biotic and abiotic stress (Emmanouilidou & Kyriacou, 2017, Albrecht & Bowman, 2019, Costa, 2019, Khankahdani et al., 2019, Santos et al., 2019, Carvalho et al., 2021a, b,).

In the present study, grafted plants could be divided into two groups according to high or low CD values at the 3.5 year evaluation. Eight of the 12 rootstock-scion combinations tested, which included the 'LCRSC' control, were classified within the high CD group. Members of this group also presented the highest PH values at 3.5 years of age with the exception of those involving the vigorous and dwarfing rootstock 'TSKC×(LCR×TR)-059'. Grafted plants with rootstocks 'LVK×LCR-038', 'TSKC×TRFD-003', 'TSKC×CTSW-041' and 'HTR-069' were assigned to the low CD group at the 3.5 year evaluation. The three trifoliate rootstocks in this group normally confer small CDs and these grafted plants presented mean CDs of 309.13 cm at 3.5 years, 367.6 cm at 4.0 years and 391.37 at 4.5 years. Interestingly, plants with 'LVK×LCR- 038' rootstocks were temporarily reassigned to the high CD group at 4.0 years of age, while those with TSKT' rootstocks were reallocated to the low CD group at 4.5 years of age.

Our results are in agreement with the findings of Machado et al. (2017), who reported higher CD values for 5-year-old plants with tangerine 'Cleópatra', 'citrandarin 1710' and 'Volkamer' lemon rootstocks in comparison with those involving the trifoliate 'Limeira' rootstock. In addition, Bettini (2019) described that dwarfing rootstocks also conferred a smaller CD to 'Tahiti' acid lime, substantiating the relationship between low PH and small CD.

Of the physical characteristics assessed in this study, CV showed the greatest variation with values ranging from 14 to 20 $m^3$ at 3.5 years, from 21 to 29 $m^3$ at 4.0 years and from 26 to 34 $m^3$ at 4.5 years. The rootstocks 'LCR- 003', 'CTSW', 'CTRI', 'CTRSD' and 'TSKC×CTSW-028' conferred high CVs to 'Tahiti' acid lime in 4.5-year-old-plants, and presented a mean CV value that was 5.42 $m^3$ higher than that of the small CV group, which comprised 'TSKC×(LCR×TR)-059', 'TSKC×CTSW- 041', 'LVK×LCR-038', 'TSKC×TRFD-003' and 'HTR-069'. Moreover, the ranking of rootstocks by CV value was similar to the order according to TD2, indicating a positive correlation between these two variables. Rodrigues et al. (2018) reported mean CV values in 6-year-old plants of 'Tahiti' acid lime that ranged between 25.18 and 51.72 $m^3$, with the smallest value being obtained with grafts involving the rootstock tangerine 'Sunki TSKC×CTSW-041' tangerine. In our study, this rootstock also induced one of the smallest CV values in 'Tahiti CNPMF-02' acid lime. In addition, Rodrigues et al. (2019) reported that rootstocks that induced small PH values also conferred small CVs in orange 'Valência' sweet orange. It is important to note that rootstocks inducing the formation of smaller CVs allow denser orchards and provide greater fruit production per unit area (Machado et al., 2017).

Regarding VVI values, grafted plants could be divided into two groups irrespective of the time of evaluation. In the high VVI group, which included grafts involving 'CTSW', 'LCR-003', 'CTRSD', 'CTRI', 'TSKC×CTSW-028' and 'TSKT' rootstocks, the values of the variable were similar to that of the control and presented a mean of 8.99 in 4.5-year-old plants. Grafted plants with rootstocks 'TSKC×CTSW-041', 'LVK×LCR-038', 'TSKC×(LCR×TR)-059', HTR-069' and 'TSKC×TRFD-003' presented VVI values that were significantly lower ($p$ <0.05) than that of the control and showed a mean value of 8.46 in 4.5-year-old plants. However, the difference between the mean VVI values of the two groups was only 0.53%.

The results of the physicochemical analysis of the fruits produced by 'Tahiti CNPMF-02' acid lime grafted onto 12 different types of rootstocks are presented in **Table**

**4**. The variables FL and FM were influenced significantly by the rootstock, while the other variables (FD, JY, TSS, TTA and VIT-C) were not.

Grafted plants could be divided into two groups with respect to FL and FM. Plants grafted with 'CTRSD', 'TSKC×(LCR×TR)-059', 'LCR-003', 'TSKC×CTSW-041', 'TSKC×TRFD-003', 'LVK×LCR-038' and 'CTRI' produced fruits similar to the control and showed mean FL and FM values of 63.98 mm and 115.65 g, respectively. In contrast, plants with rootstocks TSKT', 'HTR-069', 'CTSW' and 'TSKC×CTSW-028' produced fruit with mean FL and FM values of 61.0 mm and 102.48 g, respectively, that were significantly lower than those of the control.

In previous studies, no significant differences were found between the lengths of fruit produced by 'Tahiti' acid lime grafted onto different rootstocks, and mean values were reported variously as 61.44 mm (Santos et al., 2016, Santos, 2019) and 56.58 mm (Rodrigues et al., 2018). On the other hand, there were significant differences between the mass of fruits produced by the grafted plants, the recorded ranges of which were 91.2 to 115.7 g (Santos et al., 2016) and 83.63 to 108.23 g (Rodrigues et al., 2018). However, Bettini-Tambur et al. (2022) did not detect significant differences between the masses of fruit produced by 'Tahiti' acid lime grafted onto different rootstocks and reported a mean value of 77.13 g. We attribute the variations in FL and FM observed in the present study to the effect of the rootstock, since field conditions (soil, fertilization, cultural practices and water availability) were similar across the orchard for all of the grafted plants tested.

One of the key physical characteristics employed in the classification and commercialization of fruits of 'Tahiti' lime is FD, the mean value of which was recorded as 58.33 mm in the present study. According to the standards applied by the Companhia de Entrepostos e Armazéns Gerais de São Paulo (CEAGESP, 2011), fruits of 'Tahiti' lime with diameter > 56 mm are classified as large, and all of the fruit produced by 'Tahiti CNPMF-02' acid lime met this condition regardless of the rootstock employed. Machado et al. (2017) investigated the cultivation in southeastern Brazil (Jaíba, MG) of 'Tahiti IAC-5' acid lime grafted onto different rootstocks and reported the production of fruits with relatively small FD (mean of 54.8 mm). In this context, it is worth noting that even with variations in length and mass, all of the fruits produced by 'Tahiti CNPMF-02' acid lime, regardless of rootstock, met the requirements of the fresh food consumer and the industrial market considering that the preferred ranges are FL between 55 and 70 mm, FD between 47 and 65 mm (Luchetti et al., 2003) and FM greater than 100 g (Passos et al., 2002).

The JY of fruits produced by the grafted plants varied between 36.3 and 43.6%, depending on the rootstock, with an overall mean value of 39.14%. Although there were no significant differences between the JY of the plants, only those involving 'CTRSD', 'HTR-069', 'TSKC×CTSW-041' and 'TSKT' rootstocks produced fruits that met the minimum 40% yield standard established by CEAGESP (2011), with mean JY values of 43.58, 41.30, 40.87 and 40.23%, respectively. 'Tahiti IAC-5' acid lime grafted onto different rootstocks also produced fruits with similar values of JY (> 42%) regardless of the rootstock (Machado et al., 2017). Rodrigues et al. (2018) evaluated the fruits produced by a local variety of 'Tahiti' acid lime from Capixaba (AC, Brazil) grafted onto 10 different types of rootstock and reported a mean JY value of 52.47%, which was higher than that observed in the present study.

The mean TSS of fruit from the tested grafted plants was 7.41 °Brix, a value that is within the range of 7.0 to 7.88 °Brix reported previously by Rodrigues et al. (2018) and above the minimum of 7.0 °Brix required

**Table 4.** Physicochemical characteristics and quality of fruits produced by 'Tahiti CNPMF-02' acid lime grafted onto various rootstocks.

| Rootstocks | FL[§](mm) | FM[§](g) | FD[#](mm) | JY[#](%) | TSS[#](°Brix) | TTA[#](%) | VIT-C[#](mg 100 mL$^{-1}$) |
|---|---|---|---|---|---|---|---|
| LCRSC (control) | 63.11 a | 113.94 a | 59.13 | 34.41 | 7.04 | 4.16 | 24.29 |
| CTRI | 63.14 a | 111.41 a | 58.13 | 37.77 | 7.41 | 4.39 | 22.51 |
| CTRSD | 65.03 a | 117.06 a | 59.20 | 43.58 | 7.40 | 4.29 | 22.95 |
| TSKC×CTSW-041 | 64.07 a | 112.94 a | 58.91 | 40.87 | 7.52 | 4.51 | 22.19 |
| HTR- 069 | 61.61 b | 105.66 b | 57.66 | 41.30 | 7.42 | 4.03 | 22.80 |
| LCR-003 | 64.91 a | 120.60 a | 59.67 | 38.41 | 7.36 | 4.29 | 24.12 |
| LVK×LCR-038 | 63.19 a | 113.69 a | 58.33 | 36.29 | 7.30 | 4.18 | 22.68 |
| TSKC×CTSW-028 | 59.99 b | 98.01 b | 55.05 | 38.73 | 7.31 | 4.22 | 24.83 |
| CTSW | 60.44 b | 99.48 b | 57.04 | 39.15 | 7.44 | 4.30 | 23.20 |
| TSKC×(LCR×TR)-059 | 64.94 a | 121.08 a | 60.55 | 38.02 | 7.74 | 4.51 | 24.37 |
| TSKC×TRFD-003 | 63.49 a | 114.47 a | 58.83 | 38.95 | 7.55 | 3.98 | 24.27 |
| TSKT | 61.96 b | 106.76 b | 57.43 | 40.23 | 7.44 | 4.40 | 21.69 |
| CV (%) | 3.66 | 8.64 | 3.48 | 11.49 | 2.34 | 8.53 | 11.07 |

FL, fruit length; FM, fruit mass; FD, fruit diameter, JY, juice yield; TSS, total soluble solids; TTA, total titratable acidity; VIT C, vitamin C; CV, coefficient of variation.

[§] In each column, mean values followed by dissimilar letters are significant different at 5% probability (Scott-Knott test).

[#] In each column, mean values are not significantly different from the control.

for commercialization according to CEAGESP (2011) standards. Bremer-Neto et al. (2013) evaluated the performance of five 'Tahiti' acid lime selections ('IAC 5, 'IAC 5-1', 'CNPMF/EECB', 'CNPMF 2000' and 'CNPMF 2001') grafted onto citrumelo 'Swingle' rootstock and reported a mean TSS value of 8.47 °Brix with no differences observed between the rootstock/scion combinations. Sugar content in fruit is an intrinsic trait related to the genotype, environment, culture management and maturation, and constitutes an important parameter for the fruit juice industry since it guarantees economic yields of juice after processing (Ferreira et al., 2009).

The mean TTA of the fruit produced by 'Tahiti CNPMF-02' acid lime grafted onto the tested rootstocks was 4.27%, a value that fell below the desirable range of 7.0 to 8.0% (Stuchi et al., 2009). Similar findings have been reported by Rodrigues et al. (2018), who attributed the low acidity of grafted 'Tahiti' acid lime grown in Capixaba to the high temperature (~25.6°C) during maturation of the fruit. Our experiments were conducted in Sorriso (MT, Brazil) where the mean annual temperature is 24.7°C and an average rainfall of 312.60 mm concentrated in the period November-March (Souza et al., 2013). The TTA values reported herein are lower than those reported by Santos et al. (2016), Almeida et al. (2021) and Bettini-Tambur et al. (2022).

The fruit produced by grafted plants of 'Tahiti CNPMF-02' acid lime tested in this study presented a mean VIT-C concentration of 23.35 mg 100 $mL^{-1}$, which is well within the expected range of 20 to 40 mg 100 $mL^{-1}$ according to Gayet et al. (1995) and close to the mean value of 27.97 mg 100 $g^{-1}$ reported by Miranda & Campelo-Junior (2010) for fruits of 'Tahiti' acid lime grafted onto 'Cravo' lime and grown in Colorado do Oeste (RO, Brazil).

**Conclusions**

All tested rootstocks were compatible with the scion 'Tahiti CNPMF 02' acid lime when cultivated under the climate and soil conditions of the north of Mato Grosso. The rootstocks 'Cravo LCR - 003' lime, the citrandarins 'CTRI' and 'CTRSD', citrumelo 'CTSW' and 'Sunki TSKC×CTSW-028' tangerine induced the best vertical growth, trunk diameter, crown volume and vigor in the grafted plants. The trifoliate hybrid 'Sunki 'TSKC×(LCR×TR)-059' tangerine induced the least vertical growth, crown volume and vigor, but generated a crown volume similar to that of the control. The physicochemical characteristics and quality of the fruits produced by 'Tahiti CNPMF 02' acid lime met market expectations, except for the parameter total titratable acidity. The fruit produced by 'Tahiti CNPMF 02' acid lime grafted onto 'CTRSD', 'TSKC×(LCR×TR)-059', 'LCR-003', 'TSKC×CTSW-041', 'TSKC×TRFD-003', 'LVK×LCR-038' and 'CTRI' were the largest in terms of length and mass.

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