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Propagation

Degree days, phenology and fruit quality of 'Tahiti IAC-5' acid lime grafted onto different rootstocks in Pindorama - SP

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Abstract - Few rootstock varieties are used for 'Tahiti' acid lime; therefore, diversification is necessary and studying the phenological phases of new scion/rootstock combinations is important for orchard management strategies. The aim of this study was to evaluate the influence of different rootstocks on the sum of degree days (DD) and on the phenology of plants and also on the quality of 'Tahiti' acid lime fruits, in Pindorama, SP. Six branches were marked on plants grafted onto 13 citrandarins (H), 'Rangpur' lime (RL), 'Flying Dragon' trifoliate orange (FD) and 'Sunki' mandarin (SM). Phenological characterization (anthesis to harvest) was performed using a grading scale. DD accumulation (anthesis to harvest) was determined considering the base temperature of 13 °C. Physical (weight, height and diameter, juice yield) and chemical (acidity, total soluble solids and ratio) characteristics of fruits were also evaluated. The experimental design was in randomized blocks with three replicates and one plant per plot. The rootstocks under study influenced DD accumulation and phenology, with early (H5, H73, H121, H135, H145, H152, FD - 1,558 at 1,676 DD and 135 to 146 days) and later combinations (H10, H14, H42, H47, H70, H150, H173, RL and SM - 1,694 to 1,829 DD and 148 to 157 days) regarding fruit maturation. The harvest point of 'Tahiti' acid lime fruits grafted onto H145 citrandarin and FD was advanced about 20 days in relation to the standard rootstock, RL. Total soluble solids content and fruit size were influenced by rootstocks; however, all scion/rootstock combinations presented fruits with quality characteristics within commercial standards.

Index terms: *Citrus ×latifolia*; citrandarin; 'Rangpur' lime; *Poncirus trifoliata* 'Flying Dragon'

Graus-dia, fenologia e qualidade de fruto da Limeira-ácida 'Tahiti IAC-5' em combinação com diferentes porta-enxertos, em Pindorama - SP

Resumo - Poucas variedades de porta-enxertos são utilizadas para a limeira-ácida 'Tahiti', sendo que a diversificação se faz necessária, e o estudo das fases fenológicas de novas combinações copa/porta-enxerto é importante para as estratégias de manejo do pomar. Objetivou-se avaliar a influência de diferentes porta-enxertos no somatório dos graus-dia (GD) e na fenologia das plantas, além da qualidade dos frutos de limeira-ácida 'Tahiti IAC-5', em Pindorama-SP. Foram marcados seis ramos em plantas enxertadas em 13 citrandarins (H), no limoeiro 'Cravo' (LC), no trifoliata 'Flying Dragon' (FD) e na tangerineira 'Sunki' (TS). A caracterização fenológica (antese à colheita) foi realizada utilizando-se de uma escala de notas. O acúmulo de GD (antese à colheita) foi determinado considerando-se a temperatura-base de 13 °C. Também foram avaliadas as características físicas (massa, altura, diâmetro e rendimento de suco) e químicas (acidez, sólidos solúveis totais e *ratio*) dos frutos. O delineamento experimental foi em blocos casualizados, com três repetições e uma planta por parcela. Os porta-enxertos estudados influenciaram no acúmulo de GD e na fenologia, identificando-se combinações precoces (H5, H73, H121, H135, H145, H152, FD - 1.558 a 1.676 GD e 135 a 146 dias) e mais tardias (H10, H14, H42, H47, H70, H150, H173, LC e TS - 1.694 a 1.829 GD e 148 a 157 dias) quanto à maturação de frutos. O ponto de colheita dos frutos de limeira-ácida 'Tahiti' enxertada no citrandarin H145 e no FD foi adiantado em torno de 20 dias em relação ao porta-enxerto padrão de LC. Os teores de sólidos solúveis totais e o tamanho dos frutos foram influenciados pelos porta-enxertos, entretanto, todas as combinações apresentaram frutos com características de qualidade dentro dos padrões comerciais.

Termos para indexação: *Citrus ×latifolia*; citrandarin; limoeiro 'Cravo'; *Poncirus trifoliata* 'Flying Dragon'

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'Tahiti' acid lime [*Citrus ×latifolia* (Yu. Tanaka) Tanaka] is among the ten fruits most produced in Brazil (FAO, 2018). The country ranks fifth in the world production of limes and lemons, producing approximately 1.5 million tons (FAO, 2018). The state of São Paulo is the main producer, accounting for 79.1% of the Brazilian production, with 30,773 cultivated hectares (SIDRA, 2018).

In the state of São Paulo, the main flowering of 'Tahiti' acid lime occurs in the first semester, resulting in greater fruit supply, while the second flowering is concentrated in the months from July to November, when fruit supply is smaller. In the second semester, prices are higher, encouraging producers to provide more cultural treatments to the crop to benefit from higher pays (PIRES et al., 2011). The climatic conditions of producing regions can be restrictive to increase production in the second semester, but knowledge about the duration of the plant's phenology can help in the management and establishment of conditions necessary to increase production and fruit quality and, consequently, to provide greater profitability to producers.

Another important factor is the choice of the rootstock, as it influences characteristics related to vigor, early production, synthesis of some hormones, ripening time, fruit size, peel color, sugar and acid content, fruit permanence in the plant, postharvest conservation, drought tolerance, disease resistance, and may also be related to the scion phenological phases (SIQUEIRA and SALOMÃO, 2017).

Regarding plant phenology, the thermal sum in degree days is the most appropriate variable to determine, in various regions, the time required between flowering and fruit maturation in plant varieties and species, including citrus, which can last from 6 to 16 months. The study of the phenological phases enables a more adequate planning of periods of execution of cultural treatments and harvest (SIQUEIRA and SALOMÃO, 2017). Given the above, the aim of this study was to evaluate the influence of different rootstocks on the sum of degree days, plant phenology and quality of 'Tahiti IAC-5' acid lime fruits.

'Tahiti IAC-5' acid lime grafted onto 13 citrandarins [*C. sunki* (Hayata) hort. ex Tanaka x *Poncirus trifoliata* (L.) Raf. cv. Rubidoux - H5, H10, H14, H42, H47, H70, H73, H121, H135, H145, H150, H152 and H173], 'Rangpur' lime (*C. ×limonia* Osbeck - RL), 'Flying Dragon' trifoliate orange [*P. trifoliata* var. *monstrosa* (T. Itô) Swingle - FD] and 'Sunki' mandarin (*C. sunki* - SM), was installed on March 2013, spacing 7.0 m x 4.0 m, with no irrigation, at the Mid-Northern Regional Center of the São Paulo Agribusiness Technology Agency (APTA), in Pindorama, SP (geographic coordinates 21º13'15.7'' S and 48º54'23.3'' W and altitude of 552 m).

According to the Köppen's classification, the climate is classified as Aw, defined as a tropical climate, with dry winter and rainy summer, with average annual rainfall of 1,258 mm and average annual temperature of 22.8 °C. The soil was classified as Eutrophic, deep, well developed, well drained, with high base saturation. According to the National Soil Commission, this unit is classified as Podzolized Lins and Marília Soils, Marília variation (LEPSCH and VALADARES, 1976). Fertilization and soil corrections were carried out as recommended by Ribeiro et al. (1999), based on the soil chemical analysis in sample collected at depth of 0.0-0.20 m, in which the following average contents were found: phosphorus (46 mg dm^{-3}), potassium (2.5 mmolc dm^{-3}), calcium (21 mmolc dm^{-3}), magnesium (9.0 mmolc dm^{-3}), boron (0.16 mg dm^{-3}), copper (1.0 mg dm^{-3}), iron (44 mg dm^{-3}), manganese (9.0 mg dm^{-3}), zinc (0.6 mg dm^{-3}) and base saturation (64.4%).

For the phenological characterization of the main stages of vegetative and reproductive development of plants from the flower bud to the physiological fruit maturation (harvest point), a visual grading scale was created through photographs (Figure 1), using methodology adapted from Barbasso et al. (2005). Six branches were marked, three on each of the east and west sides of plants for weekly observation of the phenological stages according to the grading scale: (1) visible flower bud; (2) full flower with closed petals (cotton swab); (3) flower opening (anthesis); (4) dry petals with style; (5) no petals and no style; (6) fruit with 1.0 to 2.5 cm in diameter (marble); (7) fruit with 2.6 to 4.0 cm in diameter (ping-pong ball); (8) fruit close to final size with 4.1 to 4.6 cm in diameter; (9) fruit in final size (harvest point) with 4.7 to 6.5 cm in diameter. Phenological stages 3, 5, 7, 8 and 9 were considered for the characterization of scion/rootstock combinations and calculation of the duration of corresponding subperiods. Evaluations started in August 2018 and ended in March 2019, when fruits reached the final size for harvest.

The calculation of the degree days (DD) for each scion/rootstock combination, in the different subperiods, was performed using equation: $DD = (TMAX + TMIN)/2 - Tb$; where: TMAX = daily maximum temperature (°C); TMIN = daily minimum temperature (°C); and Tb = base temperature (13°C) (Villa Nova et al., 1972). DD accumulation was calculated by summing daily DD for each subperiod. Meteorological information was collected from CIIAGRO (Integrated Center for Agrometeorological Information/IAC/APTA) of the Mid-Northern Regional Center Meteorological Station/APTA, Pindorama, SP.

At the time of fruit maturation, evaluations of physicochemical characteristics were carried out, collecting five fruits in each replicate, for each rootstock, totaling 15 fruits per treatment. Analyses were carried out at the Laboratory for Improvement and Fruit Quality at the Sylvio Moreira/IAC Citriculture Center of Cordeirópolis, SP, and the following variables were quantified: fruit mass on Filizola scale with capacity of 15 kg and sensitivity of 5 g; fruit height and diameter, with the aid of graduated scale, in centimeters; juice yield was determined after extracting fruit juice using CIO (Centennial International Organization) extractor model OTTO 1800, calculated by the juice mass/fruit mass ratio, expressed as percentage; total soluble solids content, determined by direct reading in B&S refractometer, model RFM 330, expressed in °Brix; juice acidity was obtained by titration of 25 mL of juice with 0.3125 normality sodium hydroxide solution using phenolphthalein as indicator; and, Ratio was calculated by the soluble solids/juice acidity ratio.

The experimental design was in randomized blocks with three replicates and one plant per plot. For the statistical analysis of measured variables, means were submitted to analysis of variance (ANOVA) and compared by the Scott-Knott test (5%), using the SISVAR statistical software (FERREIRA, 2011). For the total duration of the 3-9 subperiod, 95% confidence intervals were determined.

The flower induction period of 'Tahiti IAC-5' acid lime fruits occurred between the months of May and June, when temperatures and rainfall began to decrease (Figure 2), and the beginning of flowering occurred on August 8, 2018, with the exception of plants grafted onto H14 citrandarin and FD, which flowered 14 and 18 days later, respectively.

Plants grafted onto H14 citrandarin and SM took 35 and 33 days to complete the 3-5 subperiod (from anthesis to fruit without style), respectively, differing from the other combinations, which varied between 14 and 21 days. Five-seven subperiod (ping-pong ball) took the longest time to complete, ranging from 62 to 70 days, with the exception of plants grafted onto H14 citrandarin, FD and SM, which completed this subperiod in 46, 49 and 55 days, respectively, differing from the other rootstocks (Table 1). Nascimento et al. (2018) also found that the 'ping-pong ball' stage was the longest (98 to 128 days) for 'Rubi' and 'Pera CNPMF-D12' sweet orange varieties [*C.* ×*sinensis* (L.) Osbeck] and for 'Page' tangelo [*C.* ×*clementine* hort. ex Tanaka x (*C.* ×*paradisi* Macfad. x *C.* × *tangerine* Tanaka)] grafted onto RL and 'Volkamer' lemon rootstocks [*C.* ×*volkameriana* (Risso) V. Ten. & Pasq.] under the conditions of the sub-middle São Francisco River Valley. For 7-8 (fruit close to final size) and 8-9 (final fruit size) subperiods, values from 30 to 43 days and 26 to 35 days, respectively, were found, but no differences were observed between evaluated combinations (Table 1). According to Coelho (1993), 'Tahiti' acid lime fruits present rapid development during the period of full water availability, which, in the present work, occurred between September and December 2018 (Figure 2), coinciding with the 7-9 subperiod.

The total duration of phenological phases (3-9 subperiod) varied among rootstocks, and two groups could be observed, an early group composed of H73, H121, H135, H145, H152 citrandarins and FD, with fruits reaching the harvest point between 135 and 143 days, and another little later group, composed of H5, H10, H14, H42, H47, H70, H150, H173 citrandarins, RL and SM, whose harvest time was between 146 and 157 days (Table 1). These values are similar to results obtained by Souza et al. (2005), who reported that the duration of the anthesis-harvest subperiod was 139 and 148 days, for irrigated and non-irrigated 'Tahiti' acid lime orchards, respectively, grafted onto RL, in Visconde do Rio Branco, MG. Miranda and Campelo Junior (2010) reported that the average number of days needed to complete the development of 'Tahiti' acid lime fruits grafted onto RL was 156 for the conditions of Colorado do Oeste, RO.

The shortest total period (anthesis-harvest) was 135 days, observed for FD, lasting 22 days less than in the combination with H14 citrandarin, in which the longest period was observed, 157 days. For H73, H121, H135, H145 and H152 citrandarins, reduction was observed between 12 and 19 days for fruits to reach the harvest point in relation to RL, considered standard rootstock for 'Tahiti' acid lime. Stenzel et al. (2006) observed that 'Folha Murcha' sweet orange (*C.* ×*sinensis*) plants grafted onto RL and 'Volkamer' lemon trees presented anticipation of the beginning of harvest by 8 and 15 days, respectively, in relation to those grafted onto 'Cleópatra' (*C. reshni* hort. ex Tanaka) and 'Sunki' mandarins, in Londrina, PR. In Paranavaí, PR, the same authors found that the beginning of fruit maturation of 'Folha Murcha' sweet orange plants grafted onto 'Volkamer' lemon occurred 15, 19 and 28 days earlier than in RL, 'Cleópatra' and 'Sunki' mandarins, respectively, reinforcing the influence of rootstock on the phenology of citrus scion varieties, as also observed in the present work.

The amount of heat required for fruit growth and maturation in each subperiod of phenological phases was obtained by estimating the degree days (DD) and the values found varied between 1,558 and 1,829 DD for H145 and H14 citrandarins, respectively. Statistical difference was observed only for the 3-5 subperiod (from anthesis to fruit without style), in which H14 citrandarin and SM required greater amount of DD to complete the subperiod (Table 1).

Regarding the total duration of phenological phases, the formation of two groups presenting different thermal demands for their fruits to reach the harvest point was observed. The first group needed between 1,695 and 1,829 DD, being represented by plants grafted, in increasing order, onto H150, H70, H10, H47, H173, SM, RL, H42 and H14 rootstocks. In the second group, the lowest values were observed, ranging from 1,558 to 1,676 DD, represented in increasing order by plants grafted onto FD, H145, H152, H135, H121, H73 and H5 rootstocks (Table 1).

In colder places, such as the State of Rio Grande do Sul, regions considered suitable for the production of 'Tahiti' acid lime fruits present thermal sum greater than 1,829 DD found for H14 citrandarin, ranging from 2,700 to 2,900 DD (CORREA et al., 1992). In Rondônia, where temperatures are higher, 'Tahiti' acid lime 'Quebra-Galho' clone grafted onto RL, required from 961 to 1,937 DD, with average of 1,649 DD to complete the phenological phases (MIRANDA and CAMPELO JUNIOR, 2010). In Visconde do Rio Branco, MG, from flower opening to harvest, 'Tahiti' acid lime plants grafted onto RL required DD accumulation of 1,493 and 1,585 for irrigated and non-irrigated orchards, respectively (SOUZA et al., 2005). KOLLER (1994) classified citrus varieties as early and late, where early ones require from 1,600 to 1,800 DD to reach maturity and late ones from 1,800 to 2,000 DD. Thus, the present work obtained scion/rootstock combinations that were later, and others earlier, emphasizing that these evaluations were carried out in Pindorama, SP, and the same combinations may present variations in other regions with different climatic conditions and crop management.

Regarding fruit quality, no significant differences were observed for variables fruit mass (62 to 92 g), juice yield (43 to 56%), titratable acidity (5.83 to 6.97 g 100 mL^{-1}) and ratio (1.57 to 1.95); however, differences were observed for variables fruit height and diameter and total soluble solids content. Largest fruits (height and diameter) were observed in H10 (5.87 and 5.33 cm), H70 (5.63 and 5.23 cm), H121 (5.57 and 5.20 cm), H135 (5.67 and 5.23 cm), H145 (5.57 and 5.23 cm), H152 (5.63 and 5.20 cm) citrandarins and RL (5.93 and 5.40 cm) and smaller fruits were found in H14 (5.03 and 4.77 cm) and H42 (5.30 and 5.07 cm) citrandarins, FD (5.33 and 5.00 cm) and SM (5.25 and 5.00 cm) rootstocks. Cantuarias-Avilés et al. (2012) evaluated the response of 'Tahiti' acid lime grafted onto 12 rootstocks in Bebedouro, SP, and obtained larger fruits with *P. trifoliata* 'Rubidoux' and 'Limeira' RL rootstocks and smaller fruits with 'Orlando' tangelo [*C. reticulata* Blanco × (*C.* ×*paradisi* Macfad.)]. Regarding fruit diameter, an important characteristic in the marketing of 'Tahiti' acid lime, mainly for the foreign market, which requires diameter from 4.7 to 6.5 cm (GAYET et al., 1995), it was observed that all rootstocks under study provided fruits within this pattern, ranging from 4.8 to 5.4 cm. Machado et al. (2017) evaluated the influence of 12 rootstocks on the quality of 'Tahiti' acid lime fruits in Jaíba, MG and also observed fruits produced within commercial standards, corroborating results of the present work.

H14 citrandarin (12.7 ºBrix), FD (12.7 ºBrix) and SM (12.5 ºBrix) had the highest levels of total soluble solids (TSS), while in other citrandarins (9.9 to 11.3 ºBrix) and in the RL (9.6 ºBrix), the lowest values were observed. These results are in agreement with those obtained by Machado et al. (2017) and Stuchi et al. (2009), who evaluated several rootstocks for 'Tahiti' acid lime and also observed higher TSS contents in fruits from plants grafted onto FD and the lowest values in fruits from plants grafted onto RL. All rootstocks under study provided higher TSS concentrations than those observed in other studies found in literature (RODRIGUES et al., 2018; BREMER NETO et al., 2013; CANTUARIAS-AVILÉS et al., 2012). In studies evaluating rootstocks for 'Valência' sweet orange (*C.* ×*sinensis*), similar results were also obtained, with lower TSS concentration for fruits when RL was used as rootstock (AULER et al., 2008; ZEKRI and AL-JALLEL, 2004). Simonetti et al. (2015) evaluated 47 citrandarins in competition with RL as rootstock for 'Valencia' sweet orange and observed that 17 citrandarins had higher SST values compared to RL, classifying them as promising for presenting better performance compared to RL.

It could be concluded that the rootstocks under study influenced the DD accumulation and the phenology of 'Tahiti' acid lime fruits, identifying early combinations (H5, H73, H121, H135, H145, H152 citrandarins and *Poncirus trifoliata* 'Flying Dragon' - 1,558 to 1,676 degree days and 135 to 146 days) and later combinations (H10, H14, H42, H47, H70, H150, H173 citrandarins, 'Rangpur' lime and 'Sunki' mandarin - 1,694 to 1,829 degree days and 148 to 157 days) regarding fruit maturation. The harvest point of 'Tahiti' acid lime fruits grafted onto H145 citrandarin and *Poncirus trifoliata* 'Flying Dragon' was advanced around 20 days in relation to the standard 'Rangpur' lime rootstock. Total soluble solids content and fruit size were influenced by rootstocks; however, all combinations presented fruits with quality characteristics within commercial standards.

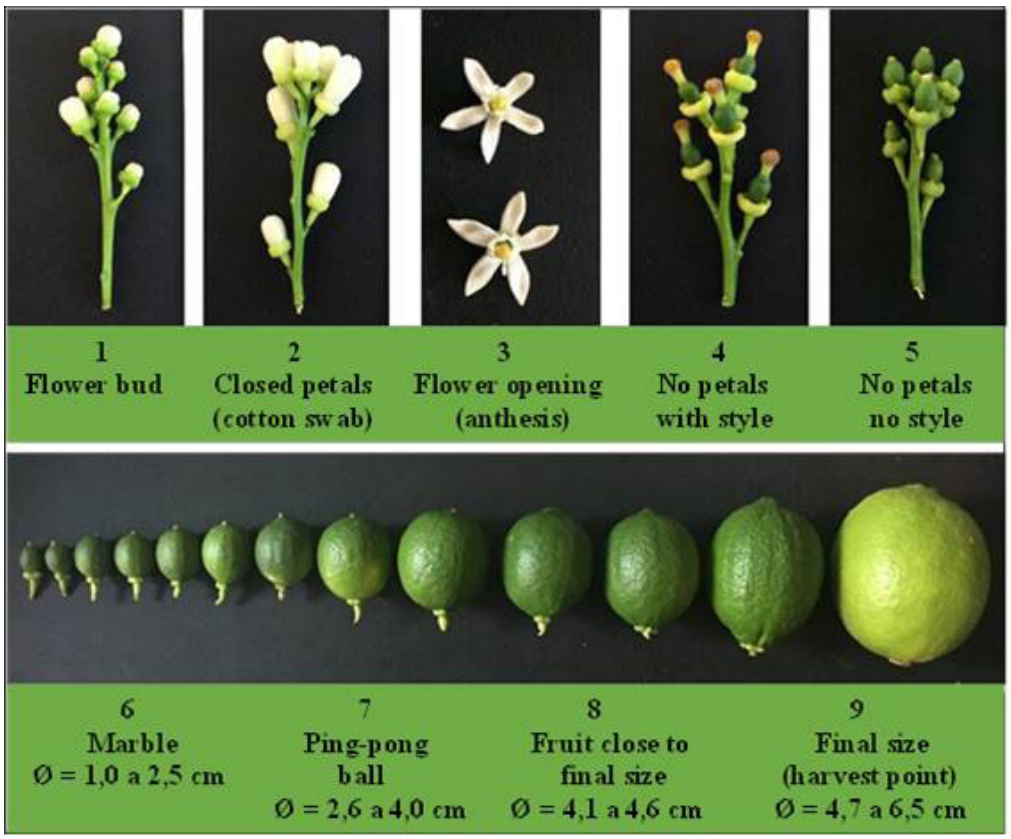

Figure 1. Grading scale designed to assess the different phenological stages of reproductive development (1 - flower bud to 9 - final fruit size) of 'Tahiti IAC-5' acid lime plants [*Citrus ×latifolia* (Yu. Tanaka) Tanaka] (Pindorama, SP, 2018). Ø = fruit diameter

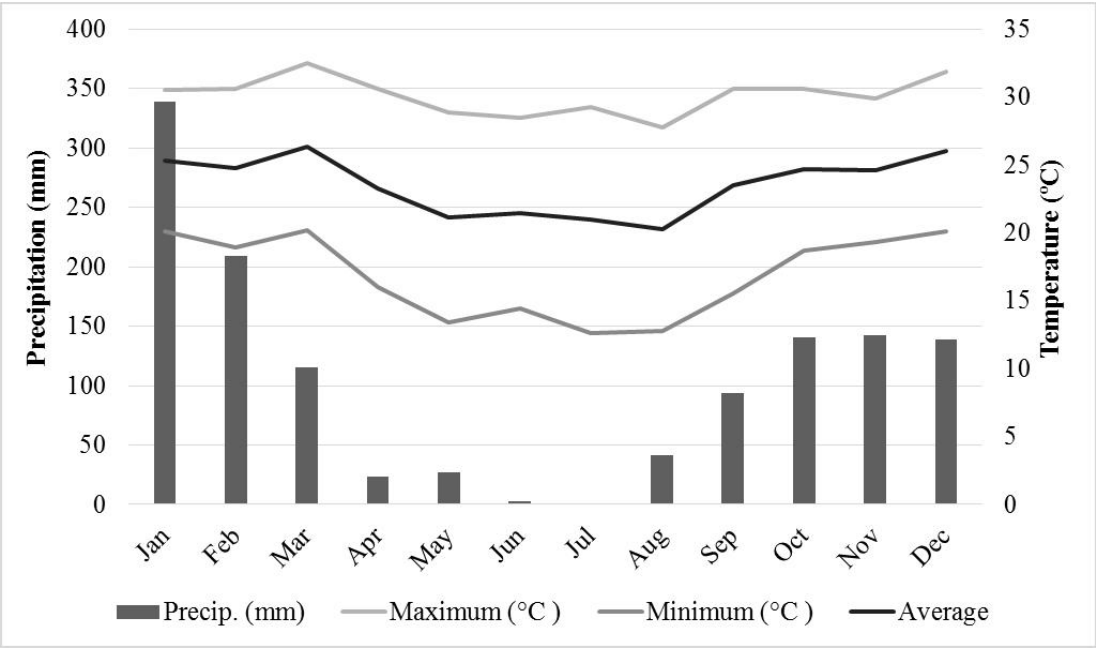

Figure 2. Maximum, minimum and average temperatures and monthly rainfall accumulated during 2018 (Pindorama, SP).

Table 1. Accumulated degree days (DD) and duration in days (D) of each subperiod of phenological phases of 'Tahiti IAC-5' acid lime fruits [*Citrus ×latifolia* (Yu. Tanaka) Tanaka] grafted onto 16 rootstocks (PE). Pindorama, SP, 2018.

PE	Subperiod of phenological phases									
	3-5		5-7		7-8		8-9		3-9	
	DD	D	DD	D	DD	D	DD	D	DD	D
H5[1]	150 b*	16 b	752[ns]	68 a	413[ns]	35[ns]	361[ns]	27[ns]	1676 ± 61 b	146 ± 5 a
H10	162 b	17 b	714	65 a	422	36	444	34	1741 ± 145 a	152 ± 11 a
H14	356 a	35 a	542	46 b	541	43	399	33	1829 ± 167 a	157 ± 18 a
H42	159 b	17 b	697	63 a	486	40	474	35	1816 ± 134 a	155 ± 13 a
H47	176 b	21 b	701	62 a	465	38	416	32	1757 ± 53 a	153 ± 5 a
H70	163 b	18 b	754	69 a	441	37	373	28	1730 ± 95 a	152 ± 9 a
H73	169 b	18 b	696	62 a	433	37	342	26	1639 ± 160 b	143 ± 13 b
H121	155 b	17 b	702	62 a	409	34	347	27	1613 ± 189 b	140 ± 14 b
H135	145 b	15 b	704	64 a	400	34	353	27	1601 ± 88 b	140 ± 9 b
H145	169 b	18 b	698	63 a	380	32	312	23	1558 ± 13 b	136 ± 1 b
H150	138 b	15 b	748	68 a	348	30	460	35	1694 ± 42 a	148 ± 3 a
H152	134 b	14 b	709	65 a	381	33	340	26	1564 ± 65 b	138 ± 6 b
H173	163 b	18 b	693	63 a	446	37	465	35	1777 ± 27 a	153 ± 2 a
FD[2]	168 b	20 b	582	49 b	417	36	393	30	1561 ± 50 b	135 ± 4 b
LC[3]	134 b	14 b	770	70 a	461	39	414	32	1778 ± 144 a	155 ± 10 a
TS[4]	317 a	33 a	630	55 b	388	33	442	34	1777 ± 36 a	155 ± 3 a
CV (%)	36.1	30.2	11.2	10.7	12.7	11.2	19.6	21.4	6.8	6.6

*Averages followed by the same letter in column do not differ (Scott-Knott 5%). ns = not significant. [1]H = [*C. sunki* (Hayata) hort. ex Tanaka x *Poncirus trifoliata* (L.) Raf. cv. Rubidoux] citrandarin; [2]FD = *P. trifoliata* cv. *monstrosa* (T. Itô) Swingle; [3]RL = 'Rangpur' lime (*C. ×limonia* Osbeck); [4]SM = 'Sunki' mandarin (*C. sunki*).

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