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THERMAL REQUIREMENT AND PHENOLOGICAL CHARACTERIZATION OF PAPAYA VARIETIES CULTIVATED UNDER SUBTROPICAL CLIMATE

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1 ABSTRACT

The thermal sum has been widely used to correlate phenological phases of a culture, a technique used to quantify the time required for any phenological phase in any type of environmental conditions, independently of the species. In view of the above, this study aimed to evaluate the thermal requirement and phenological characterization of papaya varieties cultivated under subtropical climate. It was measured the following phenological stages length: from planting to flowering (PF), from flowering to harvest (FH) and from planting to the beginning of harvest (PH), by measuring the time elapsed between each phenological phase. Female and hermaphrodite flowers were considered for measuring the growth curves of fruits by evaluating length (LF) and diameter (DF) of the fruits at 15-day intervals. The thermal requirement was measured by the accumulation of thermal sum in degree-days (DD) during different phenological phases and fruits development period. In current study conditions, it was possible to infer that Sunrise Solo variety and hybrid Tainung nº 1 are earlier, with an approximately 10-month interval between planting and the beginning of the harvest; therefore, necessitating accumulation of 1722.2 and 1798.1 degree-days, respectively.

Keywords: *Carica papaya* L., degree-days, plant performance.

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2 RESUMO

A soma térmica tem sido amplamente utilizada para correlacionar fases fenológicas de uma cultura, uma técnica utilizada para quantificar o tempo necessário para qualquer fase fenológica em qualquer tipo de condição ambiental, independentemente da espécie. Frente ao exposto, objetivou-se com este estudo avaliar a exigência térmica e caracterização fenológica de variedades de mamoeiro cultivadas sob clima subtropical. Foi mensurado a duração dos

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seguintes estádios fenológicos: plantio ao florescimento (PF), florescimento à colheita e plantio ao início da colheita, através da aferição do tempo decorrido entre cada fase fenológica. As curvas de crescimento dos frutos, acompanhadas em flores femininas e hermafroditas, foram determinadas mediante avaliação do comprimento e diâmetro dos frutos em intervalos de 15 dias. Já a exigência térmica foi mensurada através do acumulo da soma térmica em graus-dia, durante as diferentes fases fenológicas e para o período de desenvolvimento dos frutos. Nas condições do presente estudo foi possível inferir que a variedade Sunrise Solo e o híbrido Tainung nº1 são mais precoces, com intervalo entre o plantio e o início da colheita de aproximadamente 10 meses, necessitando do acúmulo de 1722,2 e 1798,1 graus-dia, respectivamente.

Palavras-chave: *Carica papaya* L., graus-dia, performance de plantas.

3 INTRODUCTION

The increase of tropical fruit market has been spectacular over the last two decades, especially papaya (*Carica papaya* L.), which has gained great popularity across the world, occupying a prominent position among tropical fruits (SAKELI et al., 2018). World production of papaya has expanded significantly in recent years, with a dynamic growth of exports in some developing countries (EVANS, BALLEN, 2013).

In Brazil, papaya agribusiness is of great economic and social importance, besides that Brazil became one of the world´s biggest producers, with a production of 1.58 million tons, i.e. 16.7% of world production in 2016 (FAO, 2016). The state of Bahia is the biggest national producer, followed by Espírito Santos and Minas Gerais, with productions of 718.7, 404.7 and 126.8 thousand tons, respectively; these states accounts for about 80% of the country´s total production in 2016 (IBGE, 2017).

In the state of São Paulo, papaya has already had great economic prominence; however, papaya mosaic virus (*Papaya ringspot virus*, PRSV-p) has contributed to its migration to other states, such as Bahia, Espírito Santos and Pará (MARTINS et al., 2016). Although it produces only 0.7% of national´s production of papaya, i.e. 11.8 thousand tons in 2016 (IBGE, 2017), the state of São Paulo presents a highly receptive market to commercialize papayas; consequently, favouring small-scale producers to run a profitable farm business (MARTINS et al., 2016).

Even though there are still some obstacles that hamper its expansion, such as phytosanitary matters and small number of varieties available for planting that meet both foreign and domestic market criteria; and different types of soil and climate conditions (DAMASCENO JÚNIOR et al., 2015).

Papaya is a typical tropical fruit; therefore, it presents regular growth and high-quality production in regions of great insolation (i.e. at between 21-33ºC temperature and 60-80% relative humidity); temperature is the most important factor for crop development, mainly flower and fruit formation (LIMA et al., 2016). Although, papaya is a tropical fruit, it has adapted well in transition regions between tropical and subtropical climate, however, growing areas that differ from the idyllic climate conditions for papaya development can affect plants phenological phases; resulting in hermaphrodite flowers disorders, mainly due to temperature extremes, soil conditions and relative humidity (OGATA et al., 2016).

To overcome such dilemma is important to evaluate papaya varieties and hybrids available for growing in different regions; such strategy is of great importance to take off the development of papaya culture in Brazil, since there is little information about the agronomic performance of them in “unfavourable” regions, limiting their expansion; consequently, by knowing their traits related to phenology, productive performance and post-harvest quality of the fruits, it would be possible to indicate the best variety accordingly to each growing area (DAMASCENO JÚNIOR et al., 2015).

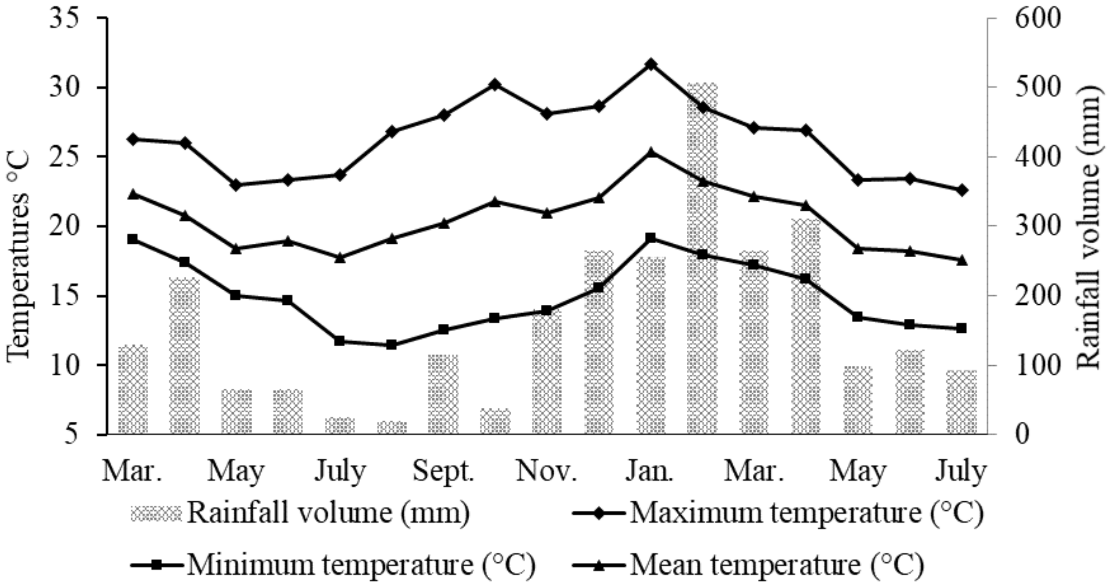
An efficient way of studying the phenological and productive behaviour of a crop is through temperature, relating it to the thermal sum expressed in degree-days, which has been used to estimate the amount of heat required for plants growth and development (SOARES et al., 2017). Currently, thermal sum has been widely used to correlate phenological phases of a single culture (CHIOU; HSIEH; CHIEN, 2015); therefore, the current study was performed by using such technique to quantify the time needed for any phenological phase in any kind of environmental conditions, regardless the species (LUCAS et al., 2012; RODRIGUES; SOUZA; LIMA, 2013; MATOS et al., 2014).

Given all the above, the current study aimed to evaluate the thermal requirement and phenological characterization of papaya varieties cultivated under subtropical climate.

4 MATERIAL E MÉTODOS

The meteorological data concerning the period of the experiment (i.e. from 2014 to 2015) were provided by the Soil and Environmental Resources Department, School of Agriculture, UNESP, Botucatu; therefore, Figure 1 shows the maximum, minimum and mean temperatures and precipitation index.

Figure 1. Maximum, minimum and mean temperatures; precipitation index from March 2014 to July 2015, referring to the city of Botucatu, SP. 2017.



Seeds used in the formation of the seedlings of the Sunrise Solo variety and of the Tainung Nº 1 hybrid were purchased from ISLA Pak seeds LTDA. For the acquisition of the seeds of the local Variety, fruits of plants of a domestic orchard located in Monte Alto Farm, municipality of São Manuel - SP, were used. All evaluations were carried out from March 2014 to July 2015, by assessing the length of the following phenological stages: from planting to flowering (PF); from flowering to harvest (FH); and from planting to the beginning of harvest (BH), by monitoring plants of the three evaluated varieties, where the time elapsed between each phenological phase was measured. Fruit growth curves were considered in female and hermaphrodite flowers after anthesis, besides being marked at the beginning of flowering.

The measurements of the fruits length (LF) and diameter (DF) in plants were carried out with a digital calliper at 15-day intervals, expressed in millimetres. Measurements started after anthesis and continued until fruit maturation. Therefore, five flowers were selected per plant and followed up to the fruit harvesting point, corresponding to maturation stage 1, i.e. up to 15% of the shell presented yellow colour.

Fruit growth curves for LF and DF followed a non-linear, sigmoidal model, which is the most common model for fruit growth analysis. The equations were adjusted by using the 'Sigma Plot 12.5' graphing software, with non-linear model, according to the equation:

$$Y = a / (1 + e^{\wedge} (-k (X - XC)) \quad (1)$$

Where a = maximum observed value, e = base of Napierian logarithm, k = average rate of accumulation or growth, X = days after anthesis and Xc = time required to reach half of growth or maximum accumulation. The calculation of degree-days (DD) for each day during different phenological phases and fruits development period was performed according to Ometto's methodology (1981), by the following equations:

$$\text{If } Tm > Tb \text{ and } TB > TM: DD = (TM + Tm/2) + (Tm - Tb) \quad (2)$$

$$\text{If } Tm \leq TM \text{ and } TB > TM: DD = (TM - Tb)^{\wedge}2 / 2 (TM - Tm) \quad (3)$$

$$\text{If } Tb > TM; TB > TM: DD = 0 \quad (4)$$

$$\text{If } Tb < Tm; TB < TM: DD = 2 [(TM - Tm)(Tm - Tb)] + [(TM - Tm)^{\wedge}2 - (TM - TB)^{\wedge}2] / 2 (TM - Tm) \quad (5)$$

$$\text{If } Tb > Tm; TB < TM: DD = 1/2 \text{ x } [(TM - Tb)^{\wedge}2 - (TM - TB)^{\wedge}2 / (TM - Tm)] \quad (6)$$

While the calculations of accumulated ADD for different phenological phases of papaya varieties studied were performed using the following equation:

$$AAD = \sum_{i=1}^{n} DDi \quad (7)$$

Where, DD = Degree-day; ADD = Accumulated degree-days; MT = average daily maximum temperature (ºC); Tm = average daily minimum temperature, (ºC); Tb = minimum basal temperature, (°C); TB = maximum basal temperature, (ºC); N = number of accumulated days; i = i^{th} day of DD count. The minimum and maximum basal temperatures used for papaya culture were 15°C and 35°C, respectively (NAKASONE; PAULL, 1988).

Data were submitted to analysis of variance and the means of the different treatments were compared by Tukey test at 5% probability. All statistical analysis was carried out using the program SISVAR (FERREIRA, 2014).

5 RESULTADOS E DISCUSSÃO

Texto resultados e discussão Regarding the phenological data, there was uniformity of initial development of plants, independently of treatments, such behaviour is confirmed by the absence of a significant difference for this response variable ($p>0.05$), i.e. all plants reached flowering at the same time (Table 1). Typically, papaya has a rapid initial growth due to high photosynthetic rates of plants, common behaviour in the varieties of this fruit (JIMÉNEZ et al., 2014).

Table 1. Mean results of number of days from planting to flowering (PF); from flowering to harvest (FH); from planting to harvest (PH); and from anthesis to fruit maturation (AFM) of three papaya plant varieties. Botucatu, SP. 2017.

Varieties	Number of days			
	PF	FH	PH	AFM
Sunrise Solo	102.0 a	199.0 b	301.0 b	150.0 c
Tainung n°1	105.2 a	205.0 b	310.2 b	165.0 b
Local variety	105.2 a	306.3 a	411.5 a	180.0 a
SMD[1]	30.05	44.18	39.39	12.16
CV (%)	18.23	11.78	7.30	5.06

Means followed by lowercase letters did not differ by Tukey test at 1 and 5 % significance. [1]Significant minimal difference.

Choosing papaya varieties whose plants reach the earliest flowering is a strategy of great value, when farmers do not know the plant´s sex at planting, they will put at least three seedlings per hole; therefore, increasing production costs, as well as affecting hermaphrodite plants development due to competition (DANTAS; LUCENA; VILAS BOAS, 2015). Moreover, papaya plants with hermaphrodite flowers are chosen at flowering, since they will rise high-quality fruits that meet both domestic and foreign markets demand.

In Campos dos Goytacazes (state of Rio de Janeiro), a study was conducted with papaya 'Improved Sunrise Solo 72/12' by Almeida et al. (2003), who obtained 120-day interval between planting and flowering; such results were lower than the current study, showing that may be associated not only with the different edaphoclimatic conditions between experiments, but also with the cultivars used in their studies.

Considering that all phenological phases that make up the papaya development are essential for its productive success; however, the interval that includes the beginning of flowering and fruit harvest is largely influenced by exogenous factors such as temperature; low relative humidity; both excess moisture in soil and a lack thereof; and great thermal amplitude, that acting together or isolated promote floral anomalies, which will imply in defective and non-market production (CARDOSO et al., 2017). Therefore, better results will be observed in plants that suffer less exposure to such exogenous factors; consequently, using cultivars that present shorter phenological cycle (i.e. from flowering to harvest). Under current study conditions, Sunrise Solo variety and hybrid Tainung nº 1 presented 199 and 205-day interval between flowering and harvest, respectively (Table 1).

The harvesting period started at 301 (Sunrise Solo) and 310 days (Tainung nº 1) after planting; i.e. approximately 10 months (Table 1). Dantas, Lucena and Vilas Boas (2015) obtained 8-month interval between planting and harvest for same papaya variety in Cruz das Almas (state of Bahia).

The earlier production obtained by them may be related to the difference in the climatic pattern between the two regions, since papaya crops needs periodic renewal of orchards; consequently, the shorter the time to start fruit production, the greater the producer's financial outcome, given the longer harvesting time.

In the northwest of São Paulo state, papaya crop has become an economically profitable alternative of income diversification for many producers and permanent replacement of some crops; however, there must be a renewal of orchards every two years after planting, because the occurrence of papaya mosaic virus (*P. ringspot virus*, PRSV-p). Therefore, using earlier varieties becomes indispensable for the success of papaya culture from all producing regions of São Paulo state.

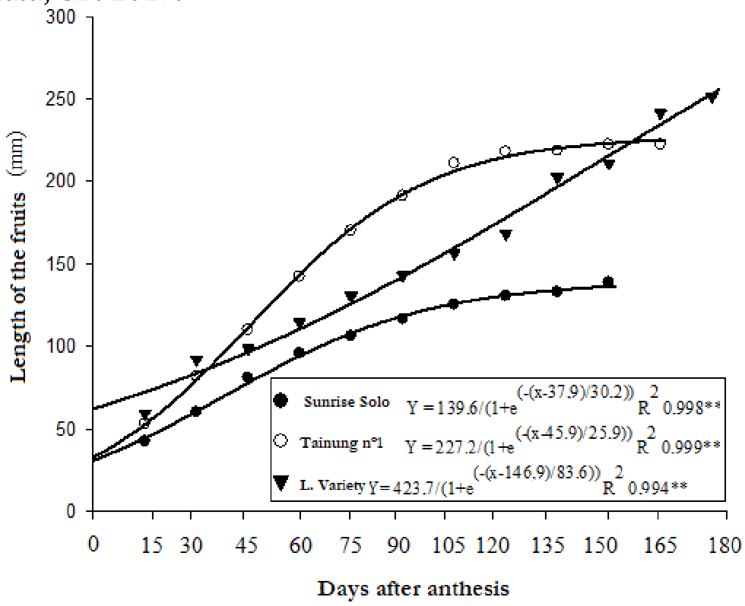
Regarding to the interval between anthesis and fruit maturation, results indicated that Sunrise Solo obtained lower number of days (an average of 150-day) compared to the other genotypes analysed (Table 1). It is verified that the current result is within the range obtained by Berilli et al. (2007) for hybrid of the Formosa group (UENF / Caliman 01) cultivated at different times of the year in Linhares (state of Espírito Santos), with 112 to 182-day interval between anthesis and fruit maturation.

During the experiment, flowers were marked in anthesis, i.e. at the end of October 2014, when high average temperatures were recorded (Figure 1). The more distant are the production areas of the idyllic climatic conditions for papaya culture, the longer the phenological phases will last; however, their agricultural exploitation will not be made unfeasible (LIMA et al., 2016).

Fruits length of the Sunrise Solo variety and hybrid Tainung nº 1 presented simple sigmoidal growth as a function of the number of days after anthesis, with a greater elongation between 45 and 105, whereas the fruits of the local variety did not follow the same growth pattern, increasing linearly in length to the maturation point (Figure 2).

As reported by Chitarra and Chitarra (2005), fruit growth tends to follow a sigmoidal pattern with accelerated elongation at the beginning of development, because of intense cell division and stretching, but slower at the end due to the biochemical transformations. The lack of sigmoidal pattern found in local variety fruits (Figure 2) can be attributed to the fact that this material presents great genetic variability, i.e. dioecious variety.

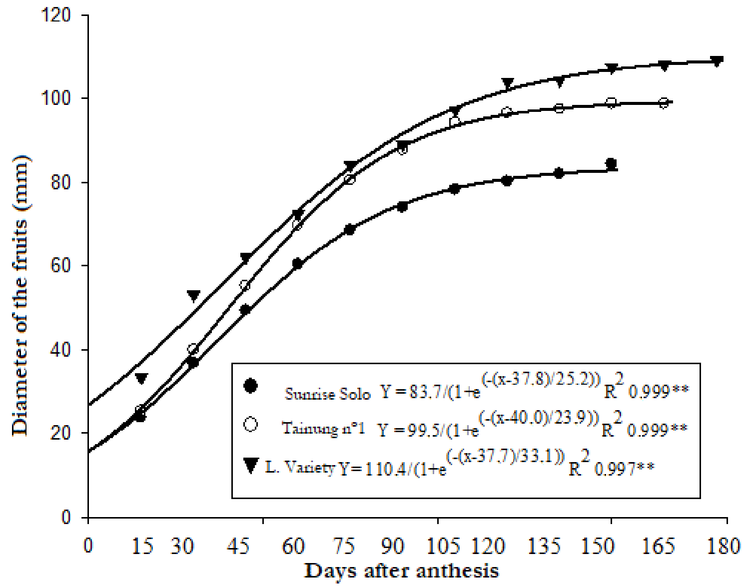
Figure 2. Length of the fruits of the three papaya varieties related to the days after anthesis. Botucatu, SP. 2017.



Knowing the fruits development stages is of great importance in crop management for better growth and maturation, since plant requires greater amount of water for fruits development during cellular division and elongation, but such requirement is lower at maturation stage.

The increase in fruit diameter of both varieties studied followed the sigmoidal model, with the phase of rapid growth between 15 and 90 days, followed by a stabilization after 120 days of anthesis (Figure 3). This pattern of fruit growth agrees with the information reported by Chitarra and Chitarra (2005) for the simple sigmoidal growth model.

Figure 3. Diameter of the fruits of the three papaya varieties related to the days after anthesis. Botucatu, SP. 2017.



About the curves behaviour in the three cultivars for diameter of fruits, it is observed that local variety presented the highest values for this variable between anthesis and harvest, followed by Tainung nº 1 and Sunrise Solo, respectively.

Studying the growth rate of papaya fruits is of great importance, as it allows to understand different phenological phases involved in their development, such as time of greatest fruit weight gain or beginning of fruit maturation, to define harvest period. Quantification of fruit growth can also reveal the critical periods in its development, allowing high-quality production of fruits, thus satisfying the most demanding consumers (BERILLI et al., 2007).

Regarding to the thermal requirement, there was a significant difference ($p < 0.05$) only for the accumulation of degree-days between flowering-harvest and planting-harvest (Table 2). Results indicated that local variety presented a higher demand (accumulated degree-days) to complete the phenological intervals from flowering to harvest (1933.3°C) and planting to harvest (2533.2°C), compared to other varieties (Table 2). The higher demand for accumulated degree days to overcome these phenological phases, resulted in a greater number of days to reach such thermal sums, showing a late behaviour in local variety.

It is worth noting that Sunrise Solo and Tainung nº 1 presented thermal requirement of 1722.4°C and 1798.4°C, respectively, from planting to beginning of fruit harvest (Table 2). While Damasceno Júnior et al. (2015), evaluated the selections of papaya from the 'Solo' group in Linhares (state of Espírito Santos), verified that plants reached the harvest when they acquired a thermal sum of approximately 2300°C. Similar results were also obtained by Almeida et al. (2003) in Campos dos Goytacazes, for the accumulation of degree-days from planting to harvest.

In a cultivar, accumulation of degree-day is a very important tool to correlate the duration of the plant cycle with climatic conditions of any region, by quantifying the time required between any phenological phase, independently of species (CHIOU; HSIEH; CHIEN, 2015).

The number of degrees-days required between anthesis and harvest for the three varieties was 1176.9ºC, 1129.2ºC and 1167.7ºC; therefore, without any significant difference ($p > 0.05$). By assessing fruit growth rate related to the time of year and accumulated degree-days, Berilli et al. (2007) inferred that after anthesis, fruits tend to stabilize the growth when there is the accumulation of approximately 800 degree-days, with maturation point for harvest reached after the accumulation of 1226.67 ° C in Linhares (state of Espírito Santos).

The rate of metabolic reactions of plants is strongly influenced by air temperature, thus affecting the growth and development of plants. These two processes occur simultaneously, so their distinction becomes difficult, since plants development is regulated by temperature; duration of phenological phases and periods; and consequently, the crop cycle varies inversely proportional to it (SCHMIDT et al., 2017).

Table 2. Average degree-days needed from planting to flowering (PF), flowering to harvest (FH), planting to harvest (PH) and anthesis to fruit maturation (AFM) of three papaya varieties.

Varieties	Degree-days PF (°C)	Degree-days FH (°C)	Degree-days PH (°C)	Degree-days AFM (°C)
Sunrise solo	592.9 a	1129.1 b	1722.4 b	1176.9 a
Tainung n°1	598.5 a	1199.9 b	1798.1 b	1129.2 a
Local variety	599.9 a	1933.3 a	2533.2 a	1167.7 a
SMD[1]	105.28	316.09	300.24	241.02
C.V. (%)	11.13	14.05	9.40	13.14

Means followed by lowercase letters did not differ by Tukey test at 1 and 5 % significance, [1]Significant minimal difference.

6 CONCLUSIONS

In current study conditions, it was possible to infer that Sunrise Solo variety and hybrid Tainung nº 1 are earlier, with an approximately 10-month interval between planting and the beginning of the harvest; therefore, necessitating accumulation of 1722.2 and 1798.1 DD, respectively.

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