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THE PHENOLOGICAL GROWTH AND THERMAL SUM OF 'Hass' AVOCADO FRUITS

Alian Cássio Pereira Cavalcante[1]; Carlos Eduardo Magalhães dos Santos[2]; Adailza Guilherme Cavalcante[3]; Guilherme Antonio Vieira de Andrade[4]; Eli Matheus de Souza Lopes[5]; Leonardo Angelo de Aquino[6]

ABSTRACT: Avocado is a perennial fruit grown in tropical and subtropical climates, and climatic diversity can alter fruit maturation. This study evaluated the phenological growth stages of 'Hass' avocado fruits 'Hass' using the Biologische Bundesanstalt Bundessortenamt und Chemische Industrie (BBCH) scale and the degree-day sum (thermal sum) to determine the requirements for efficient cultivation. From August 2018 to June 2019, avocado growth was monitored from stage 711 (initial ovary growth) to stage 719 (>90 % of the final size) in Alto Paranaíba, Minas Gerais, Brazil. At each phenological stage, the longitudinal and transversal diameters and fresh and dry masses were measured, and the dry mass percentage and accumulated thermal sum were calculated. Cultivation dates were estimated based on flowering and the thermal sum requirements at each growth stage. The largest 'Hass' avocados were observed at stage 718 (based on diameter, fresh mass, and dry matter content), requiring 2778.9 °C total.
Keywords: Fruit growth, Degree-day, *Persea americana* Mill, Management

RESUMO: O abacate é uma fruta perene cultivada em climas tropicais e subtropicais e a diversidade climática pode alterar a maturação dos frutos. Este estudo avaliou os estágios fenológicos de crescimento dos frutos de abacate 'Hass' usando a escala Biologische Bundesanstalt Bundessortenamt und Chemische Industrie (BBCH) e a soma de graus-dia (soma térmica) para determinar os requisitos para um cultivo eficiente. Foram avaliados de agosto de 2018 a junho de 2019, o crescimento do abacate foi monitorado desde o estágio 711 (crescimento inicial do ovário) até o estágio 719 (>90% do tamanho final) no Alto Paranaíba, Minas Gerais, Brasil. Em cada estádio fenológico foram medidos os diâmetros longitudinal e transversal e as massas fresca e seca, e calculada a porcentagem de massa seca e a soma térmica acumulada. As datas de cultivo foram estimadas com base na floração e nas exigências de soma térmica em cada estádio de crescimento. Os maiores abacates 'Hass' foram observados no estágio 718 (com base no diâmetro, massa fresca e teor de matéria seca), necessitando de 2.778,9 °C no total.
Palavras-chave: Crescimento de frutos, Graus-dia, *Persea americana* Mill, Manejo.

1. INTRODUCTION

Avocados (*Persea americana* Mill.) are perennial fruits belonging to the *Lauraceae* family (Ramos e Sampaio, 2008) and grow in tropical and subtropical climates (e.g., Central America and Mexico) (Chen et al., 2009; Alcaraz et al., 2013). The fruit can be consumed 'as-is' or cooked, and the oil is extracted for producing creams, lotions,

[1] Centro de Ensino Superior de São Gotardo, Minas Gerais, Brasil.
[2] Universidade Federal de Viçosa – UFV, Viçosa, Minas Gerais, Brasil.
[3] Universidade Estadual de São Paulo – UNESP, Jaboticabal, São Paulo, Brasil.
[4] Universidade Federal de Lavras, Lavras, Minas Gerais, Brasil.
[5] Universidade Federal de Viçosa – UFV, Rio Paranaíba, Minas Gerais, Brasil.
[6] Diretor Agrônomico do IPACER

and other beauty products (Falcão et al., 2001; Silva et al., 2014).

In the Brazilian market, the 'Hass' cultivar fruits are marketed as "Avocado" and are considered a gourmet-type high value fruit (Vieites et al., 2014). The "Hass" variety is rarely consumed in Brazil, but is in high demand abroad, which encourages its cultivation for export. Its fruits have a smaller caliber than those commonly sold in the domestic market and high lipid and unsaturated fatty acid content, which may prevent cardiovascular diseases (Daiuto et al., 2012).

The climatic diversity of the producing region affects the fruit ripening time (Sentelhas et al., 1995); air temperature is the primary factor affecting plant development between flowering and maturation (Oliveira et al., 2013). The degree-day sum estimation (the average and base temperature of the culture) allows for more precise and detailed regional plant development (Sentelhas et al., 1995).

The Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie (BBCH) scale is a system for uniformly identifying the phenological growth stages for all monocotyledonous and dicotyledonous plant species (Hack et al., 1992; Meier, 2001). Cultivation practices that rely on the growth stage of the plant (e.g., fertilizer application and pest, weed, and disease control) are better planned when the phenology is known (Arcila-Pulgarin et al., 1998).

Several studies have used the BBCH scale and the degree-day sum to investigate fruit trees (e.g., marmeleiro (*Cydonia oblonga* L.), Leão e Silva (2003); orange (*Citrus sinensis* L. Osbeck), Medeiros et al. (2015); the custard apple (*Annona squamosa* L.), Liu et al. (2015); sapota (*Manilkara zapota*), Kishore e Mahanti (2016). The phenological stages of avocado fruit development using the BBCH scale was described by Alcaraz et al. (2013). However, the thermal sum (degree-day sum) of the 'Hass' variety has not been documented. This study aimed to evaluate the phenological growth stages of the 'Hass' avocado fruit 'Hass' according to the BBCH scale, together with the thermal sum, to improve cultivation practices based on the phenological requirements.

2. MATERIAL AND METHODS

The phenological growth of fruits of 13-year-old 'Hass' avocado plants was monitored from August 2018 to June 2019 in Alto Paranaíba, Minas Gerais, Brazil. The local climate is classified as Cwa (monsoon-influenced humid subtropical) according to the Köppen and Geiger system (1928), and the average altitude is between 900 and 1200 m. Temperatures and rainfall amounts during the experimental timeframe are reported in Figure 1.

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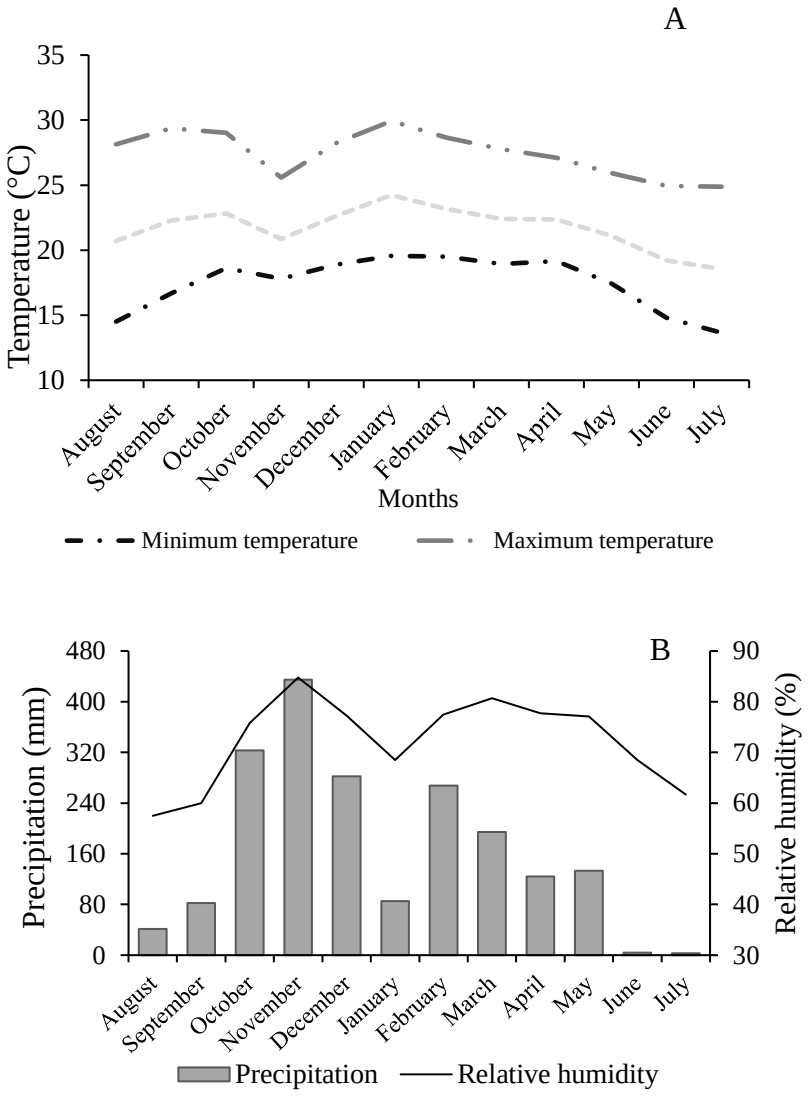
Figure 1: Minimum, maximum average temperature (A), relative humidity and average rainfall (B) from August / 2018 to July / 2019 for the Rio Paranaíba region, Minas Gerais.



Upon initial ovarian growth (stage 711), 40 fruits were marked by plants (800 total fruits) (Fig. 2B), and growth was monitored until the fruits reached >90 % of their final size (stage 719) (Figure 2). Fifty fruits were evaluated each season. Phenological stage observations were performed during the early morning hours and photographed using a Canon SX 160 IS with a 16X zoom lens.

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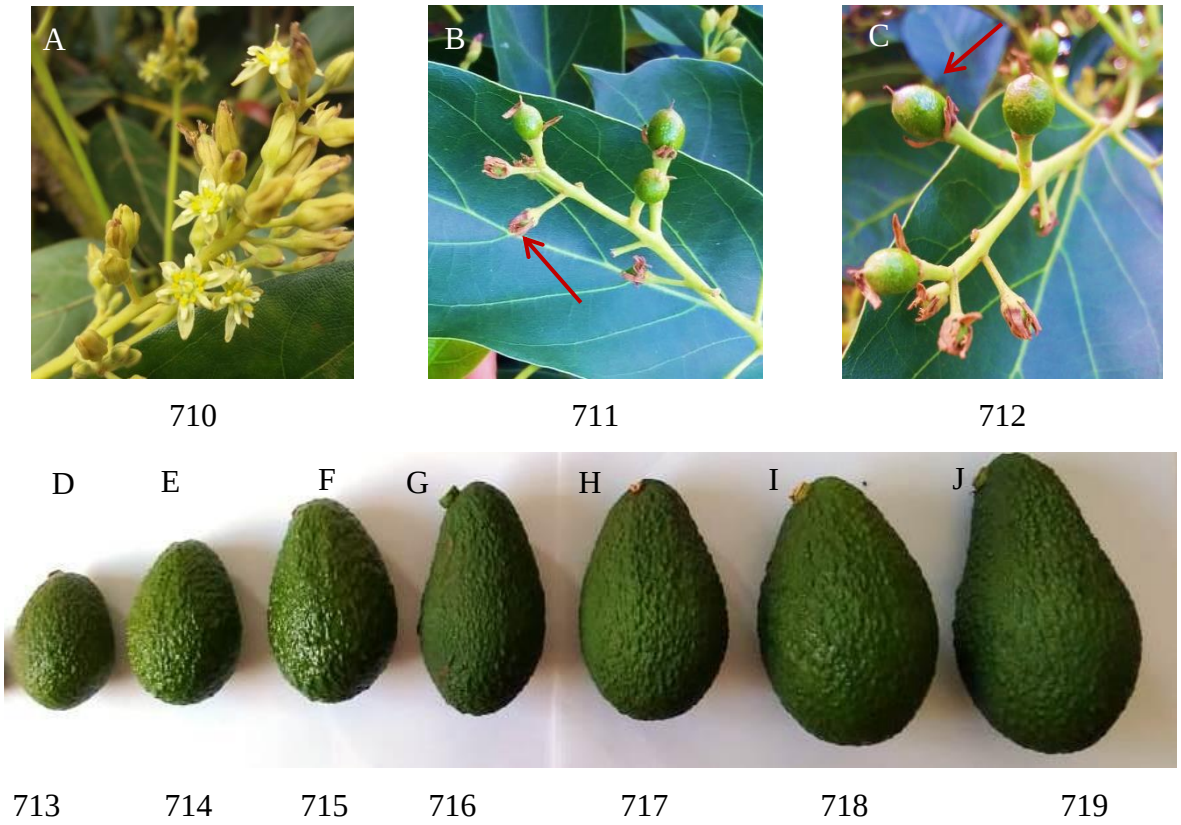
Figure 2: Phenological stages of growth of 'Hass' avocado fruits according to the extended BBCH scale.



The longitudinal and transversal diameters, fresh and dry masses, dry mass percentage, and thermal sum were evaluated in each phenological stage. The BBCH scale (proposed by Meier (2001) and adapted by Alcaraz et al. (2013)) was used to characterize phenological development ('Hass' Table 1).

The degree-days (GD) were calculated using equation 1 (Arnolds, 1960). The avocado lower base temperature (Tb) used for the accumulation of GD was 10 °C, as suggested by Praloran (1970) and Lucchesi et al. (1977).

$$STd = \left[\frac{(T^a\ Max + T^a\ Min)}{2}\right] - Tb * day$$

Equation 1 (daily thermal accumulation; STd): Tª Max = maximum air temperature (°C); Tª Min = minimum air temperature (°C); Tb = base temperature (°C).

The accumulated thermal temperature (STa) (i.e., the sum of the degree-days during the culture cycle or between phenological stages) was calculated by adding the STd (equation 1) required to reach the phenological stage (equation 2).

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$$STa = \sum_{i=l}^{n} STd$$

Equation 2 (accumulated thermal temperature; STa): n = the number of days between two consecutive phenological stages.

Table 1: Description of the main phenological growth stages of the 'Hass' avocado fruit according to the extended BBCH scale.

Principal growth stage 7: fruit development	
710	No ovary growth visible
711	Initial ovary growth
712	First fruitlet abscission
715	50% of final fruit size
716	60% of final fruit size
771	70% of final fruit size
718	80% of final fruit size
719	90% or more of final fruit size

3. RESULTS AND DISCUSSION

The meteorological oscillations during the experiment were within the expected range for avocado growth. Most rainfall occurred from October 2018 to May 2019, when the fruit is in the full-growth stage with large amounts of fresh matter accumulation. During fruit growth, adequate water availability allowed for sufficient nutrient absorption and high photosynthesis rates.

The 'Hass' avocado fruit phenological growth stages 'Hass' were identified according to the extended BBCH scale and reported in Figure 2; the degree-day sums for each stage are reported in Figure 3. The longitudinal and transversal diameters, fresh and dry masses, and dry mass percentage during fruit growth are reported in Figure 4.

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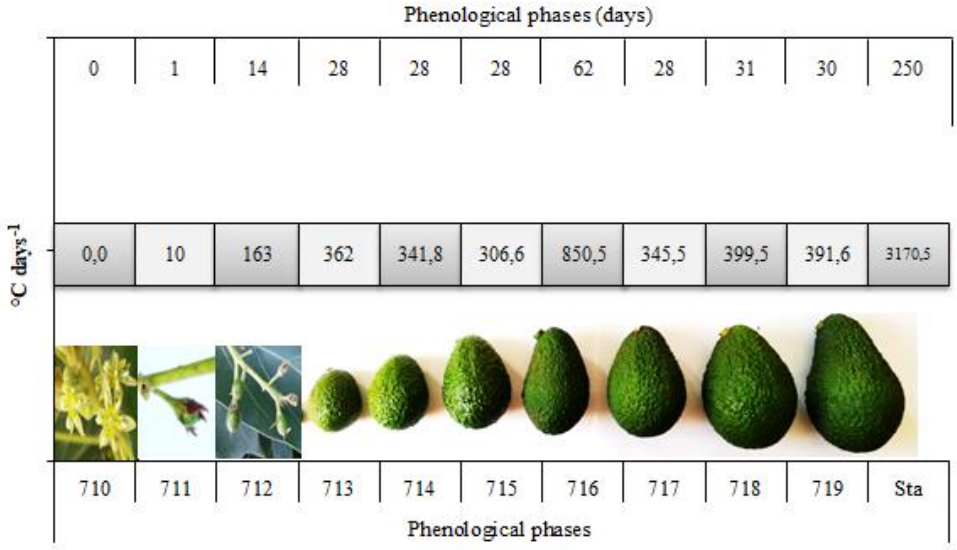
Figure 3: Phenological stages of 'Hass' avocado fruit growth and accumulated thermal sum. Paranaíba River, Minas Gerais, Brazil. 710 - No visible ovary growth; 711 - Initial growth of the ovary; 712 - first fruit abscission; 713 - 30% of the final fruit size; 714 - 40% of the final fruit size; 715 - 50% of the final size of the fruit; 716 - 60% of the final fruit size; 717 - 70% of the final fruit size; 718 - 90% of the final fruit size; 719 - 90% or more of the final fruit size and Sta - accumulated thermal sum.



Understanding the relationship between degree-days and the cultivation practices at each phenological growth stage is important for maintaining high avocado productivity (Cavalcante et al., 2020). Each growth stage has different nutritional requirements. Therefore, fertilization according to the growth stage and harvest period is beneficial (Salazar-Garćia et al., 2015). Soil nutrient mobility and the nutritional demands of the plant are other key fertilization factors, and correct planning enhances nutrient recovery and conversion into fruit production.

BBCH stage 7, which characterizes fruit development, was used to identify growth. In stage 710, ovarian fertilization occurred, but no growth was visible (Figure 2A), and in stage 711, initial ovarian growth occurred (Figure 2B). After ovary fertilization, thermal accumulation was required on the 10th day to reach this stage 711 (Figure 3), when growth monitoring began.

In stage 712, a thermal accumulation of 163 ºC per day was needed, which took 14 days after ovary fertilization to achieve depending on the weather conditions (Fig. 3). The fruits had a longitudinal diameter of 12.56 mm, a transversal diameter of 10.15 mm, a fresh fruit mass of 10.15 g, a dry mass of 0.097 g, and a dry mass of 10.5 mm (Figure 4).

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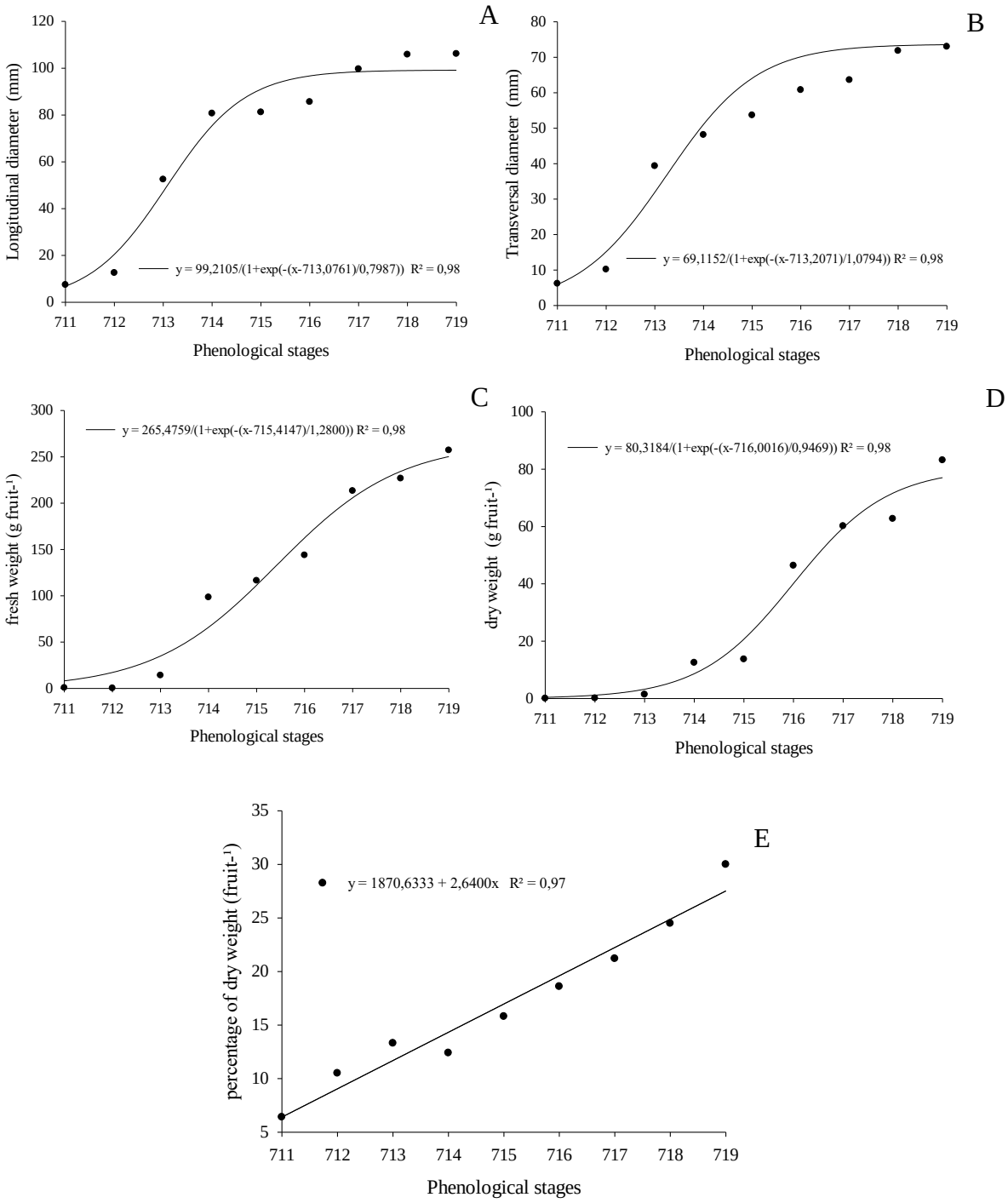
Figure 4: Longitudinal diameter (A), transversal diameter (B), fresh weight (C), dry weight (D) and percentage of dry weight (E) of the 'Hass' avocado fruits according to the phenological stages.



In avocado, the first fruit abscission occurs in stage 712, where hundreds of flowers are fertilized, and approximately 1 % produce fruits. Pollination difficulties and competition among young fruits cause flowers and fruits to fall (Duarte et al., 2018). Fruit abortion in avocado occurs in stage 712. There is an increase in peduncle cellulase activity and ethylene and peroxidase production in the abscission zone. Consequently, enzymes that degrade the cell wall and the middle lamella are synthesized, weakening the cell wall and forming a low resistance layer (Guan et al., 1995). The vascular bundle of young fruits is also prevented from connecting to the peduncle, leading to their fall (Agustí et al., 1995). Higher concentrations of plant auxin can prevent ethylene interference and the early fall of fruits (Medeiros et al., 2000). Therefore, using phytoregulators in avocado cultivation may reduce the fruit abscission effects in some varieties (Ferreira, 2008).

In stage 713, the fruits were approximately 30 % of their final size (i.e., size at harvest) (Figure 2) and required 362 °C to reach the stage. Stages 714 to 718 (Figures 2 and 3) correspond to 40 % to 80 % of the final fruit size. The required thermal accumulations were 341.8 ºC (714; 40 %), 306.6 ºC (715; 50 %), 850.5 ºC (716; 60 %), 345.5 ºC (717; 70 %), and 399.5 ºC (718; 80 %). In stage 718, a longitudinal and transverse diameter growth rate reduction was observed, and the dry mass accumulation increased (Figure 4).

The thermal requirement varied among the phenological growth stages. The largest thermal accumulations began in stage 716, likely due to an increase in the fresh and dry mass of the fruits. During this period, the fruits quickly grow, and the nutritional demand is higher, to ensure proper fruit development. The growing climate, particularly temperature and precipitation, are important for avocado cultivation. When the average temperature is lower, avocado fruits grow slowly and require more days before harvesting (Lucchesi e Montenegro, 1975). Establishing the degree-day sum is essential for producers to accurately predict the harvest period based on yearly regional temperature variations.

Compared to calendar days, the thermal sum (i.e., biological time) better represents how temperature influences plant development (Mcmaster e Smika, 1988). Planning cultivation practices based on chronology alone may cause improperly timed applications. The extended BBCH scale and the thermal sum can aid estimations of crop demands (especially for fertilizers) based on the phenological stage requirements (Cavalcante et al., 2020).

In stage 719 (Figure 2J), the fruits were 90 % or more of their final size. The longitudinal diameter was 106.1 mm, the transverse diameter was 73.01 mm, the fresh mass was 257.1 g, the dry

mass was 257.1 g, the dry mass was 83.1 g, the dry mass percentage was 30 %, and the thermal accumulation was 391.6 ºC per day.

The accumulated thermal sum was 3170.5 ºC (Figure 3), and ovary fertilization to mature fruit took 250 days. Fruit growth was adjusted to the sigmoid model (Figures 4A and 4B), and the transversal and longitudinal diameters and fresh and dry masses were stable from stage 715 to 717 (Figures 4C and 4D). The dry mass accumulation percentage increased linearly (Figure 4E).

New information about the meteorological effects on 'Hass' avocado fruit growth 'Hass' may contribute to crop management, allowing for higher productivity to meet domestic and international demands. Assessing phenological characteristics also helps to determine the largest fruit growth stages, leading to better cultivation practices and fertilization strategies (Bergamaschi, 2007).

Dry matter content is a determining factor for harvesting avocado fruits; a dry mass percentage between 20 % and 25 % has been suggested (Özdemir et al., 2009). However, consumers prefer fruits with a higher dry matter percentage because of the flavor (Gamble et al., 2010). Consumer preferences should also be considered when estimating the harvest date, along with fruit differentiation, average temperature, and thermal sum.

4. CONCLUSION

Estimating 'Hass' avocado agricultural practice dates from flowering is possible when the thermal sum for each fruit growth stage is considered. The largest 'Hass' avocado fruits (diameter, fresh mass, and dry matter content) were measured in stage 718 and required 2778.9 °C total.

5. ACKNOWLEDGEMENTS

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