

## Methodological analyses for determining thermal requirements of grape varieties in Tandil, Argentina

### Análisis de metodologías para determinar los requerimientos térmicos de variedades de vid en Tandil, Argentina

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Originales: *Recepción*: 18/10/2023 - *Aceptación*: 06/02/2025

#### ABSTRACT

This study evaluated the thermal demand of different grapevine varieties (Cabernet Franc, Merlot, Semillón, and Tannat) in Don Bosco, Tandil, Buenos Aires, Argentina. Phenology was evaluated during four productive cycles, identifying periods from budburst to flowering onset (BB-FO), flowering onset to veraison onset (FO-VO), and veraison onset to maturity (VO-M). The National Meteorological Service of Argentina provided daily maximum and minimum air temperatures. Six thermal sum methods were used: methods 1.1, 1.2, and 1.3 depended on base temperature for vine development (10°C); methods 2.1 and 2.2, considered base temperature and optimum temperature (25°C); and method 3, considered base, optimum, and threshold temperature (35°C). These methods were evaluated using the standard error of the thermal sum. Methods 2.2 and 3 best fit all four varieties, allowing adequate estimates of cumulative daily heat summation.

#### Keywords

degree-days • *Vitis vinifera* L. • phenology • temperate - humid climate

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## RESUMEN

El presente estudio tuvo como objetivo evaluar los requerimientos térmicos de diferentes variedades de vid (Cabernet Franc, Merlot, Semillón y Tannat) en viñedos plantados en Don Bosco, Tandil, Buenos Aires, Argentina. Se evaluó cronológicamente el desarrollo fenológico durante cuatro ciclos productivos, identificando las fechas de ocurrencia de los eventos y delimitando la duración de los subperíodos en días: inicio de brotación a inicio de floración, inicio de floración a inicio de envero, y envero a madurez. Las temperaturas máximas y mínimas diarias del aire se obtuvieron de los registros del Servicio Meteorológico Nacional. Se emplearon seis métodos de suma térmica: los métodos 1.1, 1.2 y 1.3, que se basan exclusivamente en la temperatura base para el desarrollo de la vid (10°C); los métodos 2.1 y 2.2, que, además de la temperatura base, consideran también la temperatura óptima (25°C); y el método 3, que incorpora los parámetros anteriores junto con la temperatura umbral (35°C). Estos métodos se evaluaron utilizando el error estándar de la suma térmica. Los métodos 2.2 y 3 demostraron el mejor ajuste para las cuatro variedades. Concluimos que los métodos 2.2 y 3 son más precisos en la estimación de la suma térmica diaria para todas las variedades estudiadas.

## Palabras clave

grados-días • *Vitis vinifera* L. • fenología • clima templado - húmedo

## INTRODUCTION

Among climatic factors, temperature plays a fundamental role in crop development. Temperature controls vegetative growth and development. Thermal weather models predicting plant development confirm its crucial role in phenology (54).

Grapevine (*Vitis vinifera* L.) is one widely cultivated fruit crop (30). Optimal production largely depends on local climatic conditions in each growing region (5). In modern viticulture, identifying phenological phases for each cultivar is crucial for effective crop management (21, 41). In recent decades, several investigations have focused on predicting grapevine budburst, flowering, and ripening (2, 15). Phenological characterization and quantification of thermal units for each phase allow harvest date estimations, suggesting site potential for viticulture (36). Thermal quantification, known as thermal sum (39) and typically expressed as degree-days (C° d) is widely used to account for temperature effects on plant development (40, 43). Daily thermal sum (DTS) considers average ambient temperature and basal temperature (BT) for each species. Grapevine has a DTS of 10°C. When the value after subtracting BT from average temperature is positive, degree-days are accumulated (16, 17, 25). This accumulated C°d can be calculated on a daily or monthly basis, for each phenological stage (20). Villaseca *et al.* (1986) indicated 850 to 950 C°d for early maturing table grape varieties and 1150 to 1350 C°d for late maturing cultivars in Chile. Chronological times between phenological stages vary with variety, climate, and geographic location (48). Thus, before introducing grape varieties in new regions, environmental effects on phenology should be considered for better technological management (4).

Unfortunately, research on grape phenology in southeastern Buenos Aires, Argentina, is limited, especially when compared to other regions of the country, such as Mendoza (14). In this province, the hilly area of Tandil constitutes a promising region for viticulture. According to Godoy and Gancedo (2022) hilly areas adequately satisfy the thermal needs of Merlot and Cabernet Franc, being Tandil an emerging region. European grape varieties of different cycles and origins are being evaluated in Tandil. According to the National Institute of Viticulture of Argentina (2022), vineyards in Buenos Aires grew by 200% between 2011 and 2021.

Several authors consider a BT of 10 °C to characterize varietal thermal requirements (29, 32, 35, 39). However, this varies with phenology. The optimal growth temperature ranges from 25 to 30°C (9). Above 30°C, growth decelerates, ceasing at approximately 38°C (38). Research on optimal temperature for each developmental stage indicates optimal average daily temperature for budburst above 10-12°C, between 18 and 22°C for flowering, between 22 and 26°C from flowering to veraison, and between 20 and 24°C from veraison to ripening (38).

Methods to calculate DTS are related to cardinal temperatures for plant development or based on air temperature (53). The former are grouped according to whether they only rely on BT or include optimum or upper threshold temperatures for plant development. The latter are grouped according to whether they rely on mean air temperature or also consider minimum and maximum temperatures (40, 51).

Defining phenological stages allows for rationalizing and optimizing cultural practices in vine cultivation (26). This study evaluated thermal requirements of Cabernet Franc, Merlot, Semillón, and Tannat varieties, by different calculation methods in the hilly region of Tandil, Buenos Aires province.

## MATERIALS AND METHODS

The research was conducted at a commercial property called “Viñedo y Bodegas Cordon Blanco,” in Tandil, southeastern Buenos Aires province (37°22'28" S, 59°06'23" W, altitude of 271 m) (figure 1). The 1.8-hectare vineyard was planted in 2008 with 1.8 m between rows, 1.2 m between plants, and 4,700 plants per hectare. It is subdivided into 40 x 25 m plots, with one vine variety per plot. We assessed four plots with Cabernet Franc, Merlot, Semillón, and Tannat. Soil is clayey and climate is temperate-humid with mild summers. Average annual temperature is 14.2°C, and average annual rainfall is 827 mm. Considering vine growing cycle from September to March, average rainfall is 539.5 mm, and average maximum and minimum temperatures are 23.9°C and 9.8°C, respectively (data provided by the National Meteorological Service of Argentina, SMN).

The vineyard was agronomically managed by pruning and phytosanitary controls. The four varieties were grafted onto a ‘101-14 Mgt’ rootstock, a *V. riparia/V. rupestris* hybrid, easy to root and graft, and resistant to *Daktulosphaira vitifoliae* (phylloxera) (31). Starting in 2013, monitoring began from budburst to berry softening during 2013 - 2014, 2016 - 2017, 2018 - 2019, and 2019 - 2020 seasons. Determinations started from the fifth growth cycle, with a fully established crop, selecting five plants from different points within each plot, considered replicates. Phenology related to thermal summation was evaluated chronologically by identifying dates for each event, determining subperiods, in days.



**Figure 1.** Aerial view of the “Cordon Blanco” vineyard, located in Tandil, Buenos Aires province, Argentina, in September 2021.

**Figura 1.** Vista aérea del viñedo “Cordon Blanco”, ubicado en Tandil, Buenos Aires, en septiembre del 2021.

Main phenological stages (24) were identified via Biologische Bundesanstalt Bundessortenamt Chemise (BBCH) scale, including sub-stages 05 (10-15% budburst) to 09 (end of budburst), 65 (flowering), 81 (veraison onset), and 85 (softening of berries, start of grape maturation). Budburst was determined when 50% of buds had visibly burst, at sub-stage 07 in the BBCH scale. Sub-stage 81 (veraison onset) was established by berry color change. Following this phenological scale, varietal growth cycles were evaluated up to sub-stage 85, until berry softening.

Minimum ( $T_{min}$ ) and maximum ( $T_{max}$ ) air temperatures and daily rainfall were obtained from the SMN. Daily mean air temperature ( $T_m$ ) was calculated as the arithmetic mean between daily  $T_{min}$  and  $T_{max}$ . As described, thermal requirements were calculated as the sum of degree-days ( $^{\circ}\text{C d}$ ) for each phenological sub-period and from budburst to ripening. DTS ( $^{\circ}\text{C d}$ ) was determined via six different methods: method 1.1 (12), method 1.2 (52), method 1.3 (45, 47), method 2.1 (34), method 2.3 (28), and method 3 (49, 55). These were grouped according to whether they used only BT (methods 1.1, 1.2, and 1.3), *i.e.* the temperature at which the vine metabolic process is minimum ( $10^{\circ}\text{C}$ ), the optimum temperature (OT) (methods 2.1 and 2.2), or the three cardinal temperatures: BT, OT and upper threshold (TT) (method 3). Table 1 shows all six methods.

**Table 1.** Daily thermal sum (DTS) methods used, equation, calculation concerning temperature parameters, and references.

**Tabla 1.** Método de suma térmica diaria (STD) utilizado con la fórmula final, su base de cálculo en relación con las temperaturas empleadas y la bibliografía asociada a cada método.

| DTS method                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Calculation basis                                                                                                                                                                                                                                                                                                                                                                                                                        | References                                                                                                                                     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>1.1</b><br>$(T_m - 10^{\circ}\text{C}) \times 1 \text{ day}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | If $T_m < 10^{\circ}\text{C}$ , then $T_m = 10^{\circ}\text{C}$                                                                                                                                                                                                                                                                                                                                                                          | Gilmore and Rogers (1958)<br><br>Villa Nova <i>et al.</i> (1972)<br><br>Strecek <i>et al.</i> (2007a, 2007b)<br><br>Paula <i>et al.</i> (2008) |
| <b>1.2</b><br>$(T_m - 10^{\circ}\text{C}) \times 1 \text{ day}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | If $T_{min} \leq 10^{\circ}\text{C}$ , then $T_{min} = 10^{\circ}\text{C}$                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                |
| <b>1.3</b><br>$\text{DTS} = \{[(T_{min} - 10^{\circ}\text{C}) + [(T_{max} - T_{min}) / 2]] \times 1 \text{ day};$<br>$\text{DTS} = \{[(T_{min} - 10^{\circ}\text{C})^2] / [2(T_{max} - T_{min})]\} \times 1 \text{ day};$<br>$\text{DTS} = (0) \times 1 \text{ day}$                                                                                                                                                                                                                                                                           | When $T_{min} > 10^{\circ}\text{C}$<br><br>When $T_{min} < 10^{\circ}\text{C}$<br><br>When $T_{max} < 10^{\circ}\text{C}$                                                                                                                                                                                                                                                                                                                |                                                                                                                                                |
| <b>2.1</b><br>$(T_m - 10^{\circ}\text{C}) \times 1 \text{ day}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | If $T_m < 10^{\circ}\text{C}$ , then $T_m = 10^{\circ}\text{C}$ ; If $T_m > 25^{\circ}\text{C}$ , then $T_m = 25^{\circ}\text{C}$                                                                                                                                                                                                                                                                                                        | Moura <i>et al.</i> (2007)                                                                                                                     |
| <b>2.2</b><br>$(T_m - 10^{\circ}\text{C}) \times 1 \text{ day}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | If $T_{min} \leq 10^{\circ}\text{C}$ , then $T_{min} = 10^{\circ}\text{C}$ ; If $T_{max} > 25^{\circ}\text{C}$ , then $T_{max} = 25^{\circ}\text{C}$                                                                                                                                                                                                                                                                                     |                                                                                                                                                |
| <b>3</b><br>$\text{DTS} = [(T_{max} - 10^{\circ}\text{C})0,5] \times 1 \text{ day};$<br>$\text{DTS} = (0) \times 1 \text{ day};$<br>$\text{DTS} = (T_m - 10^{\circ}\text{C}) \times 1 \text{ day};$<br>$\text{DTS} = \{(25^{\circ}\text{C} - 10^{\circ}\text{C}) \times [(35^{\circ}\text{C} - T_m) / (35^{\circ}\text{C} - 25^{\circ}\text{C})]\} \times 1 \text{ day};$<br>$\text{DTS} = \{(35^{\circ}\text{C} - 25^{\circ}\text{C}) \times [(35^{\circ}\text{C} - T_m) / (35^{\circ}\text{C} - 25^{\circ}\text{C})]\} \times 1 \text{ day}$ | When $T_m < 25^{\circ}\text{C}$ and $T_{min} < 10^{\circ}\text{C}$ ;<br><br>When $T_{max} < 10^{\circ}\text{C}$ ;<br><br>When $T_m < 25^{\circ}\text{C}$ and $T_{min} > 10^{\circ}\text{C}$ ;<br><br>When $T_m > 25^{\circ}\text{C}$ and $T_{max} < 35^{\circ}\text{C}$ ;<br><br>When $T_m > 25^{\circ}\text{C}$ and $T_{max} > 35^{\circ}\text{C}$ , being that if $T_{max} > 35^{\circ}\text{C}$ , then $T_{max} = 35^{\circ}\text{C}$ | Tomazetti <i>et al.</i> (2015)<br><br>Zeist <i>et al.</i> (2017)                                                                               |

$T_{max}$  is maximum temperature,  $T_m$  is mean temperature, and  $T_{min}$  is minimum temperature. Cardinal temperatures are the lower basal temperature ( $10^{\circ}\text{C}$ ), the optimum temperature ( $25^{\circ}\text{C}$ ), and the upper threshold temperature ( $35^{\circ}\text{C}$ ).  $T_{max}$  se refiere a la temperatura máxima,  $T_m$  a la temperatura media y  $T_{min}$  a la temperatura mínima. Las temperaturas cardinales son: Temperatura base inferior ( $10^{\circ}\text{C}$ ), óptima ( $25^{\circ}\text{C}$ ) y umbral superior ( $35^{\circ}\text{C}$ ).

For BT, OT, and TT, 10, 25, and 35°C were adopted respectively (55) (table 1, page 44). Cumulative thermal sum (CTS) for the whole cycle and each subperiod included individual DTS, *i.e.* CTS =  $\Sigma$ DTS (12, 44). Years were considered replicates and varietal CTS was assessed by calculating the standard error of the mean (SE). The SE of the CTS was obtained after calculating the standard deviation of the mean CTS for each year. The thermal requirements needed to complete the cycle and each phenological stage were subjected to ANOVA and compared by Tukey's test, with Infostat software (10) at  $p \geq 0.05$ .

## RESULTS AND DISCUSSION

During the four years, absolute minimum and maximum temperatures fluctuated between -6.5°C and 39.3°C, respectively (table 2). Temperatures below BT (10°C) were recorded in all production cycles (figure 2, page 46), primarily between budburst and flowering onset (BB-FO). During November, coinciding with FO, average maximum temperature was 25°C in all four periods, with an average minimum temperature of 10°C. These conditions fell within the range between BT (10°C) and OT (25°C) (figure 2, page 46). In December, average maximum temperature reached 29°C during FO-VO and 20°C when calculated as mean temperature considering the four growth cycles. Finally, temperatures above TT (35°C) were recorded in all four production cycles, particularly during 2013-2014, on December 23, 24, 28, and 29, and January 6, 15, 17, and 18. Noticeably, total rainfall recorded in 2013 was 762.6 mm, below the historical average of 30 years (889 mm), while in 2014 was 1402 mm, significantly above historical average for Tandil. Table 2 shows 442 mm total rainfall in the last cycle (2019-2020), and during winter before BB, minimum temperature of -7.8°C and rainfall of 18 mm.

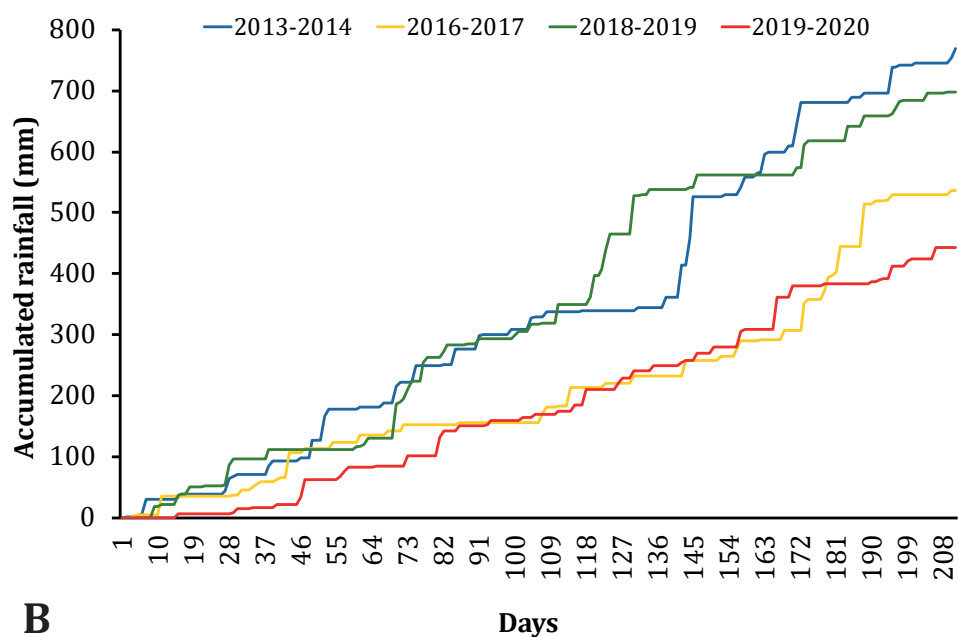
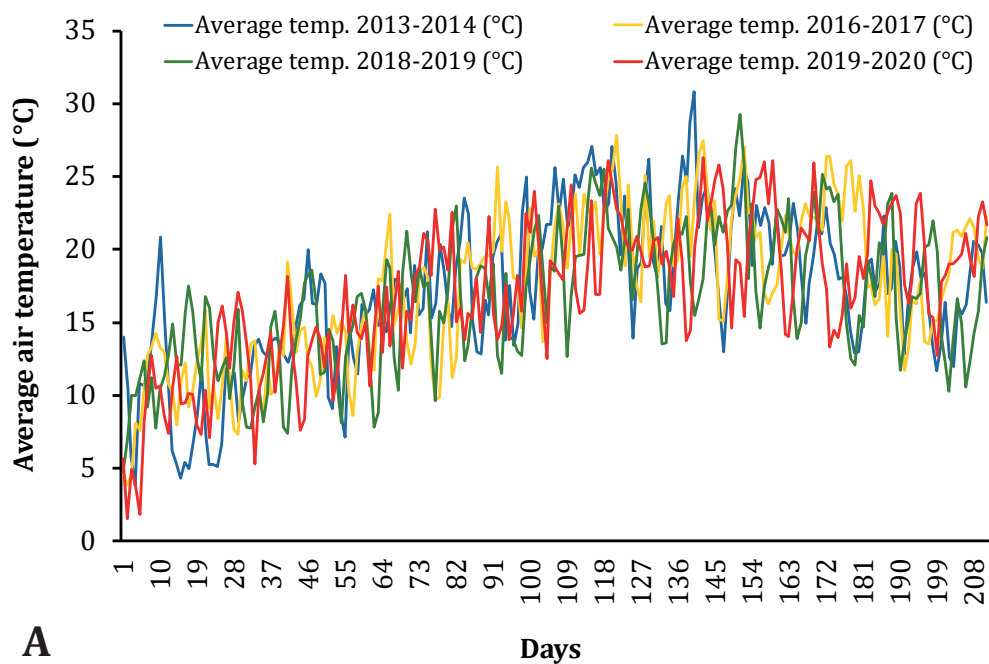
**Table 2.** Phenological evaluation of "Cabernet Franc", "Merlot", "Semillón" y "Tannat" (*Vitis vinífera* L.) in Tandil, Buenos Aires province, from September to February.

**Tabla 2.** Periodos de evaluación fenológica de las 4 variedades de *Vitis Vinífera* L. plantadas en Tandil, Buenos Aires.

Rainfall (mm), mean (Tm), absolute maximum (Tmax), and minimum (Tmin) temperatures (°C) recorded in each growth cycle.  
Precipitaciones (mm), Temperaturas medias (Tmed), máximas (Tmax) y mínimas (Tmin) absolutas (°C) registradas en cada ciclo de crecimiento.

| Period (Sept - Feb.) | Rainfall (mm) | Absolute Tmax (°C) | Absolute Tmin (°C) | Tm (°C) |
|----------------------|---------------|--------------------|--------------------|---------|
| 2013/2014            | 770.1         | 39.3               | -5.6               | 17.1    |
| 2016/2017            | 536.0         | 37.4               | -4.2               | 17.4    |
| 2018/2019            | 697.1         | 34.2               | -2.5               | 16.7    |
| 2019/2020            | 442           | 35.5               | -6.5               | 16.9    |

The complete cycle from BB to M lasted, on average, 161 days for Cabernet Franc, 162 days for Merlot, 161 days for Tannat, and 154 days for Semillón. No differences were observed between varieties ( $p > 0.05$ ). Table 3 (page 47) details phenological dates for all four seasons.



**Figure 2. A.** Average air temperature (°C) and **B.** Accumulated rainfall (mm) from September 1 to the end of March in four seasons, for Cabernet Franc, Merlot, Semillón, and Tannat grapevines (*Vitis vinifera* L.) in Tandil, Buenos Aires province, Argentina.

**Figura 2. A.** Temperaturas medias del aire (°C) y **B.** Precipitaciones acumuladas (mm), desde el 1 de septiembre hasta finales de marzo en cuatro temporadas, para las variedades de vid Cabernet Franc, Merlot, Semillón y Tannat (*Vitis vinifera* L.) en Tandil, provincia de Buenos Aires, Argentina.

**Table 3.** Phenological dates for Semillón, Cabernet Franc, Merlot, and Tannat varieties, recorded during four growing seasons: 2013 - 2014, 2016 - 2017, 2018 - 2019, and 2019 - 2020, in Tandil, Buenos Aires province.

**Tabla 3.** Fechas de los estadios fenológicos observados en las variedades: Semillón, Cabernet Franc, Merlot y Tannat, registrados durante 4 ciclos de cultivo: 2013 - 2014, 2016 - 2017, 2018 - 2019 y 2019 - 2020, en Tandil, Buenos Aires.

| <b>Cv. Semillón</b>       | <b>BB</b> | <b>FO</b> | <b>VO</b> | <b>M</b> |
|---------------------------|-----------|-----------|-----------|----------|
| 2013/2014                 | Sept 16   | Nov 24    | Jan 27    | Feb 24   |
| 2016/2017                 | Sept 15   | Nov 24    | Jan 25    | Feb 20   |
| 2018/2019                 | Sept 24   | Nov 26    | Jan 28    | Feb 28   |
| 2019/2020                 | Oct 7     | Nov 18    | Jan 27    | Feb 24   |
| <b>Cv. Cabernet Franc</b> | <b>BB</b> | <b>FO</b> | <b>VO</b> | <b>M</b> |
| 2013/2014                 | Sept 9    | Nov 16    | Jan 30    | Feb 20   |
| 2016/2017                 | Sept 12   | Nov 21    | Jan 30    | Feb 24   |
| 2018/2019                 | Sept 17   | Nov 26    | Jan 28    | Feb 23   |
| 2019/2020                 | Sept 21   | Nov 18    | Jan 27    | Feb 24   |
| <b>Cv. Merlot</b>         | <b>BB</b> | <b>FO</b> | <b>VO</b> | <b>M</b> |
| 2013/2014                 | Sept 9    | Nov 16    | Jan 31    | Mar 1    |
| 2016/2017                 | Sept 12   | Nov 29    | Jan 25    | Feb 24   |
| 2018/2019                 | Sept 17   | Nov 26    | Jan 28    | Feb 24   |
| 2019/2020                 | Sept 30   | Nov 16    | Jan 27    | Feb 28   |
| <b>Cv. Tannat</b>         | <b>BB</b> | <b>FO</b> | <b>VO</b> | <b>M</b> |
| 2013/2014                 | Sept 9    | Nov 18    | Jan 27    | Feb 26   |
| 2016/2017                 | Sept 12   | Nov 24    | Jan 23    | Feb 25   |
| 2018/2019                 | Sept 24   | Nov 26    | Feb 5     | Feb 28   |
| 2019/2020                 | Sept 30   | Nov 18    | Jan 27    | Feb 26   |

Budburst (BB),  
flowering onset (FO),  
veraison onset (VO), and  
berry softening (M).  
Los eventos fenológicos  
registrados fueron inicio  
de la brotación (IB),  
inicio de la floración  
(IF), inicio del envero  
(IE), y ablandamiento de  
yemas (M).

Methods 2.2 and 3 showed the most precise heat summation adjustments considering the whole cycle in Tannat, Semillón, and Cabernet Franc, given lower standard errors (SE) obtained in the FO-VO subperiod (table 4, page 48). These methods did not statistically differ from each other ( $p > 0.05$ ) but did differ from method 1.2 for all varieties (table 5, page 48-49). Considering method 2.2, CTS for Tannat, Semillón, and Cabernet Franc were 1219, 1182, and 1198°C d, respectively, with SE values of 13.5, 31.5, and 11.78°C d. In contrast, when using method 3, CTS were 1152, 1124, and 1135 C° d, respectively, with SE values of 28.7, 44.8, and 28.1 C° d (table 5, page 48-49). For Merlot, method 3 provided the best adjustment (lowest SE), with 1145 C° d CTS and an SE of 30.4 C° d. For Cabernet Franc and Tannat, medium and medium-late maturing varieties respectively, method 3 also showed a statistical difference of 1.3 ( $p < 0.05$ ) compared to method 2.2 (table 5, page 48-49).

Thermal demands for each subperiod were also calculated after the six thermal summation methods (figure 3, page 49 and figure 4, page 50). Noticeable trends were observed among thermal sums for the four varieties, particularly in the first subperiod (BB-FO), where methods 2.2 and 1.2 had higher CTS values than the other methods (figure 3, page 49). These methods assume that when minimum temperatures are lower than or equal to BT, minimum temperature equals BT and overestimates DTS and CTS, especially in cold months with temperatures below BT. Method 2.1 resulted in the lowest SE in Tannat and Semillón, with CTS values of  $251.2 \pm 16.6$  C° d and  $260.3 \pm 37.9$  C° d, respectively.

**Table 4.** Mean duration of each subperiod (BB-FO, FO-VO, and VO-M, in days), + standard deviation.

**Tabla 4.** Duración media de cada subperiodo en días, con su desvío estándar, IB-IF (días), IF-IE (días), IE-M (días).

| Cv. Semillón       | BB-FO (days) | FO-VO (days) | VO-M (days) |
|--------------------|--------------|--------------|-------------|
| 2013/2014          | 68.4 ± 1.1   | 64.5 ± 2.4   | 26.0 ± 1.4  |
| 2016/2017          | 68.8 ± 2.7   | 65.0 ± 3.7   | 25.4 ± 3.4  |
| 2018/2019          | 61.2 ± 2.4   | 62.6 ± 1.8   | 29.0 ± 2.0  |
| 2019/2020          | 45.0 ± 3.1   | 68.0 ± 4.3   | 26.0 ± 3.7  |
| Cv. Cabernet Franc | BB-FO (days) | FO-VO (days) | VO-M (days) |
| 2013/2014          | 68.4 ± 1.2   | 74.6 ± 3.0   | 21.2 ± 1.7  |
| 2016/2017          | 69.5 ± 1.1   | 69.7 ± 0.5   | 25.6 ± 0.9  |
| 2018/2019          | 70.4 ± 1.8   | 62.7 ± 1.3   | 25.8 ± 0.5  |
| 2019/2020          | 58.0 ± 4.3   | 68.2 ± 3.5   | 28.3 ± 0.5  |
| Cv. Merlot         | BB-FO (days) | FO-VO (days) | VO-M (days) |
| 2013/2014          | 68.6 ± 1.1   | 76.0 ± 0.7   | 27.8 ± 0.8  |
| 2016/2017          | 76.4 ± 4.7   | 58.2 ± 1.1   | 29.0 ± 1.4  |
| 2018/2019          | 71.8 ± 3.5   | 61.2 ± 3.7   | 26.2 ± 1.3  |
| 2019/2020          | 50.0 ± 5.7   | 70.7 ± 3.2   | 31.7 ± 0.6  |
| Cv. Tannat         | BB-FO (days) | FO-VO (days) | VO-M (days) |
| 2013/2014          | 70.0 ± 3.5   | 69.0 ± 3.4   | 30.0        |
| 2016/2017          | 73.3 ± 1.3   | 60.3 ± 0.5   | 31.8 ± 1.8  |
| 2018/2019          | 62.5 ± 3.3   | 70.0 ± 0.5   | 24.0 ± 2.0  |
| 2019/2020          | 47.2 ± 3.6   | 69.7 ± 1.7   | 32.5 ± 2.1  |

The table the average duration of each subperiod in days, along with its standard deviation: BB-FO (days), FO-VO (days), VO-M (days).

La tabla expresa la duración media de cada subperiodo en días, con su desvío estándar, IB-IF (días), IF-IE (días), IE-M (días).

**Table 5.** Average cumulative thermal sum (CTS) calculated for each subperiod (BB - FO, FO - VO, and VO - M) and the BB-M period for the four varieties by six methods of calculation of daily thermal sum (DTS).

**Tabla 5.** Suma térmica acumulada (STA) media calculada para cada subperíodo (IB - IF, IF - IE, IE - M) y para el período IB - M, para las 4 variedades, utilizando los 6 métodos de cálculo de la suma térmica diaria (STD).

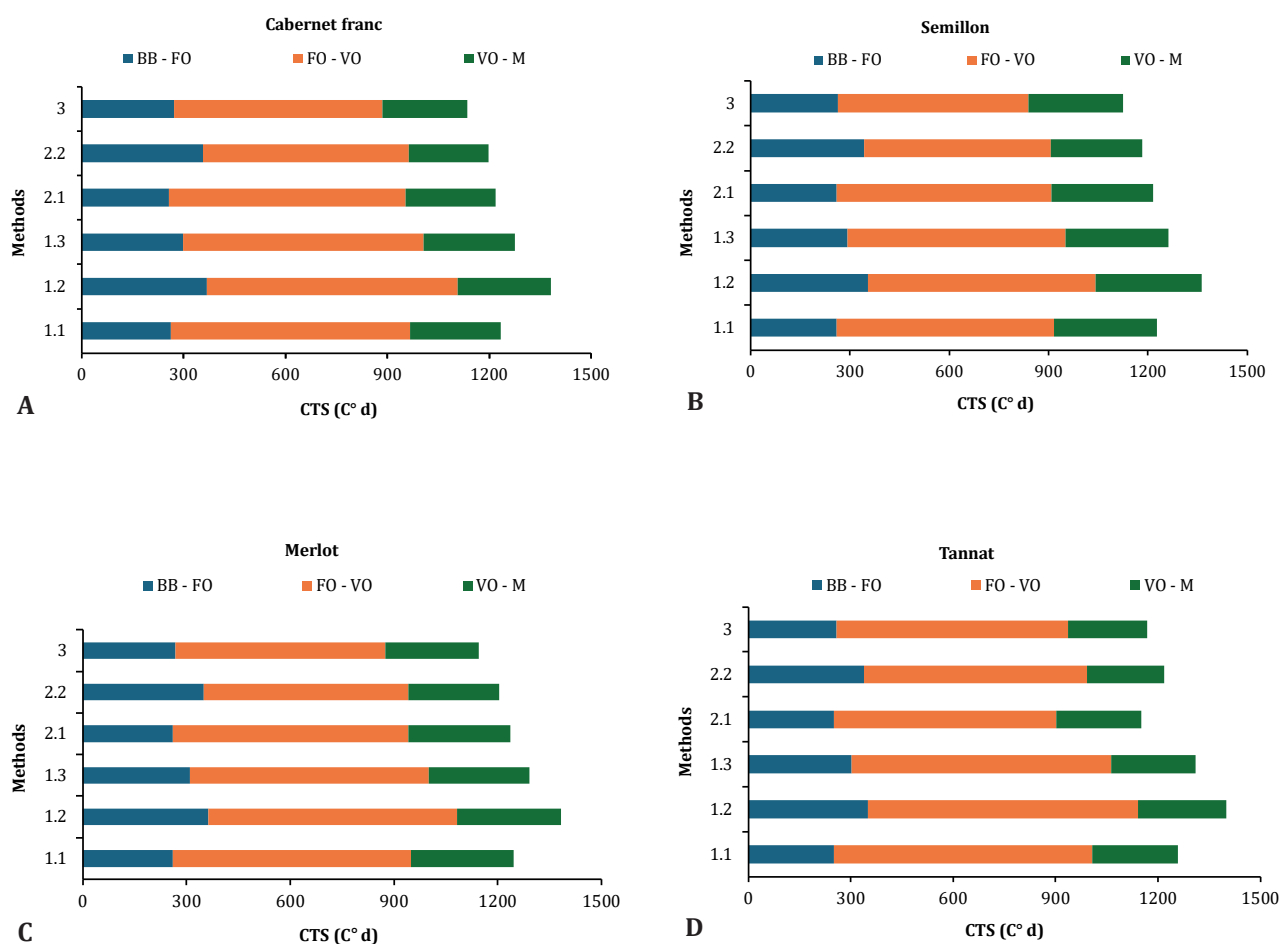
| DTS method | Varieties  | Average CTS for BB-M (C° d) | Average CTS for BB-FO (C° d) | Average CTS for FO-VO (C° d) | Average CTS for VO-M (C° d) |
|------------|------------|-----------------------------|------------------------------|------------------------------|-----------------------------|
| 1.2        | Merlot     | 1383 a                      | 362.1                        | 720.1                        | 301.6                       |
| 1.3        | Merlot     | 1299 ab                     | 309.4                        | 691.1                        | 292.0                       |
| 1.1        | Merlot     | 1245 ab                     | 259.9                        | 688.9                        | 296.9                       |
| 2.1        | Merlot     | 1235 ab                     | 260.5                        | 681.0                        | 294.2                       |
| 2.2        | Merlot     | 1189 b                      | 349.8                        | 592.4                        | 262.2                       |
| 3          | Merlot     | 1145 b                      | 268.8                        | 606.5                        | 269.4                       |
| 1.2        | Semillón   | 1362 a                      | 355.4                        | 686.2                        | 320.7                       |
| 1.3        | Semillón   | 1261 ab                     | 292.6                        | 658.1                        | 310.7                       |
| 1.1        | Semillón   | 1226 ab                     | 260.3                        | 656.1                        | 310.2                       |
| 2.1        | Semillón   | 1215 ab                     | 260.3                        | 648.1                        | 307.6                       |
| 2.2        | Semillón   | 1182 b                      | 343.2                        | 562.9                        | 276.0                       |
| 3          | Semillón   | 1124 b                      | 264.0                        | 574.8                        | 285.4                       |
| 1.2        | Cab. Franc | 1381 a                      | 369.0                        | 737.9                        | 274.3                       |

Different letters in columns indicate statistical differences ( $p > 0.05$ ).

Valores en las columnas seguidos de la misma letra, no difieren entre sí por la prueba de Tukey ( $p > 0,05$ ).

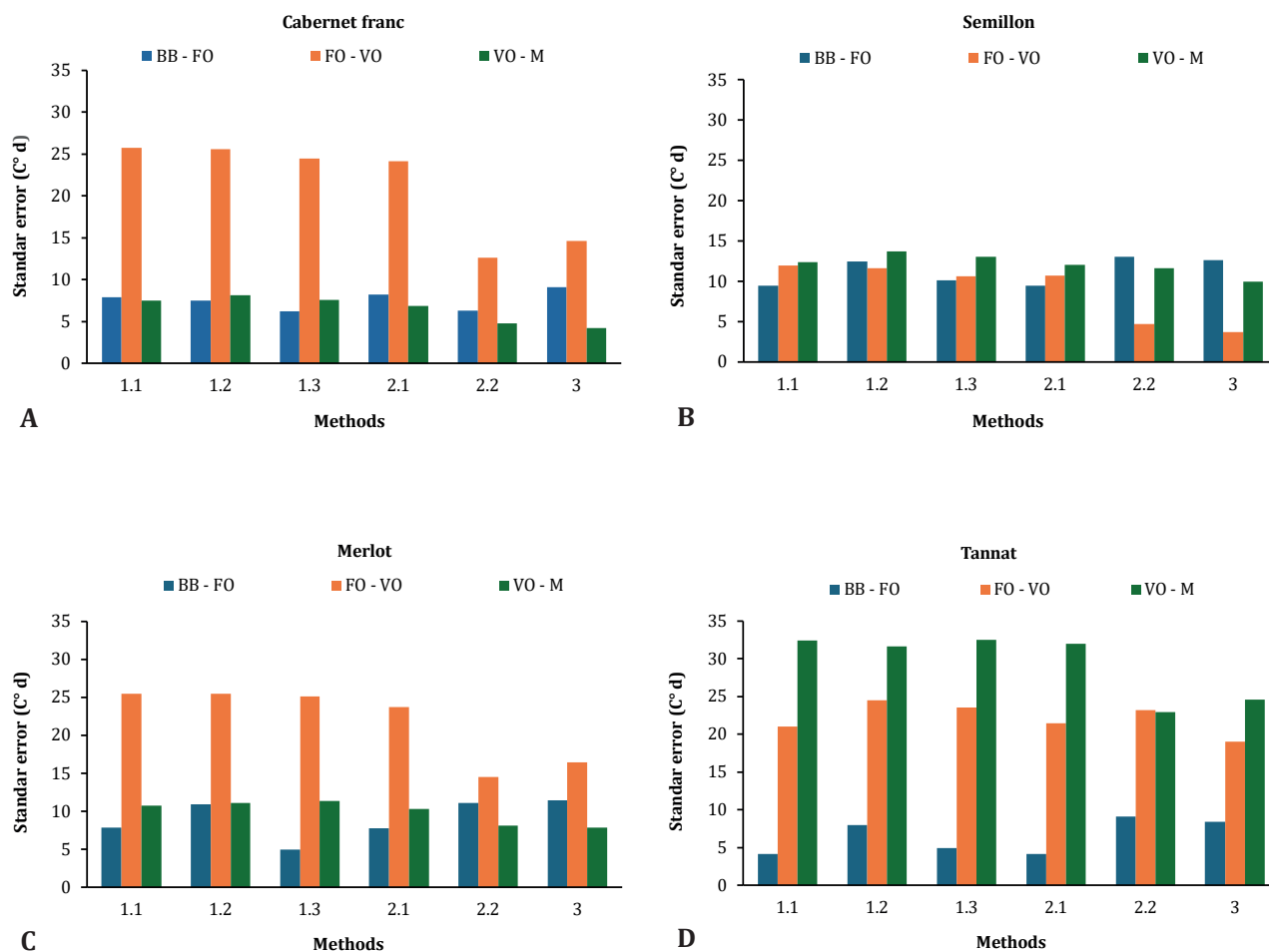
Different letters in columns indicate statistical differences ( $p > 0.05$ ).  
Valores en las columnas seguidos de la misma letra, no difieren entre sí por la prueba de Tukey ( $p > 0,05$ ).

|     |            |         |       |       |       |
|-----|------------|---------|-------|-------|-------|
| 1.3 | Cab. Franc | 1275 ab | 299.2 | 706.9 | 269.2 |
| 1.1 | Cab. Franc | 1234 bc | 262.3 | 704.0 | 267.8 |
| 2.1 | Cab. Franc | 1218 bc | 258.1 | 696.1 | 264.9 |
| 2.2 | Cab. Franc | 1198 bc | 357.6 | 605.5 | 234.4 |
| 3   | Cab. Franc | 1135 c  | 272.4 | 613.5 | 248.9 |
| 1.2 | Tannat     | 1399 a  | 349.8 | 791.1 | 258.4 |
| 1.3 | Tannat     | 1310 ab | 302.2 | 759.9 | 248.4 |
| 1.1 | Tannat     | 1259 bc | 251.2 | 757.2 | 250.5 |
| 2.1 | Tannat     | 1150 bc | 251.2 | 650.1 | 249.3 |
| 2.2 | Tannat     | 1219 bc | 339.0 | 654.0 | 225.7 |
| 3   | Tannat     | 1152 c  | 259.1 | 678.2 | 230.7 |



**Figure 3.** Cumulative thermal sum (CTS,  $^{\circ}\text{C d}$ ) calculated for each subperiod: budburst to flowering onset (BB-FO), flowering to veraison (FO - VO), and veraison to berry softening (VO - M), by six methods (1.1, 1.2, 1.3, 2.1, 2.2, and 3) estimating STD in Cabernet Franc, Semillón, Merlot, and Tannat, in Tandil, Buenos Aires province.

**Figura 3.** Suma térmica acumulada (STA,  $^{\circ}\text{C d}$ ) calculada para cada subperíodo: inicio de la brotación - inicio de la floración (IB - IF), inicio de la floración - inicio del envero (IF - IE), inicio del envero - ablandamiento de bayas (IE - M), utilizando seis métodos (1.1, 1.2, 1.3, 2.1, 2.2, y 3), estimando la STA en las variedades Cabernet Franc, Semillón, Merlot y Tannat, en Tandil, provincia de Buenos Aires.



**Figure 4.** Standard error (SE) of cumulative thermal sum (CTS, °C d) for each subperiod: budburst to flowering (BB - FO), flowering to veraison (FO - VO) and veraison to berry softening (VO - M). Six methods (1.1, 1.2, 1.3, 2.1, 2.2, and 3) estimated daily thermal sum (DTS) in Cabernet Franc, Semillón, Merlot, and Tannat in Tandil, Buenos Aires province.

**Figura 4.** Error estándar (ES) de la suma térmica acumulada (STA, °C d) para cada subperíodo: inicio de la brotación - inicio de la floración (IB - IF), inicio de la floración - inicio del envero (IF - IE), inicio del envero - ablandamiento de bayas (IE - M). Seis métodos (1.1, 1.2, 1.3, 2.1, 2.2 y 3) estimaron la suma térmica diaria (STD) en las variedades Cabernet Franc, Semillón, Merlot y Tannat en Tandil, provincia de Buenos Aires.

In Semillón, no difference was found among methods ( $p > 0.05$ ), whereas in Tannat, however, method 2.1 differed from methods 1.2 and 2.2 ( $p < 0.05$ ). In Cabernet Franc, methods 1.3 and 2.2 yielded similar SE values (6.2°C d), with CTS 300 °C d and 357 °C d, respectively, while in Merlot method 1.3 yielded a lower SE (figure 4), and no differences with methods 2.2 and 3 ( $p > 0.05$ ). Overall, methods 2.2 and 1.2 had significantly ( $p > 0.05$ ) higher CTS values for this subperiod (BB - FO), while method 2.1 yielded the lowest CTS for Tannat and Semillón. Additionally, Tannat had a significantly different CTS calculated using method 2.1 from the estimated using methods 1.2 and 2.2 ( $p < 0.05$ ). Although these variations between methods showed no differences for most varieties, they suggest that calculation method influences CTS estimation. Considering Cabernet Franc and Merlot, BB occurred on September 15 and 17, respectively, averaging four observation cycles (table 3, page 47). In other regions of South America, such as southern Brazil, BB for Merlot and Cabernet Franc

occurs around September 13 (26). Additionally, during 2018-19 and 2019-20, a two-week delayed BB was observed compared to previous years (table 3, page 47). This delay could be attributed to the lower temperatures recorded toward the end of winter, along with lower precipitation (figure 2, page 46), considering varietal BB phenological pattern is primarily influenced by air temperature (26).

The longest subperiod (63 - 91 days) with the highest thermal sum requirement was FO-VO, in all four varieties. Minimum SE for this subperiod was recorded for methods 2.2 and 3. Considering Merlot, Cabernet Franc, and Tannat, no statistical differences were observed with the other methods (figure 4, page 50). However, for Semillón, methods 2.2 and 3 showed differences in SE (figure 4, page 50) and CTS (table 4, page 48) compared to methods 1.1, 1.2 and 1.3 ( $p < 0.05$ ). Merlot had CTS  $\pm$  SE of  $592.2 \pm 14.5$  °C d with method 2.2 and  $606.5 \pm 16.4$  °C d with method 3. Semillón, showed  $562.9 \pm 4.7$  °C d with method 2.2 and  $574.8 \pm 3.7$  °C d with method 3. Cabernet Franc had CTS  $605.5 \pm 12.6$  °C d with method 2.2 and  $613.5 \pm 14.6$  °C d with method 3. Finally, CTS in Tannat was  $662.5 \pm 19.0$  °C d with method 3. Considering Tannat, all six methods showed high SE (figure 4, page 50).

The VO-M subperiod showed no statistical differences among methods ( $p > 0.05$ ) or the four varieties. However, method 3 yielded the best fit in three varieties (figure 4, page 50). In detail, CTS  $\pm$  SE for Merlot, Cabernet Franc, and Semillón were  $269.4 \pm 7.9$  °C d,  $248.9 \pm 4.2$  °C d, and  $285.4 \pm 10.0$  °C d respectively. Instead, in the VO-M subperiod, Tannat showed higher SE than the other varieties while, with method 2.2, it obtained the minimum SE (figure 4, page 50) with CTS of  $225.7 \pm 24.6$  °C d. This late variety had a delayed VO in the last two cycles (table 3, page 47). Between February 20 and March 1, 50% of the plants of all varieties (table 3, page 47) were at sub-stage 89. Harvesting occurred later, particularly in the intermediate to late varieties. As latitude increases, more days are needed to reach a particular phenological stage (3).

Methods 1.1, 1.2, and 1.3 generated higher SE values for the four varieties. This lower methodological efficiency in representing thermal accumulation has been previously reported in southern Brazil (49). These three methods, based only on BT, showed higher variability (high SE) in CTS estimation than methods considering OT (methods 2.1 and 2.2) and TT (method 3). In other crops like wheat, Rosa *et al.* (2009) found that methods incorporating daily minimum and maximum air temperature to cardinal temperatures, improved phenological simulation. Our results indicate greater accuracy in calculating the thermal sum via methods including OT and TT in addition to BT. Therefore, we discourage methods based solely on the BT, especially considering that, during summer, higher temperatures can affect plant metabolism (45, 49).

These results suggest that, concerning grapevine development and climate change scenarios, simulations should use methods 2.1, 2.2, and 3. This is particularly relevant for Buenos Aires and its frequent extreme climatic events (6). Future scenarios predict increasing average air temperature in several regions of the planet (19), with negative consequences for viticulture (52). This acceleration of climate change invalidates old phenological calculations based on number of days (8, 22). Recent studies have shown significant correlations between temperature increase and earlier beginning of several stages in grapevine (1), with shortened phenological stages (3, 20, 41). Some prominent phenological changes suggest a significantly reduced anthesis-ripening duration (26). Besides reduced vine growth and yields, other possible undesirable implications for the wine industry include changes in wine quality (11, 37, 50, 52). In this context, considering that grapevine phenology is a crucial indicator of environmental impacts (7), accurate estimations of thermal requirements based on cardinal temperatures can be beneficial, regardless of the time required to satisfy them (33).

Considering methods 2.2 and 3, both demonstrating the lowest SE in the CTS, the varieties evaluated exhibited no statistical differences in thermal requirements during FO-VO and VO-M. Both methods estimated SE from 0.77 to 1.66 days for FO-VO and from 0.47 to 1.47 days for VO-M for Cabernet Franc, Merlot, and Semillón, indicating relatively low dispersion compared to the other four methods, where SE was twice higher. For Tannat, SE was two days, using these methods and approximately four days with the remaining four methods, in both subperiods. In BB-FO, the lowest SE was 1.18 days by method 2.2 for Cabernet Franc, while SE for the other varieties, was higher.

Our results provide information on thermal requirements of four grapevine varieties at different phenological stages in the region of Tandil, center Buenos Aires, Argentina. The use of degree-days improved phenological prediction, compared to other approaches considering days between phenological events (23). Considering the onset of autumn in our region, high humidity levels and low evapotranspiration may negatively affect fruit quality. Therefore, harvest should occur before the end of March. Future research should determine thermal requirements for maturity and harvest, contributing to climate risk mitigation and definition of optimal harvest time.

## CONCLUSION

According to method 3, Merlot, Cabernet Franc, Semillón, and Tannat grown in Tandil require 1145, 1135, 1125, and 1153 °C d, respectively, to reach BBCH sub-stage 85.

The period between budburst and flowering onset showed the highest variability in thermal sum when comparing six methods for thermal requirement determination.

We conclude that methods 2.2 and 3 most accurately estimate cumulative daily heat summation in these varieties, in Tandil, using optimum temperature and upper threshold temperature for *Vitis vinifera* L.

Method 2.2 was accurate in this specific region, given the low frequency of temperatures above 35°C during the periods evaluated. Considering changes in climatic events in the center of Buenos Aires, we recommend models capable of recording daily variations in maximum and minimum temperatures. Further research will determine thermal requirements of different grapevine varieties in this region, especially between veraison and harvest.

## REFERENCES

1. Alikadic, A.; Pertot, I.; Eccel, E.; Dolcia, C.; Zarbo, C.; Caffarra, A.; De Filippi, R.; Furlanello, C. 2019. The impact of climate change on grapevine phenology and the influence of altitude: A regional study. *Agric. For. Meteorol.* 271: 73-82.
2. Almanza, P.; Serrano, P.; Fischer, G. 2012. Manual de viticultura tropical. Grupo Imprenta y Publicaciones UPTC. Tunja. Colombia. 120 p.
3. Antonacci, D.; Ramos, J.; Dalla, J. 2001. Influenza della disponibilità termica sulle manifestazioni fenologiche della vite in diverse aree di produzione dei due emisferi. *Frutticoltura e di ortofloricoltura*. 63(12): 65-72.
4. Anzanello, R.; Souza, P. V. D. de; Coelho P.F. 2012. Fenologia, exigência térmica e produtividade de videiras 'Niagara Branca', 'Niagara Rosada' e 'Concord' submetidas a duas safras por ciclo vegetativo. *Revista Brasileira de Fruticultura*. 34: 366-376.
5. Bem, B. P. de; Bogo, A.; Everhart, S.; Casa, R. T.; Gonçalves, M. J.; Marcon Filho, J. L.; Cunha, I. C. da. 2015. Effect of Y-trellis and vertical shoot positioning training systems on downy mildew and botrytis bunch rot of grape in highlands of southern Brazil. *Scientia Horticulturae*. 185: 162-166. DOI: 10.1016/j.scienta.2015.01.023
6. Confalone, A.; Navarro, M.; Vilatte, C.; Aguas, L.; Lázaro, L.; Mestelan, S.; Sau, F. 2016. Parametrización y uso del modelo CROPGRO -soja en Azul, Buenos Aires. *Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. Mendoza. Argentina*. 48(1): 49-64.
7. Bernardo, S.; Dinis, L. T.; Machado, N.; Moutinho-Pereira, J. 2018. Grapevine abiotic stress assessment and search for sustainable adaptation strategies in Mediterranean-like climates. A review. *Agron. Sustain.* 38(66).
8. Bock, A.; Sparks, T.; Estrella, N.; Menzel, A. 2011. Changes in the phenology and composition of wine from Franconia, Germany. *Clim. Res.* 50: 69-81.
9. Del Barrio, R. A.; Gallo, S. L.; Martin, D. M. 2016. Aspectos bio y agroclimáticos del cultivo de vid para vinificar en el Valle Inferior del Río Negro. *RIA. Rev. Investig. Agropecu.* 42(3): 283-290. [http://www.scielo.org.ar/scielo.php?script=sci\\_arttext&pid=S1669-23142016000300008&lng=es&nrm=iso](http://www.scielo.org.ar/scielo.php?script=sci_arttext&pid=S1669-23142016000300008&lng=es&nrm=iso)
10. Di Rienzo, J. A.; Casanoves, F.; Balzarini, M. G.; Gonzalez, L.; Tablada, M.; Robledo, C. W. 2019. InfoStat versión 2019. Centro de Transferencia InfoStat, FCA. Universidad Nacional de Córdoba. Argentina. <http://www.infostat.com.ar>
11. Fraga, H.; Malheiro, A. C.; Moutinho-Pereira, J.; Santos, J. A. 2012. Future scenarios for viticultural zoning in Europe: Ensemble projections and uncertainties. *Int. J. Biometeorol.* 57: 909-925.
12. Gilmore, E.; Rogers, J. S. 1958. Heat units as a method of measuring maturity in corn. *Agron. J.* 50: 611-615.
13. Godoy Baduino, C. A.; Gancedo Desgens, E. 2022. Aptitud vitícola del sudeste bonaerense en base a índices bioclimáticos. *Rev. Facultad de Agronomía UBA*. 42(2): 7-12.

14. Gomez Talquenca, S.; Lanza Volpe, M.; Setien, N.; Gracia, O.; Grau, O. 2023. Serological relationships among strains of grapevine leafroll-associated virus 4 reflect the evolutive behavior of its coat protein gene. *Revista de la Facultad de Ciencias Agrarias*. Universidad Nacional de Cuyo. Mendoza. Argentina. 55(1): 104-114. DOI: <https://doi.org/10.48162/rev.39.100>.
15. Gris, E. F.; Burin, V. M.; Brighenti, E.; Vieira, H.; Bordignon-Luiz, M. T. 2010. Fenología y maduración de las variedades de *Vitis vinifera* L. de uva en São Joaquim, sur de Brasil: una nueva región de cultivo de la vid en América del Sur. *Cien. Inv. Agr.* 37(2): 61-75.
16. Hidalgo, L. 2002. Tratado de viticultura general. Ediciones Mundi-Prensa, Madrid.
17. Ibacache G. A. 2008. Cómo influye la temperatura sobre la época de cosecha en vides [en línea]. *Tierra Adentro*. 81: 8-10. <https://hdl.handle.net/20.500.14001/6416> (Consultado: 30 abril 2024).
18. Instituto Nacional de Vitivinicultura. 2022. Informe elaborado por el laboratorio estadístico del Instituto Nacional de Vitivinicultura. Registro de viñedos y superficie. Mendoza.
19. IPCC 2022: Climate Change 2022: Mitigation of climate change. Contribution of working Group III to the sixth assessment report of the intergovernmental panel on climate change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press. Cambridge. UK and New York. NY. USA. DOI: 10.1017/9781009157926
20. Jones, G. V.; Alves, F. 2012. Impact of climate change on wine production: A global overview and regional assessment in the Douro Valley of Portugal. *Int. J. Glob. Warm.* 4: 383-406.
21. Jubileu, B. S.; Sato, A. J.; Roberto, S. R. 2010. Caracterização fenológica e produtiva das videiras 'Cabernet Sauvignon' e 'Alicante' (*Vitis vinifera* L.) produzidas fora de época, no norte do Paraná. *Revista Brasileira de Fruticultura*. 32: 451-462.
22. Labbé, T.; Pfister, C.; Brönnimann, S.; Rousseau, D.; Franke, J.; Bois, B. 2019. The longest homogeneous series of grape harvest dates, Beaune 1354-2018, and its significance for the understanding of past and present climate. *Clim. Past*. 15: 1485-1501. DOI: 10.5194/cp-15-1485-2019
23. Li, Z.; Huang, H.; Duan, Z.; Zhang, W. 2023. Control temperature of greenhouse for higher yield and higher quality grapes production by combining STB *in situ* service with on time sensor monitoring. *Heliyon*. 9(2): e13521.
24. Lorenz, D. H.; Eichhorn, K. W.; Blei-Holder, H.; Klose, R.; Meier, U.; Weber, E. 1994: Phänologische Entwicklungsstadien der Weinrebe (*Vitis vinifera* L. ssp. *vinifera*). *Vitic. Enol. Sci.* 49: 66-70.
25. Lucas, D. D. P.; Streck, N. A.; Bortoluzzi, M. P.; Trentin, R.; Maldaner, I. C. 2012. Temperatura base para emissão de nós e plastocrono de plantas de melancia. *Revista Ciência Agronômica*. 43: 288-292. DOI: 10.1590/S1806-66902012000200011
26. Mandelli, F.; Berlato, M. A.; Tonietto, J.; Bergamaschi, H. 2003. Fenologia da videira na Serra Gaúcha. *Pesquisa Agropecuária Gaúcha*. 9: 129-144.
27. Moriondo, M.; Bindi, M. 2007. Impact of climate change on the phenology of typical Mediterranean crops. *Ital. J. Agrometeorol.* 3: 5-12.
28. Moura, M. S. B. de; Brandao, E. O.; Soares, J. M.; Donosco, C. S.; Silva, T. G. F. da; Souza, L. S. B. 2007. Exigência térmica e caracterização fenológica da videira Cabernet Sauvignon no Vale São Francisco, Brasil. Congreso Latinoamericano de Viticultura y Enología. Mendoza. Seduciendo al consumidor de hoy. Mendoza: IVV: CLEIFRA: SECYT. 2007.
29. Nagata, R. K.; Scarpate Filho, J. A.; Kluge, R. A.; Nova, N. A. V. 2000. Temperatura base e soma térmica (graus-dia) para videiras 'Brasil' e 'Benitaka'. *Revista Brasileira de Fruticultura*, Cruz das Almas. 22(3): 329-333.
30. Nikolaou, K. E.; Chatzistathis, T.; Theocharis, S.; Argiriou, A.; Koundouras, S.; Zioziou, E. 2022. Cultivars Effects of chromium toxicity on physiological performance and nutrient uptake in two grapevine cultivars (*Vitis vinifera* L.) growing on own roots or grafted onto different rootstocks. *Horticulturae*. 8(6): 493. <https://doi.org/10.3390/horticulturae8060493>
31. Nikolaou, K. E.; Chatzistathis, T.; Theocharis, S.; Argiriou, A.; Koundouras, S. 2023. Physiological and nutritional responses of ungrafted merlot and cabernet sauvignon vines or grafted to 101-14 Mgt and 1103P rootstocks exposed to an excess of boron. *Horticulturae*. 9(4): 508. <https://doi.org/10.3390/horticulturae9040508>
32. Oliveira, M. 1998. Calculation of budbreak and flowering base temperatures for *Vitis vinifera* cv. Touriga Francesa in the Douro Region of Portugal. *Am. J. Enol. Vitic.* 49: 74-78.
33. Parker, A. K.; García de Cortázar-Atauri, I.; Gény, L.; Spring, J. L.; Destrac, A.; Schultz, H.; Molitor, D.; Lacombe, T.; Graça, A.; Monamy, C.; Stoll, M.; Storchi, P.; Trought, M. C. T.; Hofmann, R. W.; van Leeuwen, C. 2020. Temperature-based grapevine sugar ripeness modelling for a wide range of *Vitis vinifera* L. cultivars. *Agric. For. Meteorol.* 285-286:107902. doi: 10.1016/j.agrformet.2020.107902
34. Paula, G. M. de; Streck, N. A. 2008. Temperatura base para emissão de folhas e nós, filocrono e plastocrono das plantas daninhas papua e corriola. *Ciência Rural*. 38: 2457-2463.
35. Pedro Júnior, M. J.; Sentelhas, P. C.; Pommer, C. V.; Martins, F. P. 1994. Determinação da temperatura-base, graus-dia e índice biometeorológico para a videira 'Niagara Rosada'. *Revista Brasileira de Agrometeorologia*, Santa Maria. 2: 51-56.
36. Radünz, A. L.; Schöffel, E. R.; Borges, C. T.; Malgarim, M. B.; Pötter, G. H. 2015. Necessidades térmicas de videiras na região da Campanha do Rio Grande do Sul - Brasil. *Ciência Rural*. 45: 626-632. DOI: 10.1590/0103-8478cr20140134

37. Reyes, M. 2015. Informe proyecto "Aseguramiento de la sustentabilidad de la viticultura nacional frente a los nuevos escenarios que impone el cambio climático". Código 502063-70. Centro Regional de Investigación Raihuen.
38. Reynier, A. 2005. 6ª ed. Manual de Viticultura. Mundi-Prensa. Madrid. España. 497 p.
39. Roberto, S. R.; Sato, A. J.; Brenner, E. A.; Jubilei, B. S.; Santos, C. E.; Genta, W. 2005. Caracterização fenológica e exigência térmica (graus-dia) para a uva 'Cabernet Sauvignon' em zona subtropical. *Acta Scientiarum Agronomy*. 27(1): 183- 187.
40. Rosa, H. T.; Walter, L. C.; Streck, N. A.; Alberto, C. M. 2009. Métodos de soma térmica e datas de semeadura na determinação de filocrono de cultivares de trigo. *Pesquisa Agropecuária Brasileira*. 44: 1374-1382.
41. Santos, C. E. dos; Roberto, S. R.; Sato, A. J.; Jubileu, B. da S. 2007. Caracterização da fenologia e da demanda térmica das videiras 'Cabernet Sauvignon' e 'Tannat' para a região norte do Paraná. *Acta Scientiarum. Agronomy*. 29: 361-366.
42. Sato, A. J.; Jubileu, B. da S.; Assis, A. M. de; Roberto, S. R. 2011. Fenologia, produção e composição do mosto da 'Cabernet sauvignon' e 'Tannat' em clima subtropical. *Revista Brasileira de Fruticultura*. 33: 491-499. DOI: 10.1590/S0100-29452011005000079
43. Stenzel, N. M. C.; Neves, C. S. V. J.; Marur, C. J.; Scholz, M. B. d. S.; Gomes, J. C. 2006. Maturations curves and degree-days accumulation for fruits of "Folha Murcha" orange trees. *Sci. Agric*. 63(3): 219-225.
44. Streck, N. A.; Tibola, T.; Lago, I.; Buriol, G. A.; Heldwein, A. B.; Schneider, F. M.; Zago, V. 2005. Estimativa do plastocrono em meloeiro (*Cucumis melo* L.) cultivado em estufa plástica em diferentes épocas do ano. *Ciência Rural*. 35: 1275-1280.
45. Streck, N. A.; Alberto, C. M. 2006. Estudo numérico do impacto da mudança climática sobre o rendimento de trigo, soja e milho. *Pesquisa Agropecuária Brasileira*. 41: 1351-1359.
46. Streck, N. A.; Michelin, S.; Rosa, H. T.; Walter, L. C.; Bosco, L. C.; Paula, G. M. de; Camera, C.; Samboranza, F. K.; Marcolin, E.; Lopes, S. J. 2007a. Filocrono de genótipos de arroz irrigado em função da época de semeadura. *Ciência Rural*. 37: 323-329.
47. Streck, N. A.; Paula, F. L. M. de; Bisognin, D. A.; Heldwein, A. B.; Dellai, J. 2007b. Simulating the development of field grown potato (*Solanum tuberosum* L.). *Agricultural and Forest Meteorology*. 142: 1-11. DOI: 10.1016/j.agrformet.2006.09.012
48. Tesic, D.; Woolley, D. J.; Hewett, E. W.; Martin, D. J. 2001. Environmental effects on cv Cabernet Sauvignon (*Vitis vinifera* L.) grown in Hawke's Bay, New Zealand: 2. Development of a site index. *Australian journal of grape and wine research*. 8(1): 27-35.
49. Tomazetti, T. C.; Rossarolla, M. D.; Zeist, A. R.; Giacobbo, C. L.; Welter, L. J.; Alberto, C. M. 2015. Fenologia e acúmulo térmico em videiras viníferas na região da Fronteira Oeste do Rio Grande do Sul. *Pesquisa Agropecuária Brasileira*. 50: 1033-1041.
50. Van Leeuwen, C.; Destrac-Irvine, A.; Dubernet, M.; Duchêne, E.; Gowdy, M.; Marguerit, E.; Pieri, P.; Parker, A.; De Ressaiguier, L.; Ollat, N. 2019. An update on the impact of climate change in viticulture and potential adaptations. *Agronomy*. 9: 514.
51. Venios, X.; Korkas, E.; Nisiotou, A.; Banilas, G. 2020. Grapevine responses to heat stress and global warming. *Plants*. 9(12): 1754. <https://doi.org/10.3390/plants9121754>
52. Villa Nova, N. A.; Pedro Jr, M. J.; Pereira, A. R.; Ometto, J. C. 1972. Estimativa de graus-dia acumulados acima de qualquer temperatura base, em função das temperaturas: máximas e mínimas. *Caderno de Ciências da Terra*. São Paulo. 30: 1-8.
53. Villaseca, S.; Novoa, R.; Muñoz, I. 1986. Fenología y sumas de temperatura en 24 variedades de vid. *Agricultura Técnica*. Chile. 46: 63-67. <https://hdl.handle.net/20.500.14001/41010>
54. Zapata, D.; Salazar-Gutierrez, M.; Chaves, B.; Keller, M.; Hoogenboom, G. 2017. Predicting key phenological stages for 17 grapevine cultivars (*Vitis vinifera* L.). *American Journal Enology and Viticulture*. 68: 60-72. DOI: 10.5344/ajev.2016.15077
55. Zeist, A. R.; Tomazetti, T. C.; Rossarolla, M. D.; Alberto, C. M.; Giacobbo, C. L.; Welter, L. J. 2017. Plastochron index of 'Cabernet Sauvignon' and 'Chardonnay' grapevines in Fronteira Oeste, in the state of Rio Grande do Sul, Brazil. *Pesquisa Agropecuária Brasileira*. 52(4): 244-251. <https://doi.org/10.1590/S0100-204X2017000400004>