COMPARISON OF VARIOUS EFFECTIVE HEAT SUMMATION REQUIREMENT (GROWING DEGREE-DAY) CALCULATION METHODS ON DIFFERENT GRAPE CULTIVARS

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Abstract. Grapes are a fruit species that has attracted attention due to its proven positive effects on human health. However, vineyards will have to be relocated to new regions in the near future due to the increasing effects of global climate change. Although it is known that the genotypic differences of grape cultivars allow them to exhibit phenotypic plasticity in new ecologies, the suitability of different grape cultivars for new ecologies needs to be estimated via numerical data with high accuracy. In this study, the effective heat summation requirement (EHSR) values of 12 grape cultivars grown in the Adıyaman province of Turkey, in between different phenological growth stages were determined using 3 different daily average temperature (DAT) calculation methods and 3 different EHSR calculation methods. The results showed that the EHSR values of the grape cultivars changed according to the methods used to determine them, but the order among the grape cultivars was constant. The DAT-1 (24-h temperature average) and DAT-2 (daily max. and min. temperature average) methods can be used interchangeably to determine the EHSR values of grapes. The Winkler index was found to be the most appropriate of the methods tested, it clarified the differences between grape cultivars, was affected by daily temperature extremes to a lesser extent, and measured the heat summation requirements between the bud burst (BB) and full bloom (FB) stages in grapevines most accurately. In addition, according to the EHSR value, there was a weak linear relationship between the BB-FB and veraison (V)-maturity (M) stages and a strong linear relationship between the FB-V, V-M, and BB-M stages. Moreover, the earliness of ripening in grape cultivars was caused by the shortness of the time elapsed between veraison and maturity.
Keywords: *climate, daily temperature, phenology, vegetation period, Vitis vinifera L.*

Introduction

Grape, one of the oldest cultivated plant species in the world, is nowadays produced over a wide geographical area and in considerable amounts (Alston and Sambucci, 2019). The positive effects of grapes on human health have increased interest in this species (Çakır et al., 2023). This has necessitated further research on grape cultivars suitable for economic and sustainable viticulture in potential production areas. There are many factors (genotype, rainfall, sunshine duration, altitude, exposure, soil characteristics, age of the grapevine, cultivation practices, rootstocks used, etc.) that affect the yield and ripening time of grape cultivars (Ağaoğlu, 2002; Menora et al., 2015). Among these, the foremost factor affecting the ripening time of grape cultivars is the temperature values of the region where the vineyard is located during the vegetation period (Köse, 2014). In grapevines, many biochemical activities take place in different tissues of the plant from bud burst until the dormancy phase. The berries of grapevines, the product with the highest economic value produced by vines, are among the organs in which these biochemical activities take place most intensively. Monosaccharides, organic acids, minerals, fatty acids, water, and other phytochemicals are stored in the berries starting from flower fertilization until the grapes reach harvest maturity (Dokoozlian and Kliewer, 1996; Coombe and McCarthy, 2000; Yang et al., 2009; Dai et

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al., 2011; Yang and Xiao, 2013). Grape cultivars have the most suitable taste and aroma and are ready for consumption or processing when these phytochemicals reach certain concentrations (Du Plessis, 1984). In practice, grapes are harvested when the amount of dry matter in their must reaches a certain concentration or when they reach the sugar–acid balance (maturity index) specific to the relevant grape cultivar, which are also important criteria for commercial suitability (Rolle et al., 2011; Shiraishi et al., 2018).

The dates at which cultivated grape cultivars reach harvest maturity vary due to genotypic differences (Maante et al., 2015; Yilmaz and Uzun, 2021). Depending on the commercial use of the grape cultivar, the desired concentration of dry matter in the grains varies, which affects the date chosen for harvesting (Sabir et al., 2010). The date at which the berries of a certain grape cultivar ripen may also vary depending on the climate trends of the growing year (Lisek, 2008). Despite these factors, producers can accurately predict the harvest dates of certain grape cultivars in regions where they have been grown intensively for many years. However, when planning the relocation of a grape cultivar to a new region with different ecological characteristics, there are various factors to be considered. Some of these factors include the physiological responses of this cultivar to new ecological conditions, whether the cultivar will encounter adversities due to extreme climate conditions (chilling, frost, etc.), and on which date the cultivar will reach harvest maturity (Odabaşıoğlu and Gürsöz, 2021). Predicting these factors with high accuracy is important to prevent financial losses. These considerations have led to the need to distinguish grape cultivars from each other through indicators based on numerical data. Indices (heliothermic, bioclimatic, Winkler, hydrothermic, latitude temperature, spring frost, drought, Jones, etc.) that numerically explain the relationships between grapevine cultivars and climate factors of the regions where they are grown have been developed for this purpose (Kök and Çelik, 2003; Goldammer, 2013; Çelik, 2011).

The effective heat summation requirement (EHSR) is a measure of the Winkler index, which is one of the aforementioned climate indices. This concept has been named differently by various researchers (growing degree day, degree day, growing heat summation, heat unit, thermal unit, heat requirement, etc.) (Undersander and Christiansen, 1986; Valentini et al., 2002; Gu, 2016). The EHSR values of grape cultivars are calculated by summing the temperatures above the minimum growth temperature (threshold/base temperature) during the time between phenological growth stages (Çelik et al., 1998; Çakır, 2021). EHSR is not a method specific to grapevines. It is also used in other cultivated plant species and various modeling studies have been performed using it (Ünver and Çelik, 1999; Bourgeois et al., 2000; Sikder, 2009; İkinci et al., 2014). Different calculation methods for determining the EHSR values of different plant species have been proposed by various researchers (Wang, 1960; McMaster and Wilhelm, 1997; Gu, 2016; Nunes et al., 2016). The method suggested by Winkler et al. (1974) (Winkler index) is the most accepted and widely used method for determining the EHSR values of grape cultivars. Although the threshold temperature for grape cultivars used in EHSR calculations was early on admitted as 9°C, the threshold of 10°C specified by Winkler and Williams (1939) was accepted and widely used by many researchers (Winkler, 1948; Alwan, 1979; Thakur et al., 2008; Zapata et al., 2015; Kok, 2020; Alonso et al., 2021). However, the method used to determine the daily average temperature (DAT) value, which factors into EHSR calculations, can affect the EHRS value calculated for the relevant plant cultivar (Aktürk and Uzun, 2020).

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As a result of phenological observations and calculations made by previous researchers on individual plants of a grape cultivar grown in different ecologies, it was found that the EHSR value of the grape cultivar varied according to the ecology the plant is cultivated in (Ateş and Uysal, 2017; Bekar and Cangi, 2017; Aktürk and Uzun, 2020). Another noteworthy finding of prior studies is that the EHSR values of grape cultivars reported to ripen in different stages were similar to each other, as reported in studies conducted in different ecologies (Çelik et al., 2005; Çelik, 2006; Cangi and Altun, 2015; Aktürk and Uzun, 2019). In their studies conducted in different ecologies, various researchers have also reported that the EHSR values of grape cultivars may vary depending on the year of cultivation (van Leeuwen et al., 2004; Kaya and Özdemir, 2015; Söğüt and Özdemir, 2015; Bozkurt et al., 2018; Cangi and Demir, 2019; Kaya Demirkeser and Kamiloğlu, 2020; Ünal and Sezgin, 2022). The variation in results in the literature may be due to differences in the methods used to calculate EHSR or DAT values. The aforementioned findings of previous studies led to the conclusion that it was necessary to conduct the present study, in which the EHSR values, representing the temperature values required for plants to grow through different phenological stages, of 12 grape cultivars were determined using different DAT and EHSR calculation methods. Differences between the grape cultivars and the calculation methods used were examined.

Materials and methods

Grape cultivars and experimental vineyard

The study was conducted in 2021-2022 in the vineyard of Adıyaman University Agricultural Practices and Land Management Application and Research Center (ADYÜTAYAM), 17 km from Adıyaman (Turkey) (37° 46′ 33″ N, 38° 25′ 54″ E). The vineyard is located at an altitude of 700 meters. The study included 12 different grape cultivars as plant material (*Table 1*).

Table 1. *Some descriptive characteristics of the grape cultivars investigated*

Cultivar	Berry form	Berry color	Cluster form	Seed	Utilization
Perlette	Round	Greenish yellow	Winged conical	-	Table
Alphonse Lavallee	Oblong round	Purplish black	Winged conical	1-4	Table
Red Globe	Round	Pinky red	Conical	3-4	Table
Royal	Slightly oblate round	Purplish black	Winged	2-3	Table
Banazı Karası	Ovoid	Blue-Black	Winged cylindrical	1-3	Table-Raisin
İtalia	Ovoid	Yellow	Conical-pyramidal	1-2	Table
Syrah	Short ovoid	Black	Winged cylindrical	1-2	Wine
Yalova İncisi	Ovoid	Green-Yellow	Shouldered conical	1-3	Table
Öküz Gözü	Ellipsoidal	Black	Winged conical	2-3	Wine
Boğazkere	Round	Violet-Black	Winged conical	2-3	Wine
Trakya İlkeren	Round	Blue-Black	Winged conical	2-3	Table
Flame Seedless	Round	Red	Conical	-	Table

The experimental vineyard consisted of a single plot and was arranged in consecutive rows of cultivars (7 replicates) with each cultivar forming a line (*Fig. 1*). The vines were planted according to a planting density of 1 m × 3 m and were trained with Guyot

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training. The cultivars examined were grafted on 99 R rootstock and the saplings were planted in the experimental vineyard in 2014. During the study, routine tillage (in Spring and Autumn with cultivator), spraying (3 times with pulverizator), and irrigation (6 times for each growing season with drip irrigation system via 7 days intervals) were carried out in the vineyard.

Figure 1. Map and image of the experimental vineyard

Climatic conditions and soil properties of the experimental vineyard

The meteorological data of the region where the vineyard was located for the years of the study were determined with the climate station (Metos, Pessl Instruments, Austria) and presented in *Table 2*.

Table 2. *Some climatic data of the region where the vineyard is located*

	Mean temp. (°C)		Max. temp. (°C)		Min. temp. (°C)		Total rainfall (mm)		Humidity (%)	
	2021	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**
I	6.42	3.17	11.21	6.56	2.48	0.44	165.2	47.4	66.26	71.98
II	8.30	8.19	14.08	13.45	3.74	3.82	15.8	35.6	63.04	62.14
III	9.24	6.27	15.33	11.34	3.82	2.08	126.2	132.6	63.86	67.41
IV	15.93	17.42	24.07	25.30	8.81	10.36	7.6	9.8	58.12	40.86
V	23.85	19.87	32.49	27.55	15.27	12.61	7.8	30.6	33.06	41.75
VI	27.05	27.73	35.08	35.62	18.79	19.82	0.8	1.4	31.36	29.77
VII	32.28	31.69	39.81	39.30	25.02	24.34	2.2	0	22.59	18.23
VIII	31.93	31.52	39.81	40.14	25.05	22.81	2.8	0	22.88	27.55
IX	25.84	27.67	33.48	35.86	18.94	20.14	6.6	0.4	27.63	21.21
X	20.05	21.11	27.32	28.01	14.15	15.54	33.8	8.2	30.55	30.93
XI	13.85	12.96	19.40	17.96	9.63	9.18	20.8	165.0	58.96	69.20
XII	6.88	9.29	11.86	14.24	3.11	5.72	35.6	24.6	64.38	73.55
Ave.	18.47	18.07	25.33	24.61	12.40	12.24	425.2	455.6	45.22	46.22

The results of the physical and chemical analysis of soil samples taken from 12 different locations (on grape variety lines) and two different depths in the experimental

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vineyard are presented in *Table 3*. According to these results, the soil of the vineyard is clay-loam, moderately alkaline, saline, very calcareous, and low in organic matter. The soil is low in nitrogen and iron but sufficient in other nutrients required for grape cultivation.

Table 3. *Soil properties of the experimental vineyard*

	0-30 cm	**30-60 cm**
Saturation (%)	68.39	68.11
pH	7.98	8.13
EC (%)	30.72	26.24
Lime ($CaCO_3$) (%)	16.67	20.75
Organic matter (%)	0.95	0.65
N (%)	0.05	0.14
P_2O_5 (kg da^{-1})	34.69	20.78
K2O (kg da^{-1})	274.05	78.30
Ca (ppm)	60350.0	62870.0
Mg (ppm)	15810.0	14790.0
Fe (ppm)	1.20	1.47
Zn (ppm)	1.36	0.63
Mn (ppm)	15.40	3.20
Cu (ppm)	6.00	7.50

Phenological observations

In order to determine the EHSR values necessary for the grape cultivars to reach different phenological growth stages, 100 vinestocks of each cultivar were marked during the dormancy stage (February 2021). In 2021 and 2022, periodical phenological observations of the cultivars were conducted and recorded. The dates of bud burst, full bloom, and veraison of the 12 grape cultivars examined in the study were determined according to the method reported by Ergenoğlu (1985). Accordingly,

Bud burst (BB): Accepted and recorded as the date when the green offshoot tip was observed in 50% of the winter buds of the grape cultivar examined.

Full bloom (FB): Accepted and recorded as the date when 50% of the flowers in the clusters of the grape cultivar examined bloomed (50% of the corollas were shed).

Veraison (V): Accepted and recorded as the date when the berries in the clusters of the grape cultivar examined started to soften and 50% of the berries changed color.

Maturity (M): Accepted and recorded as the date when the total soluble solids (TSS) content of the berries of the grape cultivar examined reached the desired values. TSS values were determined by refractometer (Atago, Japan) in the vineyard. The dates when the TSS values of table cultivars reached 16-18 °Bx and wine and raisin cultivars reached 18-21 °Bx were accepted as the harvest dates.

Daily average temperature calculation methods

The daily average temperature (DAT) value used to calculate EHSR can be determined by different calculation methods. To determine the differences between the

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methods used to calculate the DAT value, the values obtained from different DAT calculation methods were used in the EHSR calculation equation (*Eq. 1*) in accordance with the Winkler index (Winkler et al., 1974).

$$EHSR\ (Growing\ Degree\ Day) = \sum(T_{DAT} - T_{base}) \qquad \text{(Eq.1)}$$

T_{DAT} = Daily average temperature (DAT) (°C); T_{base} = 10°C (Winkler and Williams, 1939); when $T_{DAT} \leq T_{base}$; EHSR (GDD) = 0.

The EHSR values from the date of bursting of the winter buds (BB) to the date of harvest maturity (M) in both seasons of examination for the 12 grape cultivars examined were calculated separately with 3 DAT calculation methods. These methods are as follows:

DAT-1

Calculated by taking the average of hourly temperature values obtained from the climate station (*Eq. 2*).

$$T_{DAT\text{-}1}\,(°C) = \frac{(\sum_{h=1}^{24} T)}{24} \qquad \text{(Eq.2)}$$

T = hourly mean temperature (°C); h = hour.

DAT-2

Calculated by taking the average of maximum (highest) temperature (T_{max}) values and minimum (lowest) temperature (T_{min}) values obtained from the climate station (*Eq. 3*) (Birgücü and Karsavuran, 2009).

$$T_{DAT\text{-}2}\,(°C) = \frac{(Tmax + Tmin)}{2} \qquad \text{(Eq.3)}$$

DAT-3

Calculated by *Equation 4*, using the maximum temperature (T_{max}) values and minimum temperature (T_{min}) values obtained from the climate station (Birgücü and Karsavuran, 2009).

$$T_{DAT\text{-}3}\,(°C) = \frac{(Tmax + (2 * Tmin))}{3} \qquad \text{(Eq.4)}$$

Effective heat summation requirement calculation methods

Within the scope of the study, 3 different calculation methods were used to determine the EHSR values required by the grape cultivars during between different phenological growth stages (bud burst–full bloom, full bloom–veraison, veraison–maturity, bud burst–maturity).

Method 1

Utilizes the calculation method reported by Winkler et al. (1974) (Winkler index). The equation (*Eq. 5*) used to calculate the Winkler index is presented below.

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$$EHSR\ (Growing\ Degree\ Day) = \sum (T_{DAT} - T_{Base}) \qquad \text{(Eq.5)}$$

$T_{DAT} = T_{DAT-1}$ (°C); $T_{base} = 10$°C; when $T_{DAT} \leq T_{base}$; EHSR (GDD) = 0.

Method 2

Utilizes the calculation method reported by Nunes et al. (2016). This method involves two different equations (*Eqs. 6* and *7*) using daily minimum temperatures (T_{min}) and threshold temperature (T_{base}).

$$EHSR\ (GDD) = \sum \left[\frac{(Tmin - Tbase) + (Tmax - Tbase)}{2}\right] \text{ when } T_{min} > T_{base} \qquad \text{(Eq.6)}$$

$$EHSR\ (GDD) = \sum \left[\frac{(Tmax - Tbase)^2}{2\ (Tmax - Tmin)}\right] \text{ when } T_{min} < T_{base} \qquad \text{(Eq. 7)}$$

T_{max} = Daily maximum temperature (°C), T_{min} = Daily minimum temperature (°C), T_{base} = 10°C.

Method 3

Utilizes the calculation method reported by McMaster and Wilhelm (1997). This method involves the following equation (*Eq. 8*) using daily minimum temperatures (T_{min}) and daily maximum temperatures (T_{max}).

$$EHSR\ (GDD) = \sum \left[\left(\frac{Tmax + Tmin}{2}\right) - T_{base}\right] \qquad \text{(Eq.8)}$$

When $T_{max} < T_{base}$; $T_{max} = T_{base}$
When $T_{min} < T_{base}$; $T_{min} = T_{base}$.
T_{max} = Daily maximum temperature (°C); T_{min} = Daily minimum temperature (°C); T_{base} = 10°C.

Statistical analysis

The daily meteorological data of the region where the experimental vineyard is located were obtained from the climate station. The data were imported to Microsoft Excel (Microsoft, USA) and the EHSR values of different phenological growth stages of the grape cultivars were calculated using this program. The findings obtained were subjected to one-way analysis of variance (ANOVA) in Minitab ver. 18 (Minitab Inc., USA). The differences between the mean values obtained by the methods used to calculate the EHSR values of the grape cultivars were examined by Tukey multiple comparison test. In addition to this, Pearson correlation coefficients between EHSR (GDD) values of grape cultivars at key phenological growth stages were analyzed with Minitab ver. 18 software.

Results

Phenological stages of grape cultivars

The dates when the grape cultivars examined reached their four main phenological growth stages in 2021 and 2022 are presented in *Table 4*. In 2021, Boğazkere was the

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cultivar that reached bud burst first, while in 2022, Perlette, Boğazkere, and Flame Seedless reached bud burst on the same date and earlier than the other cultivars. Syrah was the cultivar that reached bud burst the latest in both years. Boğazkere was the earliest cultivar to reach full bloom in both years, while Perlette was the last to reach full bloom in both years. Trakya İlkeren was the earliest cultivar to reach veraison in both years, while Italia was the last to reach full bloom in both years, with Boğazkere reaching veraison at the same date as Italia in 2022. In both years of examination, Trakya İlkeren was the earliest cultivar to reach harvest maturity and Boğazkere was the last to reach harvest maturity.

Table 4. *Dates when grape cultivars reached their phenological growth stages*

Cultivar	Budbrust		Full Bloom		Veraison		Maturity	
	2021	2022	2021	2022	2021	2022	2021	2022
Perlette	04/04	9/04	16/05	24/05	5/07	7/07	26/07	28/07
Alphonse Lavallee	07/04	14/04	12/05	19/05	11/07	18/07	13/08	14/08
Red Globe	05/04	11/04	13/05	20/05	3/07	12/07	8/08	12/08
Royal	09/04	13/04	13/05	19/05	9/07	16/07	7/08	10/08
Banazı Karası	01/04	14/04	15/05	20/05	10/07	20/07	14/08	19/08
İtalia	05/04	15/04	12/05	21/05	16/07	27/07	13/08	17/08
Syrah	11/04	17/04	14/05	22/05	7/07	13/07	3/08	05/08
Yalova İncisi	08/04	14/04	14/05	21/05	25/06	4/07	24/07	25/07
Öküz Gözü	05/04	13/04	13/05	21/05	01/07	10/07	28/07	29/07
Boğazkere	31/03	9/04	11/05	17/05	12/07	27/07	20/08	22/08
Trakya İlkeren	03/04	10/04	12/05	18/05	16/06	26/06	12/07	14/07
Flame Seedless	02/04	9/04	14/05	20/05	23/06	1/07	29/07	31/07

The time spent between different phenological growth stages by the grape cultivars included in the study in 2021 and 2022 are presented in *Table 5*. Depending on the cultivar and the year of cultivation, the time between the BB and FB periods of the grape cultivars varied between 34 and 45 days, the time between the FB and V periods varied between 35 and 71 days, and the time between the V and M periods varied between 19 and 40 days. In addition, the time between the BB and M periods ranged between 96 and 143 days in the grape cultivars examined. When the time elapsed between phenological growth stages in the cultivars were examined, it was seen that the FB-V period took the longest, followed by BB-FB and V-M.

EHSR of grape cultivars calculated with different DAT calculation methods

The EHSR values for the different grape cultivars examined in the study between the four main phenological growth stages in the 2021-2022 growing years were determined with the values obtained from 3 different DAT calculation methods and the results are presented in *Table 6*.

When the grape cultivars examined were compared according to their EHSRs for BB-FB, FB-V, and V-M, the cultivars with the highest values in all three DAT calculation methods did not differ. Accordingly, the Perlette had the highest ESHR value between BB and FB in both study years and in the average of the years. Italia had the highest EHSR value between FB and V in 2021 and in the average of the years,

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while Boğazkere had the highest EHSR value between FB and V in 2022. Reg Globe had the highest EHSR value between V and M in 2022 and in the average of the years, while Boğazkere had the highest EHSR value between FB and V in 2021.

Table 5. *The time (day) spent between phenological growth stages by the grape cultivars*

Cultivar	BB-FB		FB-V		V-M		BB-M	
	2021	2022	2021	2022	2021	2022	2021	2022
Perlette	42	45	50	44	22	22	114	111
Alphonse Lavallee	35	35	60	60	34	28	129	123
Red Globe	38	39	51	53	37	32	126	124
Royal	34	36	57	58	30	26	121	120
Banazı Karası	44	36	56	61	36	31	136	128
İtalia	37	36	65	67	29	22	131	125
Syrah	33	35	54	52	28	24	115	111
Yalova İncisi	36	37	42	44	30	22	108	103
Öküz Gözü	38	38	49	50	28	20	115	108
Boğazkere	41	38	62	71	40	27	143	136
Trakya İlkeren	39	38	35	39	27	19	101	96
Flame Seedless	42	41	40	42	37	31	119	114

Table 6. *EHSR (GDD) values of grape cultivars between key growth stages (BB-FB, FB-V, and V-M) according to different DAT calculation methods*

Year	Cultivars	DAT-1			DAT-2			DAT-3		
		BB-FB	***FB-V***	***V-M***	***BB-FB***	***FB-V***	***V-M***	***BB-FB***	***FB-V***	***V-M***
2021	Perlette	371.84	839.61	490.88	384.47	834.08	492.38	283.22	695.15	438.31
	Alphonse Lavallee	312.22	1022.99	767.90	325.17	1016.05	782.80	241.97	848.57	702.98
	Red Globe	327.04	844.29	835.99	340.52	836.82	845.64	252.30	693.26	755.30
	Royal	310.16	964.19	695.11	321.62	957.53	703.57	240.62	798.26	630.83
	Banazı Karası	358.71	959.14	810.90	372.51	952.55	826.91	272.30	797.70	742.92
	İtalia	314.33	1137.42	653.47	327.62	1131.99	666.86	242.64	954.23	597.32
	Syrah	318.06	906.39	640.80	328.06	899.48	647.99	248.02	748.51	580.79
	Yalova İncisi	332.06	650.04	666.98	343.84	638.81	673.81	256.58	517.59	600.19
	Öküz Gözü	327.04	795.57	620.59	340.52	788.35	622.68	252.30	650.03	553.02
	Boğazkere	310.74	1056.75	895.74	324.78	1051.47	913.67	235.16	879.59	819.41
	Trakya İlkeren	316.10	521.79	545.85	330.25	512.73	548.34	242.64	412.23	476.79
	Flame Seedless	342.50	615.08	809.27	356.45	604.11	815.85	262.09	488.56	724.66
2022	Perlette	353.54	775.88	480.29	371.55	773.08	485.31	263.61	658.11	431.22
	Alphonse Lavallee	276.52	1071.74	619.61	292.43	1069.19	619.57	206.95	913.54	542.10
	Red Globe	297.86	923.69	710.59	314.95	919.41	712.13	221.51	780.40	626.73
	Royal	276.52	1027.44	574.89	292.43	1025.20	574.57	206.95	874.71	503.58
	Banazı Karası	288.07	1107.16	678.06	303.73	1106.38	676.03	215.51	949.12	588.71
	İtalia	296.65	1241.76	490.02	311.53	1242.17	487.02	222.34	1069.81	422.30
	Syrah	296.06	928.11	535.52	310.94	924.31	537.87	224.14	787.76	475.03
	Yalova İncisi	296.97	743.56	476.76	312.31	739.17	481.07	222.34	622.51	427.72
	Öküz Gözü	296.97	876.52	435.49	312.31	873.04	440.49	222.34	741.86	391.33
	Boğazkere	278.07	1285.36	599.26	296.74	1285.68	596.53	206.24	1103.99	518.46
	Trakya İlkeren	280.26	631.91	384.57	298.09	628.85	385.88	207.16	524.68	339.90
	Flame Seedless	312.77	692.89	672.48	331.68	688.96	676.49	233.59	577.45	599.19

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Average	Perlette	362.69	807.75	485.59	378.01	803.58	488.85	273.42	676.63	434.77
	Alphonse Lavallee	294.37	1047.37	693.76	308.80	1042.62	701.19	224.46	881.06	622.54
	Red Globe	312.45	883.99	773.29	327.74	878.12	778.89	236.91	736.83	691.02
	Royal	293.34	995.82	635.00	307.03	991.37	639.07	223.79	836.49	567.21
	Banazı Karası	323.39	1033.15	744.48	338.12	1029.47	751.47	243.91	873.41	665.82
	İtalia	305.49	1189.59	571.75	319.58	1187.08	576.94	232.49	1012.02	509.81
	Syrah	307.06	917.25	588.16	319.50	911.90	592.93	236.08	768.14	527.91
	Yalova İncisi	314.52	696.80	571.87	328.08	688.99	577.44	239.46	570.05	513.96
	Öküz Gözü	312.01	836.04	528.04	326.42	830.70	531.59	237.32	695.95	472.18
	Boğazkere	294.41	1171.06	747.50	310.76	1168.58	755.10	220.70	991.79	668.94
	Trakya İlkeren	298.18	576.85	465.21	314.17	570.79	467.11	224.90	468.46	408.35
	Flame Seedless	327.64	653.99	740.88	344.07	646.54	746.17	247.84	533.01	661.93

The cultivars with the lowest EHSR values between FB and V and V and M did not change with DAT calculation method. However, the DAT-1 and DAT-2 methods suggested the same grape cultivar had the lowest EHSR value between BB and FB, while the DAT-3 method suggested a different cultivar had the lowest EHSR value between BB and FB. Trakya İlkeren had the lowest EHSR between FB and V in both years of examination and in the average of the years. Perlette had the lowest EHSR value between V and M in 2021, while Trakya İlkeren had the lowest EHSR value between V and M in 2022 and in the average of the years. According to the DAT-1 and DAT-2 methods, Royal had the lowest EHSR value between BB and FB in 2021 and in the average of years, while both Royal and Alphonse Lavallee had the lowest EHSR value in 2022. On the other hand, according to the DAT-3 method, Boğazkere had the lowest EHSR value between BB and FB in both years of examination and in the average of the years (*Table 6*).

In practice, the EHSR values of grape cultivars between the BB and M periods are the main consideration. Among the cultivars examined, those with the lowest and highest EHSR values between the BB and M periods did not vary between the different DAT calculation methods. Accordingly, Trakya İlkeren had the lowest EHSR value and Boğazkere the highest EHSR value between BB and M (*Table 7*).

Table 7. *EHSR (GDD) values of grape cultivars between BB and M calculated by different DAT calculation methods*

Cultivar	DAT-1			DAT-2			DAT-3		
	2021	**2022**	**Ave.**	**2021**	**2022**	**Ave.**	**2021**	**2022**	**Ave.**
Perlette	1702.33	1609.71	1656.02	1710.92	1629.93	1670.43	1416.67	1352.95	1384.81
Alphonse Lavallee	2103.11	1967.87	2035.49	2124.01	1981.18	2052.60	1793.51	1662.59	1728.05
Red Globe	2007.32	1932.14	1969.73	2022.97	1946.48	1984.73	1700.86	1628.64	1664.75
Royal	1969.46	1878.85	1924.16	1982.72	1892.20	1937.46	1669.71	1585.24	1627.48
Banazı Karası	2128.75	2073.29	2101.02	2151.97	2086.14	2119.06	1812.92	1753.34	1783.13
İtalia	2105.22	2028.43	2066.83	2126.46	2040.71	2083.59	1794.19	1714.45	1754.32
Syrah	1865.25	1759.69	1812.47	1875.54	1773.12	1824.33	1577.31	1486.93	1532.12
Yalova İncisi	1649.08	1517.29	1583.19	1656.45	1532.54	1594.50	1374.36	1272.56	1323.46
Öküz Gözü	1743.20	1608.98	1676.09	1751.54	1625.83	1688.69	1455.35	1355.53	1405.44
Boğazkere	2263.23	2162.69	2212.96	2289.91	2178.95	2234.43	1934.16	1828.68	1881.42
Trakya İlkeren	1383.74	1296.74	1340.24	1391.31	1312.82	1352.07	1131.67	1071.73	1101.70
Flame Seedless	1766.85	1678.14	1722.50	1776.40	1697.13	1736.77	1475.31	1410.24	1442.78

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When the DAT calculation methods were compared, it was seen that the highest EHSR values between BB and FB, V and M, and BB and M in both years and in the average of the years were calculated using DAT-2, followed by DAT-1 and DAT-3. However, the highest EHSR values between FB and V were calculated using DAT-1, followed by DAT-2 and DAT-3. There was no significant difference between DAT-1 and DAT-2 in terms of calculating the EHSR values of the grape cultivars analyzed between BB and FB ($p < 0.01$), FB and V ($p < 0.05$), or BB and M ($p < 0.01$) or in the average of the years (*Table 8*).

Table 8. *Variation in EHSR (GDD) values between key phenological growth stages of grape cultivars according to different DAT calculation methods*

Year	Period	DAT-1	DAT-2	DAT-3
2021	BB-FB**	328.40 ± 19.96 a	341.32 ± 20.18 a	252.49 ± 14.18 b
	FB-V^{ns}	859.42 ± 187.90	852.00 ± 189.50	706.97 ± 166.00
	V-M^{ns}	702.80 ± 122.90	711.70 ± 127.30	635.20 ± 116.30
	BB-M**	1890.60 ± 251.40 a	1905.0 ± 257.70 a	1594.70 ± 231.10 b
2022	BB-FB**	295.85 ± 21.30 a	312.39 ± 21.75 a	221.06 ± 16.02 b
	FB-V^{ns}	942.20 ± 210.90	939.60 ± 212.30	800.30 ± 187.50
	V-M^{ns}	554.80 ± 104.10	556.10 ± 103.30	488.90 ± 89.70
	BB-M**	1792.80 ± 258.00 a	1808.10 ± 256.70 a	1510.20 ± 224.20 b
Average	BB-FB**	312.13 ± 26.15 a	326.85 ± 25.28 a	236.77 ± 21.83 b
	FB-V*	900.80 ± 199.80 a	895.80 ± 201.80 a	753.70 ± 179.70 b
	V-M^{ns}	628.80 ± 134.60	633.90 ± 138.40	562.00 ± 126.10
	BB-M**	1841.70 ± 254.00 a	1856.60 ± 256.40 a	1552.50 ± 226.80 b

There is a statistically significant (*: $p < 0.05$; **: $p < 0.01$; ns: non-significant) difference between the mean values expressed with different letters in the same row

Although not applicable to all of the grape cultivars examined in the study, in general, it was determined through all three DAT calculation methods that the cultivars' EHSRs to reach different phenological growth stages were highest in the FB-V period, followed by V-M and BB-FB (*Tables 6* and *8*).

EHSR of grape cultivars calculated with different EHSR calculation methods

The EHSR of the 12 different grape cultivars for the BB-FB, FB-V, and V-M periods in 2021-2022 and in the average of the years were calculated by 3 different methods (McMaster and Wilhelm, 1997; Winkler et al., 1974; Nunes et al., 2016) and the findings are presented in *Table 9*.

In all three methods used to calculate the EHSR value, the cultivars with the highest value did not differ between BB and FB, FB and V, or V and M. Perlette had the highest EHSR value between BB and FB in both years and in the average of the years. Italia had the highest EHSR value between FB and V in 2021 and in the average of the years, while Boğazkere had the highest EHSR value between FB and V in 2022. Boğazkere had the highest EHSR value between V and M in 2021, while Red Globe had the highest EHSR value between V and M in 2022 and in the average of the years.

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Table 9. *EHSR (GDD) values of grape cultivars between key growth stages (BB-FB, FB-V, and V-M) according to different EHSR calculation methods*

Year	Cultivars	Winkler et al. (1974)			Nunes et al. (2016)			McMaster and Wilhelm (1997)		
		BB-FB	FB-V	V-M	BB-FB	FB-V	V-M	BB-FB	FB-V	V-M
2021	Perlette	371.84	839.61	490.88	394.68	834.08	492.38	412.15	834.08	492.38
	Alphonse Lavallee	312.22	1022.99	767.90	332.79	1016.05	782.80	346.20	1016.05	782.80
	Red Globe	327.04	844.29	835.99	349.75	836.82	845.64	365.44	836.82	845.64
	Royal	310.16	964.19	695.11	329.24	957.53	703.57	342.43	957.53	703.57
	Banazı Karası	358.71	959.14	810.90	386.95	952.55	826.91	409.57	952.55	826.91
	İtalia	314.33	1137.42	653.47	336.85	1131.99	666.86	352.54	1131.99	666.86
	Syrah	318.06	906.39	640.80	334.40	899.48	647.99	344.76	899.48	647.99
	Yalova İncisi	332.06	650.04	666.98	351.45	638.81	673.81	364.65	638.81	673.81
	Öküz Gözü	327.04	795.57	620.59	349.75	788.35	622.68	365.44	788.35	622.68
	Boğazkere	310.74	1056.75	895.74	339.51	1051.47	913.67	363.30	1051.47	913.67
	Trakya İlkeren	316.10	521.79	545.85	342.49	512.73	548.34	362.18	512.73	548.34
	Flame Seedless	342.50	615.08	809.27	370.10	604.11	815.85	391.22	604.11	815.85
2022	Perlette	353.54	775.88	480.29	375.81	773.08	485.31	388.05	773.08	485.31
	Alphonse Lavallee	276.52	1071.74	619.61	295.33	1069.19	619.57	304.42	1069.19	619.57
	Red Globe	297.86	923.69	710.59	319.21	919.41	712.13	331.46	919.41	712.13
	Royal	276.52	1027.44	574.89	296.21	1025.20	574.57	306.72	1025.20	574.57
	Banazı Karası	288.07	1107.16	678.06	306.63	1106.38	676.03	315.72	1106.38	676.03
	İtalia	296.65	1241.76	490.02	313.01	1242.17	487.02	320.35	1242.17	487.02
	Syrah	296.06	928.11	535.52	311.91	924.31	537.87	317.43	924.31	537.87
	Yalova İncisi	296.97	743.56	476.76	315.20	739.17	481.07	320.35	739.17	481.07
	Öküz Gözü	296.97	876.52	435.49	316.09	873.04	440.49	326.60	873.04	440.49
	Boğazkere	278.07	1285.36	599.26	301.00	1285.68	596.53	313.25	1285.68	596.53
	Trakya İlkeren	280.26	631.91	384.57	302.35	628.85	385.88	314.60	628.85	385.88
	Flame Seedless	312.77	692.89	672.48	335.94	688.96	676.49	348.19	688.96	676.49
Average	Perlette	362.69	807.75	485.59	385.25	803.58	488.85	400.10	803.58	488.85
	Alphonse Lavallee	294.37	1047.37	693.76	314.06	1042.62	701.19	325.31	1042.62	701.19
	Red Globe	312.45	883.99	773.29	334.48	878.12	778.89	348.45	878.12	778.89
	Royal	293.34	995.82	635.00	312.73	991.37	639.07	324.58	991.37	639.07
	Banazı Karası	323.39	1033.15	744.48	346.79	1029.47	751.47	362.65	1029.47	751.47
	İtalia	305.49	1189.59	571.75	324.93	1187.08	576.94	336.45	1187.08	576.94
	Syrah	307.06	917.25	588.16	323.16	911.90	592.93	331.10	911.90	592.93
	Yalova İncisi	314.52	696.80	571.87	333.33	688.99	577.44	342.50	688.99	577.44
	Öküz Gözü	312.01	836.05	528.04	332.92	830.70	531.59	346.02	830.70	531.59
	Boğazkere	294.41	1171.06	747.50	320.26	1168.58	755.10	338.28	1168.58	755.10
	Trakya İlkeren	298.18	576.85	465.21	322.42	570.79	467.11	338.39	570.79	467.11
	Flame Seedless	327.64	653.99	740.88	353.02	646.54	746.17	369.71	646.54	746.17

Among the grape cultivars analyzed, those with the lowest and highest EHSR values for the FB-V and V-M periods in both years and in the average of the years did not vary according to different EHSR calculation methods. The cultivar with the lowest EHSR

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value between FB and V in 2021-2022 and in the average of the years was Trakya İlkeren according to all three methods. Perlette had the lowest EHSR value between V and M in 2021, while Trakya İlkeren had the lowest EHSR value between V and M in 2022 and in the average of the years. The cultivar with the lowest ESHR value between BB and FB in 2021 and in the average of the years was Royal according to all three calculation methods. However, the cultivars with the lowest EHSR value between BB and FB in 2022 were Alphonse Lavallee and Royal according to the method described by Winkler et al. (1974) and Alphonse Lavallee according to the methods reported by McMaster and Wilhelm (1997) and Nunes et al. (2016) (*Table 9*).

The grape cultivars with the lowest and highest EHSR values between BB and M did not change according to the different EHSR calculation methods. It was determined by all three methods that Trakya İlkeren had the lowest EHSR value and Boğazkere had the highest EHSR value between BB and M (*Table 10*).

Table 10. *EHSR (GDD) values of grape cultivars between BB and M calculated through different EHSR calculation methods*

Cultivars	Winkler et al. (1974)			Nunes et al. (2016)			McMaster and Wilhelm (1997)		
	2021	2022	Ave.	2021	2022	Ave.	2021	2022	Ave.
Perlette	1702.33	1609.71	1656.02	1721.13	1505.41	1613.27	1738.61	1646.44	1692.53
Alphonse Lavalleee	2103.11	1967.87	2035.49	2131.64	1984.08	2057.86	2145.05	1993.17	2069.11
Red Globe	2007.32	1932.14	1969.73	2032.20	1950.74	1991.47	2047.90	1962.99	2005.45
Royal	1969.46	1878.85	1924.16	1990.34	1895.98	1943.16	2003.53	1906.49	1955.01
Banazı Karası	2128.75	2073.29	2101.02	2166.40	2089.03	2127.72	2189.03	2098.13	2143.58
İtalia	2105.22	2028.43	2066.83	2135.69	2042.19	2088.94	2151.39	2049.53	2100.46
Syrah	1865.25	1759.69	1812.47	1881.87	1774.09	1827.98	1892.23	1779.61	1835.92
Yalova İncisi	1649.08	1517.29	1583.19	1664.06	1535.44	1599.75	1662.29	1544.53	1603.41
Öküz Gözü	1743.20	1608.98	1676.09	1760.77	1629.61	1695.19	1776.47	1640.12	1708.30
Boğazkere	2263.23	2162.69	2212.96	2304.64	2183.21	2243.93	2328.43	2195.45	2261.94
Trakya İlkeren	1383.74	1296.74	1340.24	1403.55	1317.08	1360.32	1423.24	1329.33	1376.29
Flame Seedless	1766.85	1678.14	1722.50	1790.06	1701.39	1745.73	1811.17	1713.64	1762.41

When the EHSR calculation methods were compared, it was seen that the highest EHSR values for BB-FB and BB-M in both years and in the average of years were calculated using the method reported by McMaster and Wilhelm (1997), followed by the methods described by Nunes et al. (2016) and Winkler et al. (1974). On the other hand, the highest EHSR values of grape cultivars between FB and V were calculated using Winkler et al.'s method (1974), followed by the methods described by Nunes et al. (2016) and McMaster and Wilhelm (1997), which calculated the same values. The highest EHSR values of grape cultivars between V and M were calculated using the methods devised by McMaster and Wilhelm (1997) and Nunes et al. (2016), which calculated the same values, followed by the method described by Winkler et al. (1974). When considered independently of grape cultivars, a significant difference ($p < 0.01$) was found between the calculation methods only in terms of ESHR values between BB and FB, and this difference was only between the results of Winkler et al. (1974) and McMaster and Wilhelm (1997) and Nunes et al. (2016), which were both in the same

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statistical group. ESHR values between BB and FB calculated according to the method described by Winkler et al. (1974) were lower than the results from the other two methods (*Table 11*).

Table 11. *Variation in EHSR (GDD) values between key phenological growth stages of grape cultivars according to different EHSR calculation methods*

Year	Period	Winkler et al. (1974)	Nunes et al. (2016)	McMaster and Wilhelm (1997)
2021	BB-FB**	328.40 ± 19.96 b	351.50 ± 21.43 a	368.32 ± 23.75 a
	FB-V^{ns}	859.40 ± 187.90	852.00 ± 189.50	852.00 ± 189.50
	V-M^{ns}	702.80 ± 122.90	711.70 ± 127.30	711.70 ± 127.30
	BB-M^{ns}	1890.60 ± 251.40	1915.20 ± 258.10	1930.80 ± 260.20
2022	BB-FB**	295.85 ± 21.30 b	315.72 ± 22.01 ab	325.59 ± 22.85 a
	FB-V^{ns}	942.20 ± 210.90	939.60 ± 212.30	939.60 ± 212.30
	V-M^{ns}	554.80 ± 104.10	556.10 ± 103.30	556.10 ± 103.30
	BB-M^{ns}	1792.80 ± 258.00	1800.70 ± 267.00	1821.60 ± 256.00
Average	BB-FB**	312.13 ± 26.15 b	333.61 ± 28.02 a	346.96 ± 31.56 a
	FB-V^{ns}	900.80 ± 199.80	895.80 ± 201.80	895.80 ± 201.80
	V-M^{ns}	628.80 ± 134.60	633.90 ± 138.40	633.90 ± 138.40
	BB-M^{ns}	1841.70 ± 254.00	1857.90 ± 263.40	1876.20 ± 258.50

There is a statistically significant (**: p < 0.01; ns: non-significant) difference between the mean values expressed with different letters in the same row

Considered independently of grape cultivars, all EHSR calculation methods suggested that the cultivars had the highest EHSRs between FB and V, followed by V and M and BB and FB (*Table 11*). However, this does not apply to all grape cultivars and years examined. All EHSR calculation methods suggested that Trakya İlkeren, Flame Seedless, and Perlette had the highest EHSRs between V and M, followed by FB and V and BB and FB in 2021, while only Flame Seedless had the highest EHSRs between V and M, followed by FB and V and BB and FB in the average of years (*Table 9*).

Correlations between growth stages

According to all DAT calculation methods and their result averages, there is a positive correlation ($p < 0.01$) between the EHSR values of grape cultivars for the FB-V and V-M periods and the EHSR values they have between BB and M. However, when EHSR values were calculated according to the DAT-2 and DAT-3 methods, there was a negative correlation ($p < 0.05$) for the BB-FB and FB-V periods. Although not suggested by the individual DAT calculation method results, a positive correlation ($r = 0.344$, $p < 0.01$) was found for BB-FB and V-M according to the average of the results of these methods (*Table 12*).

According to the findings obtained through different EHSR calculation methods, both the individual EHSR calculation method results and the average of the results of these methods suggest that there was a positive correlation ($p < 0.01$) between FB-V and V-M values and BB-M values. In addition, according to the method reported by Nunes et al. (2016) ($p < 0.05$) and the average of the results of the methods ($p < 0.01$),

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there was a negative correlation between the EHSR values between BB-FB and FB-V periods. Although not suggested by the individual EHSR calculation method results, a positive correlation (*r = 0.285, p < 0.05*) was found between BB-FB and V-M EHSR values according to the average of the results of these methods (*Table 12*).

Table 12. *Pearson correlation coefficients between EHSR (GDD) values of grape cultivars at key phenological growth stages*

	DAT-1			**Winkler et al. (1974)**		
	FB-V	**V-M**	**BB-M**	**FB-V**	**V-M**	**BB-M**
BB-FB	-0.391	0.250	-0.072	-0.391	0.250	-0.072
FB-V		0.151	0.826**		0.151	0.826**
V-M			0.674**			0.674**
	DAT-2			**Nunes et al. (2016)**		
	FB-V	**V-M**	**BB-M**	**FB-V**	**V-M**	**BB-M**
BB-FB	-0.404*	0.240	-0.090	-0.405*	0.308	-0.075
FB-V		0.137	0.821**		0.137	0.808**
V-M			0.671**			0.686**
	DAT-3			**McMaster and Wilhelm (1997)**		
	FB-V	**V-M**	**BB-M**	**FB-V**	**V-M**	**BB-M**
BB-FB	-0.413*	0.339	-0.043	-0.397	0.366	0.006
FB-V		0.092	0.803**		0.137	0.808**
V-M			0.662**			0.685**
	DAT Calculation Methods Average			**EHSR Calculation Methods Average**		
	FB-V	**V-M**	**BB-M**	**FB-V**	**V-M**	**BB-M**
BB-FB	0.088	0.344**	0.395**	-0.358**	0.285*	-0.014
FB-V		0.199	0.835**		0.141	0.812**
V-M			0.684**			0.682**

*Correlation is significant at the p < 0.05 level, **correlation is significant at the p < 0.01 level

Discussion

The findings obtained in the present study regarding the periods between different phenological growth stages of the cultivars examined are similar to the findings reported previously. In general, the time the cultivars examined were determined to take between BB and M were shorter than the times reported by Çelik et al. (2005), Cangi et al. (2008), Cangi and Altun (2015), Menora et al. (2015), Söğüt and Özdemir (2015), Bekar (2017), Kunter et al. (2017), Bozkurt et al. (2018), Cangi and Demir (2019), and Keskin et al. (2023), but were similar to the findings published by Aktürk and Uzun (2019), Aktürk and Uzun (2020), and Odabaşıoğlu and Gürsöz (2021). The fact that the experimental vineyard is located in an ecology with a hot and semi-arid climate resulted in the cultivars examined taking shorter times between the BB and FB and FB and V periods when compared to the results reported in the literature, and the cultivars examined taking much shorter times between V and M. Many factors affect the time it takes for vines to grow from bud burst to harvest maturity. The ecological characteristics of the region where the vines are grown, the age of the vines, pruning times, the type of training given to the vinestock, the amount of irrigation applied to the

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vineyard, the rootstocks on which the vines are grafted, and the climatic trends in the year of cultivation are among these factors (Lopez et al., 2007; Gazioğlu Şensoy et al., 2009; Scarpare et al., 2012; Çakır and Öylek, 2016; Cameron et al., 2022; Rafique et al., 2023). These factors can change not only the time between BB and M periods, but also the date at which a grape cultivar reaches harvest maturity. Different results regarding harvest dates and lengths of time between phenological growth stages of the same grape cultivars being determined in the current study may have been due to the fact that the studies in the literature were mostly conducted in climates with lower temperatures and higher total precipitation rates than where the current study was conducted. In addition, the length of time the grape cultivars examined took to grow between the V and M stages was shorter in 2022 than in 2021. This difference between the years may be due to the difference in the amount of precipitation the vineyard had during the vegetation period, the difference in the amount of irrigation applied to the vineyard, and the difference in the TSS content of the grapes at the time of harvest. Similarly, Gazioğlu Şensoy et al. (2009) reported that the harvest date of a grape cultivar can vary by 1-37 days between two growing seasons, while Bozkurt et al. (2018) reported that it can vary by 4-35 days.

Differences in EHSR values occurred due to the different calculation methods used for the DAT value utilized in the method (*Eq. 1*) reported by Winkler et al. (1974) in determining the EHSR values between different phenological growth stages of the 12 grape cultivars examined. Although the cultivars with the highest and lowest EHSR values in the FB-V, V-M, and BB-M periods did not change according to the DAT method used, the cultivar with the lowest EHSR value between BB and FB did vary according to the DAT method used. In general (except for FB-V), the highest EHSR values of grape cultivars examined between phenological growth stages were calculated using DAT-2, followed by DAT-1 and DAT-3. The reason for this difference between the DAT methods is that during the early spring (the last week of March and the first two weeks of April) when vines burst into bud, the temperature sometimes drops below 10°C, which is the minimum growth temperature for the vines. In fact, DAT-2 and DAT-3 use the $T_{\min}$ value, which therefore directly affects T_{DAT} values. However, DAT-1 and DAT-2, which are generally used to calculate T_{DAT}, provided very similar results regarding the EHSR values of grape cultivars and were interchangeable. This similarity between DAT-1 and DAT-2 and the same order of DAT calculation methods in terms of the EHSR values obtained were also reported by Aktürk and Uzun (2020). When using $T_{DAT\text{-}3}$ calculated by DAT-3, grape cultivars appear to have very similar EHSR values between different phenological growth stages and it is difficult to make a clear distinction between cultivars. The EHSR values of grape cultivars between different phenological growth stages are used not only to determine the suitability of the said grape cultivars to be grown in a new ecology, but also to indicate the differences between grape cultivars, types, and cultivar candidates (Uzun, 1997; Kamiloğlu et al., 2014; Gönen, 2021). The fact that the cultivars had very similar EHSR values when calculations were made using DAT-3 shows that this method is not suitable for distinguishing grape cultivars based on EHSR values. Hence, further studies are required to examine the usability of DAT-3 in ecologies with similar $T_{\max}$ and $T_{\min}$ values.

The cultivars with the highest EHSR values between different phenological growth stages (BB-FB, FB-V, V-M, and BB-M) did not change according to the methods used to calculate those values (Winkler et al., 1974; Nunes et al., 2016; McMaster and

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Wilhelm, 1997). Similarly, the cultivars with the lowest EHSR values did not vary according to the methods used to calculate them, except between BB and FB. Among the grape cultivars examined, the grape cultivar with the lowest EHSR value between BB and FB varied according to the calculation methods, which was due to the fact that the values of T_{min} and T_{mean} were sometimes below the T_{base} value during the dates between these periods. However, the EHSR values between FB and V and V and M in both years calculated by the methods of Nunes et al. (2016) and McMaster and Wilhelm (1997) were similar, since the T_{max} and T_{min} values were higher than the T_{base} values at and after the full bloom periods of all the grape cultivars examined. The highest EHSR values of grape cultivars between BB and FB and BB and M were calculated using the method reported by McMaster and Wilhelm (1997), followed by the methods described by Nunes et al. (2016) and Winkler et al. (1974). The same order of methods was reported by Aktürk and Uzun (2020), who analyzed the EHSR values of 34 different grape cultivars between BB and M in Antalya (Turkey). On the other hand, in the present study this order was not valid for the FB-V and V-M periods. Although the methods were ordered differently in case of some grape cultivars (Alphonse Lavallee, Italia, Banazı Karası, and Boğazkere) in 2022, the highest EHSR values of the grape cultivars between V and M were calculated using the methods of McMaster and Wilhelm (1997) and Nunes et al. (2016), followed by method of Winkler et al. (1974). In contrast, the highest EHSR values of the grape cultivars (except for Italia and Boğazkere in 2022) between FB and V were calculated using the method described by Winkler et al. (1974), followed by the methods reported by Nunes et al. (2016) and McMaster and Wilhelm (1997), which provided similar results. However, there were no significant differences between the methods used in the calculation of EHSR values between FB and V or V and M of the cultivars. Therefore, it was concluded that the three EHSR calculation methods tested can be used interchangeably to determine the EHSR values of grape cultivars between any two phenological growth stages after the FB period.

In addition, the grape cultivars had the highest EHSR values between FB and V, followed by V-M and BB-FB. Moreover, this order did not change according to different DAT and EHSR calculation methods. This is directly correlated with the length of time between the phenological growth stages of the grape cultivars examined. Similarly, Cangi and Altun (2015), Söğüt and Özdemir (2015), Bekar and Cangi (2017), and Odabaşıoğlu and Gürsöz (2021), who examined the EHSR values of grapes between phenological growth stages in different ecologies and different grape cultivars, also reported the same order of stages. Some researchers (Kök and Çelik, 2003; Bozkurt et al., 2018) reported that this order may be replaced by V-M > FB-V > BB-FB in late and very late grape cultivars depending on the year of cultivation.

The EHSR values of the grape cultivars examined in the present study between BB and M differed according to different calculation methods. However, among the grape cultivars examined, the lowest EHSR values between BB and M were observed in Trakya İlkeren, followed by Yalova İncisi, Perlette, Öküzgözü, Flame Seedless, Syrah, Royal, Red Globe, Alphonse Lavallee, Italia, Banazı Karası, and Boğazkere, in that order. This order did not differ with different DAT and EHSR calculation methods. Moreover, previous researchers (Çelik et al., 2005; Kunter et al., 2017; Aktürk and Uzun, 2019; Keskin et al., 2023), who examined the EHSR values of some of these grape cultivars between BB and M, found similar results. In addition, although the EHSR value of the grape cultivars varied according to the year of

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cultivation in the current study, the order among the cultivars did not change. Similarly, previous researchers (Kök and Çelik, 2003; Cangi et al., 2008; Gazioğlu Şensoy et al., 2009; Kaya and Özdemir, 2015; Söğüt and Özdemir, 2015; Bozkurt et al., 2018; Cangi and Demir, 2019; Ünal, 2019) also reported that the EHSR values of grape cultivars may vary slightly depending on the year of cultivation examined, but the order of grape cultivars according to their EHSR values between BB and M remained almost the same.

The findings obtained from both different DAT and different EHSR calculation methods suggest that the EHSR values of grapes between BB and M were linearly correlated with EHSR values between FB and V and V and M. A linear correlation was also found between the EHSR values of the grapes between BB and FB and the EHSR values between V and M. However, this correlation was more variable than the other correlations found. These findings showed that the earliness of grapes depends on the EHSR in the FB-V and V-M periods rather than the earlier onset of the BB period or the EHSR between BB and FB of the grape cultivar examined. Similarly, the mechanism of late ripening of berries in grape cultivars varied independently of the date when the BB period started. In other words, the grape cultivars whose berries ripen late are not the cultivars that exhibit late bud burst, but rather the cultivars with higher EHSR values in the FB-V and V-M periods. In their studies on different grape cultivars conducted in Ankara and Şanlıurfa for 4 and 2 years, respectively, Çelik et al. (2005) and Odabaşıoğlu and Gürsöz (2021) found similar results. Similar findings were also found in many studies on different grape cultivars (Cangi et al., 2008; Cangi and Altun, 2015; Kunter et al., 2017). Therefore, the relevant findings of the present study are close to those of other studies in the literature.

Conclusion

Among the methods used to calculate EHSR values of grape cultivars, Winkler et al.'s (1974) was the most appropriate since it provided a clear distinction and comparison between grape cultivars both between different phenological growth stages and between periods from bud burst to harvest. In addition, using DAT-1 to calculate the T_{DAT} value (T_{DAT-1}) utilized in the method reported by Winkler et al. (1974) was the most appropriate method that can provide results closest to reality. The calculation methods of DAT-1 and Winkler et al. (1974) can be used not only to determine the EHSR values of grapes between different phenological growth stages, but also to determine the EHSR values between different growth stages of different plant species and the effective heat summation potential of a given region. It should also be noted that it is important to use daily temperature values instead of monthly temperature values in calculating the EHSR values of grape cultivars and other plant species in order to obtain more precise and accurate results. Additionally, it is suggested that a new thermal index and calculation method for use in climate change conditions that are expected to become more aggravated in the future can be established by reorganizing the EHSR calculation methods examined in the present study by integrating the upper base temperature (*Tub*) values of grapevines into these methods. Further studies using different datasets obtained in different climate conditions may demonstrate the usability of the DAT and EHSR calculation methods examined in the present study in determining the EHSR value of grape cultivars grown in different ecologies or in evaluating the suitability of a particular region in terms of viticulture.

Conflict of interests. The author declares no conflict of interests.

Data availability. The data of this study can be requested from the author via email.

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