International Journal of
Agriculture, Environment and Food Sciences

e-ISSN: 2618-5946 https://dergipark.org.tr/jaefs

DOI: https://doi.org/10.31015/jaefs.2024.4.26 Int. J. Agric. Environ. Food Sci. 2024; 8(4): 970-979

Effects of temperature rise on grapevine phenology (*Vitis vinifera* L.): Impacts on early flowering and harvest in the 2024 Growing Season

Turcan Teker[1]

[1]Department of Horticulture, Faculty of Agriculture, Eskişehir Osmangazi University, Eskişehir, Türkiye

Article History
Received: November 02, 2024
Revised: December 22, 2024
Accepted: December 25, 2024
Published Online: December 26, 2024

Article Info
Article Type: Research Article
Article Subject: Oenology and Viticulture

Corresponding Author
Turcan Teker
turcan.teker@ogu.edu.tr

Available at
https://dergipark.org.tr/jaefs/issue/87864/1588981

DergiPark AKADEMİK

Abstract

Numerous studies have documented that climate change will considerably impact grapevine phenology. In the 2024 growing season, notable differences emerged from the previous five years, between 2019 and 2023. Rising temperatures at the beginning of the growth cycle of grapevines began the phenology phases earlier, leading to earlier bud burst and flowering for various grape varieties in many regions of Türkiye. This study examines variations in phenological phases across different years, using short-term climate data from a weather station in a cv. Sultan 7 (*Vitis vinifera* L.) vineyard in Yunusemre, Manisa, Türkiye. The objective of the study is to determine the impact of temperature fluctuations ranging from January to September on grapevine phenology intervals during critical stages: bud burst, full bloom, veraison, and maturity, specifically for between 2019 and 2024. Evaluations focused on critical factors, including growth cycle duration, days within specific temperature ranges, effective heat summation for the variety, and the Winkler Index values. The 2024 growing season recorded the highest temperatures in April and June, and bud burst occurred 5 days (2021) to 10 days (2019) earlier, while full bloom was determined for 16 days (2019 and 2022) to 27 days (2021) earlier than in previous years. The findings showed that years characterized by earlier flowering, 2024 (day of the year (DOY) 120) and 2022 (DOY 136), may be associated with earlier harvest. In addition, the Winkler Index recorded a highest of 2945.01 growing degree days (GDD) in 2024, with a specific effective heat summation value of 2,138.79 GDD for variety in a shorter timeframe. The findings suggest that although the intervals between veraison and harvest tend to remain almost similar each year, early flowering, the ripening period, and elevated temperatures before veraison in the same season can greatly contribute to prompting an earlier harvest.

Keywords: Bloom, Phenology, Heat requirement, Grape, Climate change, Vineyard

Cite this article as: Teker, T. (2024). Effects of temperature rise on grapevine phenology (*Vitis vinifera* L.): Impacts on early flowering and harvest in the 2024 Growing Season. International Journal of Agriculture, Environment and Food Sciences, 8(4), 970-979. https://doi.org/10.31015/jaefs.2024.4.26

INTRODUCTION

Many studies from around the globe have underscored the effects of climate change on viticulture. Particularly, rising temperatures significantly affect the phenology (Fraga et al., 2012; Munoz-Organero et al., 2022; Cameron et al., 2022; Ramos et al., 2023; Parker et al., 2024; Espinosa-Roldán et al., 2024) and physiological responses of grapevines (Bartlett and Sinclair, 2021; Arias et al., 2022; Wu et al., 2023), as well as vine yield and grape quality (Rogiers et al., 2022; Rafique et al., 2023; Teker 2023; Teker and Soltekin, 2023).

Previous research indicates that the impact of climate change on grapes and their phenological cycles will differ based on location and cultivar (Jones et al., 2012; Arias et al., 2022; Parker et al., 2024). The relationship between grapevine phenology and climate variables differs in various phenophases. Moreover, maximum temperatures strongly influence early season events, such as bud break and bloom. In contrast, for later season events like veraison and harvest, average temperatures, growing degree-days (Winkler Index), and Huglin index values play a more significant role (Dalla Marta et al., 2010; Alikadic et al., 2019). On the other hand, rising temperatures have been associated with an advance of 6 to 25 days in the phenological stages of various grape varieties across Europe. On average, this shift corresponds to a response of 3 to 6 days for each 1°C increase in temperature observed over the past 30 to 50 years (Jones et al., 2005; Jones, 2007). Moreover, a recent study in Italy by Alba et al. (2024) indicates that wine regions must adjust to considerably warmer climate conditions, which may impact the quality and distinctiveness of the wines produced.

During the 2024 growing season, many regions worldwide faced record-high temperatures in April. The global surface air temperature reached 15.03°C, 0.67°C above the 1991-2020 average and 0.14°C higher than the previous April record of 14.89°C set in 2016. In Europe, April 2024 was 1.49°C warmer than the 1991-2020 average, marking it the continent's second-warmest April (Copernicus Climate Change Service [CCCS], 2024). Similarly, analysis indicates that April and June are the hottest months in Türkiye over the past 53 years. Average temperatures increased from 12.3°C in April and 21.8°C in June between 1991 and 2020 to 16.6°C and 25.4°C, respectively, in 2024 (TMS, 2024a; 2024b). This phenomenon also impacted various viticultural regions in Türkiye during key phases of grapevine growth, particularly at the onset of growth in April and during the berry set in June. Consequently, this unusual climatic occurrence is believed to have led to an earlier-than-expected harvest time of many varieties in 2024.

This study examined the changes in phenological phases of the grape variety cv. Sultan 7 (*Vitis vinifera* L.) has been widely cultivated in the Aegean Region in the western part of Türkiye over the past six years (2019-2024). This study focuses on three main questions: 1) What minimum, average, and maximum temperatures were recorded from January to September (from a near-dormant phase to the time of harvest) between 2019 and 2024? 2) How did the variations between the years impact the grapevine growth cycle and phenological phases? 3) How was the variation in effective heat summation, a measure of cumulative growing degree days from budburst to harvest for the grape cultivar studied, and how did the temperatures influence the Winkler Index?

MATERIALS AND METHODS

Study area and plant material

Temperature data, including minimum, mean, and maximum values, were collected monthly and daily from 2019 to 2024 from a weather station (iMETOS IMT 280, Pessl Instruments, Weiz, Austria) situated in Yunusemre (YE) [38°37′ N, 27°24′ E; Altitude (A): 44 m], which is centrally located in the Manisa province of western Türkiye. Due to the unavailability of data for October 2024 from the Yunusemre station, information was obtained from the Muradiye station (38°41′ N, 27°22′ E; A: 23 m), located almost 6.37 kilometers away from the YE station. Manisa city center generally has a warm-temperate climate, with recent hot and dry summer seasons and limited rain (Teker and Altındişli, 2021). However, the average annual temperatures are 16.9 ℃ with 743.6 mm of precipitation per year according to the long-term regime from 1930-2023 (TMS, 2024c). As a plant material, cv. Sultan 7 (*Vitis vinifera* L.) cultivar was used to understand the length of the vegetation period and emphasize the phenological phase differences between years.

Determination of phenological stages in cv. Sultan 7 (*Vitis vinifera* L.)

To assess the phenological stages of cv. Sultan 7 between 2019 and 2024, the modified Eichhorn & Lorenz (EL) system, as outlined by Coombe (1995), was employed. This approach allowed for the precise determination of key stages, including bud burst (EL 4), full bloom (EL 26), veraison (EL 35), and harvest (EL 38). The vegetation period length was also determined using these terms in each year.

Seasonal temperature ranges and variations (2019-2024)

Minimum, mean, and maximum temperatures were recorded daily between 2019 and 2024. The number of days with temperatures below 0°C (T°C ≤ 0°C), as well as those within the ranges of 0°C to 5°C, 5°C to 10°C, and 10°C to 20°C, specifically during January, February, March, and April was determined. Maximum temperature ranges were analyzed, focusing on the number of days with increasing temperatures from April to September. This evaluation encompassed the onset of the growth cycle and the period following the harvest. These ranges included 10℃ to 25℃, 25℃ to 30℃, 30℃ to 35℃, 35℃ to 40℃, and temperatures exceeding 40℃ (where T℃ is greater than or equal to 40). April 2024 was included in both evaluations due to its notable differences from the other years under consideration. The variations in these temperature ranges across different years were then depicted in graphs.

The determination of heat summation as growing degree days for studied cultivar

The phenological observation dates established for the cv. Sultan 7 grape variety were utilized to calculate heat summation as Growing Degree Days (GDD). Cumulative values of GDD were determined based on the specific phenological stages of the variety, which include the periods from bud burst to full bloom, from full bloom to veraison, and between veraison and harvest in the vegetation period of grapevines. The cumulative GDD formula employed in these calculations is presented in Equation 1.

$$\sum_{Bud\ Burst}^{Full\ Bloom}\left(\frac{Tmax+Tmin}{2}-10℃\right)+\sum_{Full\ Bloom}^{Veraison}\left(\frac{Tmax+Tmin}{2}-10℃\right)+\sum_{Veraison}^{Harvest}\left(\frac{Tmax+Tmin}{2}-10℃\right)=\sum_{Bud\ Burst}^{Harvest}\left(\frac{Tmax+Tmin}{2}-10℃\right) \quad (1)$$

Winkler Index (WI)

The WI was determined as GDD by summing the total degrees of mean daily temperatures exceeding 10°C for each day during the vegetation period, which was conducted from April 1 to October 31 across the years 2019 to 2024 (Winkler, 1974). Differences were revealed between years. The formula utilized for these calculations is provided in Equation 2.

$$WI = \sum_{April\ 1}^{October\ 31} \left(\frac{Tmax + Tmin}{2} - 10°C \right) \quad (2)$$

Statistical analysis and evaluation data

From January to October, the average, maximum, and minimum temperatures were analyzed monthly using statistical methods. The temperature values underwent a Shapiro-Wilk normality test. As a result, differences between 2019 and 2024 are presented as monthly comparisons based on a one-way ANOVA test accompanied by Tukey's multiple comparison test. Furthermore, the number of days within specific monthly temperature ranges was calculated, and these results were presented as raw data. The cumulative GDD values, Winkler Index calculations, vegetation period length, and phenological phases for each year were presented as raw data, and the differences were represented in a graph.

RESULTS AND DISCUSSION

Weather conditions of the study area and phenological phases

This study investigates the reasons behind the earlier grape harvest in Türkiye in 2024 compared to the previous five years (2019-2023) and a change driven by rising temperatures, a trend observed in many regions worldwide. Furthermore, the study explores the relationship between temperature fluctuations and the phenological changes that occur throughout the growing seasons of the relevant years.

According to the monthly bulletins from the Copernicus Climate Change Service, average temperatures recorded in 2024 have set new national and global records compared to values from 1991 to 2020. Notably, February, April, and June have experienced unprecedented temperatures (CCCS, 2024). In Türkiye, April and June in 2024 have also marked the highest temperatures in the past 53 years (TMS, 2024a; 2024b). Previous research has shown a notable advancement in the timing of three critical phenological phases of grapevines: flowering, veraison, and maturity (Cameron et al., 2022). Studies suggest that temperature is a key factor driving these changes in phenological phases (Bock et al., 2011; Ramos et al., 2023; Parker et al., 2024). As a result, there have been significant shifts in the timing of grape harvests compared to previous years, with many regions completing their harvests earlier in 2024.

Assessment of variations in monthly temperatures (2019-2024)

Figure 1 illustrates the variations in the monthly mean values of minimum, average, and maximum temperatures from January to September between 2019 and 2024. Notably, during the months that are crucial for the growing season and vegetative development of grapevines, particularly February (Figure 1B), March (Figure 1C), April (Figure 1D), and June (Figure 1F) in 2024, the average and maximum temperature values, monthly for 2024 were notably higher than those recorded in the preceding five years. In the western region of Türkiye, specifically in Manisa, the elevated average temperatures recorded in March and April were critical in determining the beginning of the grapevine growth period, as early as bud burst and flowering time. According to previous studies, the temperature values recorded during these months are significant, as they provide critical insights into initiating the primary growth cycle and the timing of flowering events (Molitor et al., 2014; García de Cortázar-Atauri et al., 2017). These findings, especially for bud burst (EL 4) in 2024, support the understanding that a rapid growth period occurs in this location. High temperatures may shorten the grapevine growth cycle between bud burst (EL 4) and flowering (EL 26). The highest average maximum temperatures in May over the past six years were recorded in 2021. However, May 2020 experienced exceptionally high temperatures that adversely affected the berry set (EL 27) of cv. Sultana Seedless and cv. Sultan 7 grapes, with temperatures surpassing 40°C for five consecutive days during their flowering period (Teker and Soltekin, 2023). In contrast, May 2024 experienced notably lower temperatures compared to previous years. Upon reviewing the May temperature data across multiple years, it has become evident that the lowest mean temperatures were observed in May 2023 and May 2024. Flowering occurred earlier in 2024 than in previous years; however, low May temperatures following a warm April slowed down growth.

In the summer, the maximum average temperature was recorded as 38.01°C in June 2024. While temperature values from previous years were similar, July 2020 reached the maximum temperature at 38.43°C, and August 2023 experienced a peak of 40.33°C. In 2024, monthly average temperatures reached the highest levels for June, July, and August, with values recorded at 29.01°C, 29.99°C, and 29.24°C, respectively, compared to the average values between 2019 and 2023 (Figure 1F-H).

Analysis of minimum temperatures showed remarkable fluctuations between previous years and 2024 because, for January through April, the differences between 2019 and 2024 were mainly due to changes in the day distribution of minimum temperatures rather than daily averages (Figure 2A). The years with the highest number of days in January recording minimum temperatures below 0°C were 2020 (17 days) and 2022 (14 days). In contrast, February exhibited a notable increase in the number of days with temperatures dropping below 0°C, with 12 days recorded in both 2022 and 2023. In sharp contrast, 2024 experienced a significant decline, reporting only 2 days below 0°C (Figure 2B). March 2022 had a considerable number of days with temperatures below zero (10 days) and between 0°C and 5°C (21 days), characterizing it as a particularly cold month because there were no days with temperatures ranging from 5°C to 10°C or from 10°C to 20°C (Figure 3C). Furthermore, it was found that 2020 (16 and 4 days, respectively) and 2024 (14 and 4 days, respectively) had a similar number of cold days during these temperature intervals. Additionally, in April 2024, no recorded day was below 5 °C, and the number of days with temperatures between 10 and 20 °C (22 days) was determined to be higher than in previous years, 2019-2023 (Figure 2D).

As for maximum temperatures, national official records indicate that April 2024 was the hottest month in the past 53 years (TMS, 2024a). This study showed that many days during that month experienced temperatures in the ranges of 25°C to 30°C and 30°C to 35°C in 2024 (Figure 3A). However, in 2023 (24 days), as well as in 2019 (23 days) and 2021 (22 days), there was a significant number of days with temperatures ranging from 10°C to 25°C. In May 2024, data indicated that the number of days with high temperatures between 25°C and 30°C, as well as between 30°C and 35°C, was comparable to the number of such days recorded in May 2023. Additionally, in the past six years, it was determined that May temperatures, particularly in 2020, reached levels exceeding 40°C (Figure 3B).

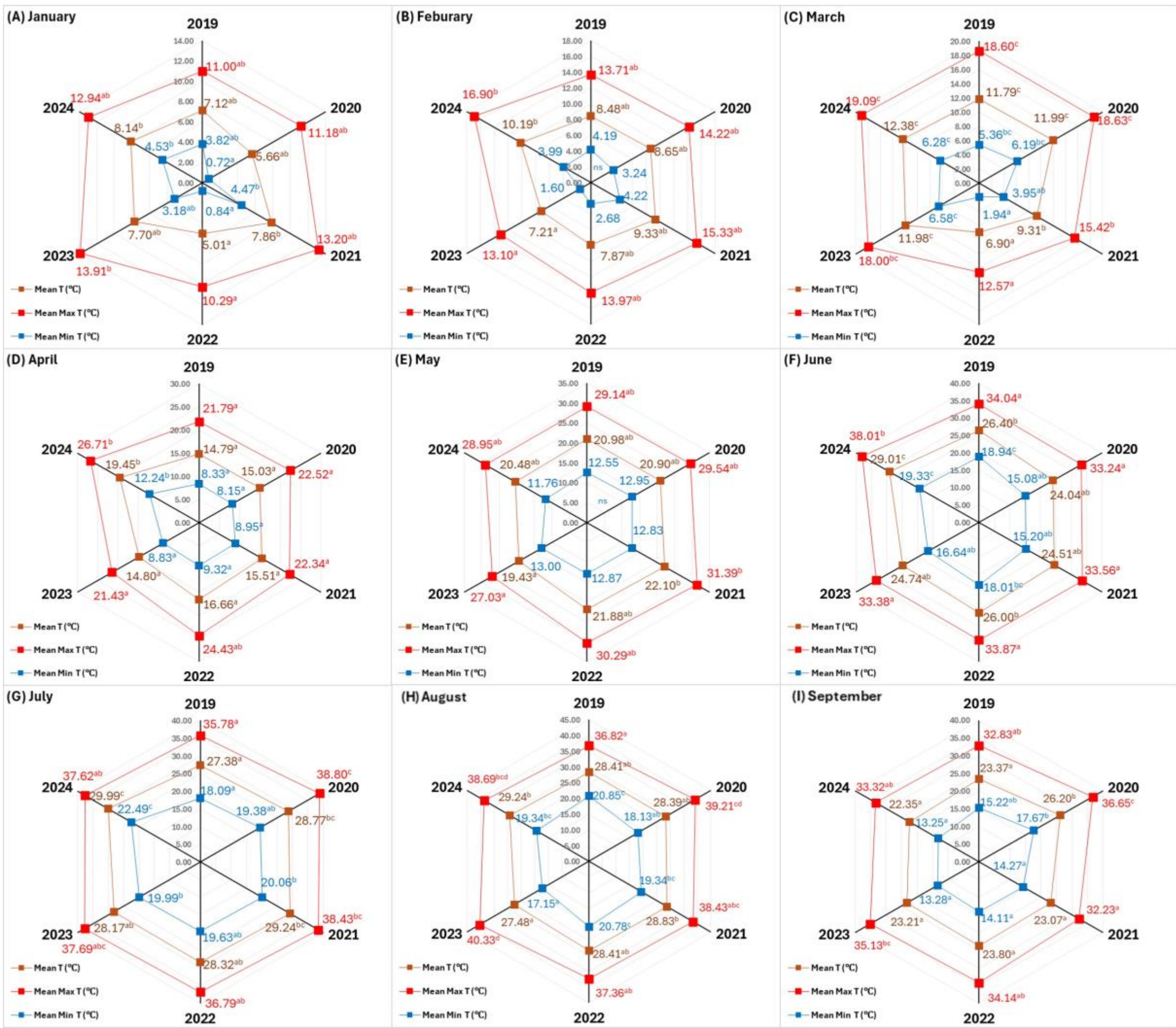

Figure 1. Monthly average minimum, mean, and maximum temperature data between January and September (A-I) from 2019 to 2024. Differences between years are indicated by letters of significance (p≤0.05). ns: non-significant.

During the summer months, particularly in June 2024, there was a significant increase in the number of days with temperatures ranging from 35°C to 40°C (24 days) exceeding 40°C (4 days). This trend made June markedly hotter in comparison to previous years. Additionally, this observation is substantiated by data indicating that temperatures in June reached unprecedented levels across the country, marking the highest recordings in the past 53 years (TMS, 2024b). A decrease in hot days was noted in July 2024; however, data showed that the highest temperatures exceeding 40°C were recorded in 2020 (11 days) and 2021 (9 days) (Figure 3E). Moreover, an analysis of temperature data reveals that August 2024 (7 days) experienced a lower frequency of high-temperature days than August 2023 (18 days), characterized by exceptionally intense heatwaves (Figure 3E).

Winkler Index values of the years

In April 2024, the WI value started with 283.41 GDD, indicating significantly warmer conditions compared to previous years, which recorded values ranging from 143.57 GDD to 199.66 GDD. As illustrated in Figure 1D, the average and maximum temperatures in April were higher than in previous years, further supporting this observation. Despite the low GDD value observed in previous years, except in 2023, a similar trend emerged in June when the GDD value reached 570.29. The maximum temperatures in July 2024 were comparable to those in previous years; however, a significant increase was observed in June due to elevated average and minimum temperatures (Figure 1G), contributing to a GDD of 620.28 (Figure 4). The WI value in 2024 was notably high due to the increased temperatures recorded in April and June during the growing season. The total WI for 2024 reached 2,945.01 GDD. By contrast, the year with the lowest GDD was 2023, with a total of 2,538.57 GDD (Figure 4).

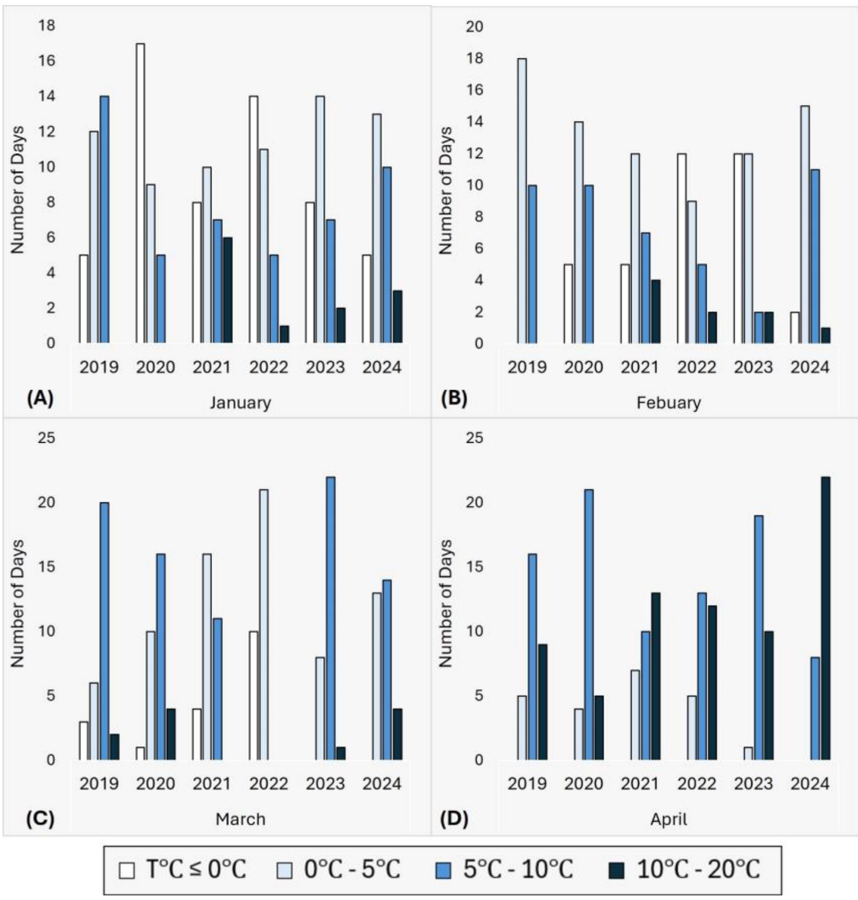

Figure 2. Illustration of the number of days with minimum temperatures in the ranges of T°C ≤ 0°C; 0°C - 5°C; 5°C - 10°C; and 10°C - 20°C from January to April (A-D) for the years 2019 to 2024.

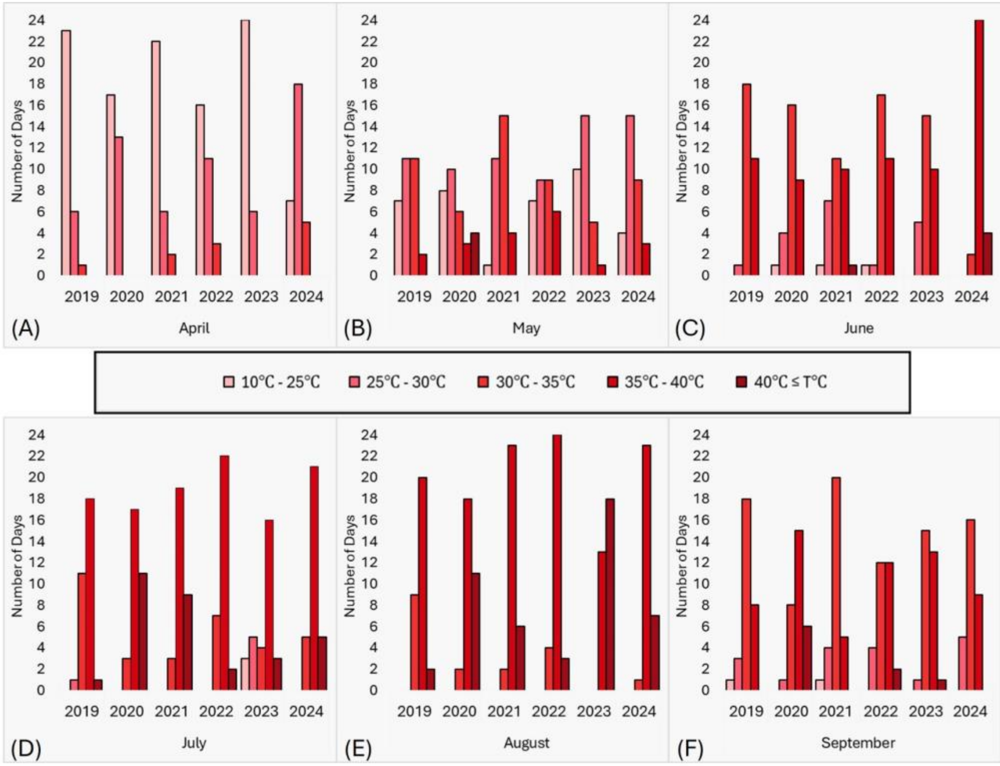

Figure 3. Illustration of the number of days with maximum temperatures in the ranges of 10°C - 25°C; 25°C - 30°C; 30°C - 35°; 35°C - 40°C and 40°C ≤ T°C from April to September (A-F) for the years 2019 to 2024.

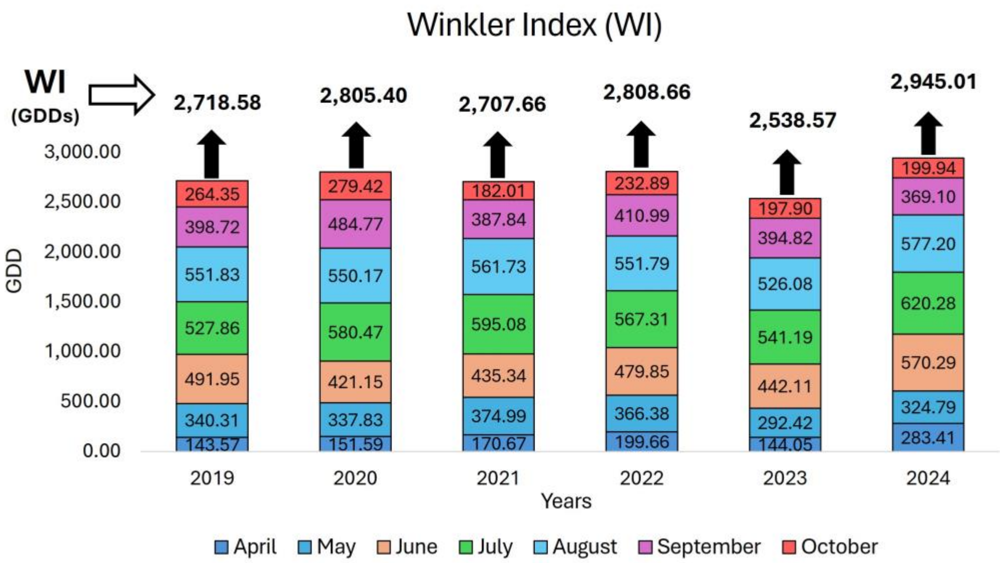

Figure 4. The graph of the calculation of Winkler Index values by months for 2019-2024.

Vegetation period and growing degree days

The period of grapevine phenological phases changes by season and is mainly impacted by climate (Fraga et al., 2012; Santos et al., 2020; Cameron et al., 2022). This study examined the variations in the length of the growth cycle of grapevines (Figure 4) and total effective heat summation values for the selected cultivar cv. Sultan 7 (Figure 5), providing a knowledge of yearly differences. The vegetation periods for grape variety were pretty much the same between 2019 and 2023. However, the vegetation period in 2024 was shorter than in 2019 and 2023 (Figure 4). Although the cultivar experienced its longest vegetation period in 2020 and 2023 (248 days), 2024 also experienced its shortest vegetation period (228 days).

There is a noticeable difference in bud burst and flowering timings in 2024 between 2019 and 2023. While bud burst varied between 79 and 85 days between the beginning of the year (January 1st) between 2019 and 2023, bud burst occurred in 75 days in 2024. Furthermore, while there was a lengthy difference between bud burst and full bloom between 2019 and 2023, which varied between 51 and 67 days, the full bloom was completed on the 120th day of the year, 45 days after bud burst, as an early time interval in 2024. Cameron et al. (2022) found that the interval from budburst to flowering can be reduced more significantly than the intervals between berry set, veraison, and harvest, with a curvilinear relationship between these intervals and maximum temperature.

Previous research has investigated the interval between flowering and veraison. Malheiro et al. (2013) reported the strongest correlation between these two stages across all varieties studied. Additionally, Tomasi et al. (2011) noted that this interval exhibited variation, further supporting their conclusions.

This study determined that the interval between flowering and veraison ranged from 50 days in 2021 to 65 days in 2024. Remarkably, the difference between flowering and veraison was more significant in 2024, even though early flowering occurred that year. In contrast, the longest interval between veraison and harvest was 49 days, as seen in 2021 and 2023. The period between veraison and harvest also reduced to 41 days in 2022, 43 days in 2019, and 2024, and these years also experienced the shortest time from bud burst to full bloom (Figure 5). The variations in the durations during these periods have led to differing interpretations. Jones and Davis (2000) suggested that there could be a notable reduction in the intervals between flowering and veraison, flowering and harvest, veraison and harvest. Similarly, Bock et al. (2011) observed a trend of shortening in the interval between flowering and veraison in Franconia, Germany. Another study by Kartschall et al. (2015) reveals that in Germany, the acceleration of grapes' phenological development across all major stages may reach 11 ± 3 days, with harvest maturity occurring 13 ± 1 day earlier. Likewise, Duchêne et al. (2014) observed that in Alsace, France, phenological stages could advance by 8 to 11 days for budburst and by 16 to 24 days for ripening by the end of the 21st century. In contrast, Tomasi et al. (2011) did not identify a significant decrease in the intervals between flowering and veraison or between flowering and harvest. In addition, it is essential to note that the decisions made by viticulturists and winemakers can influence harvest timing (Tomasi et al., 2011; Cameron et al., 2022).

The analysis of all years in this study demonstrated that early flowering time (the day interval between bud burst and full bloom) may be more significant than the interval between flowering and veraison in predicting an early harvest date. Furthermore, it was noted that early flowering occurred in 2019, 2022 (DOY 136), and 2024 (DOY 120), all of which were associated with earlier harvest dates (DOY 240, DOY 236, and DOY 228, respectively).

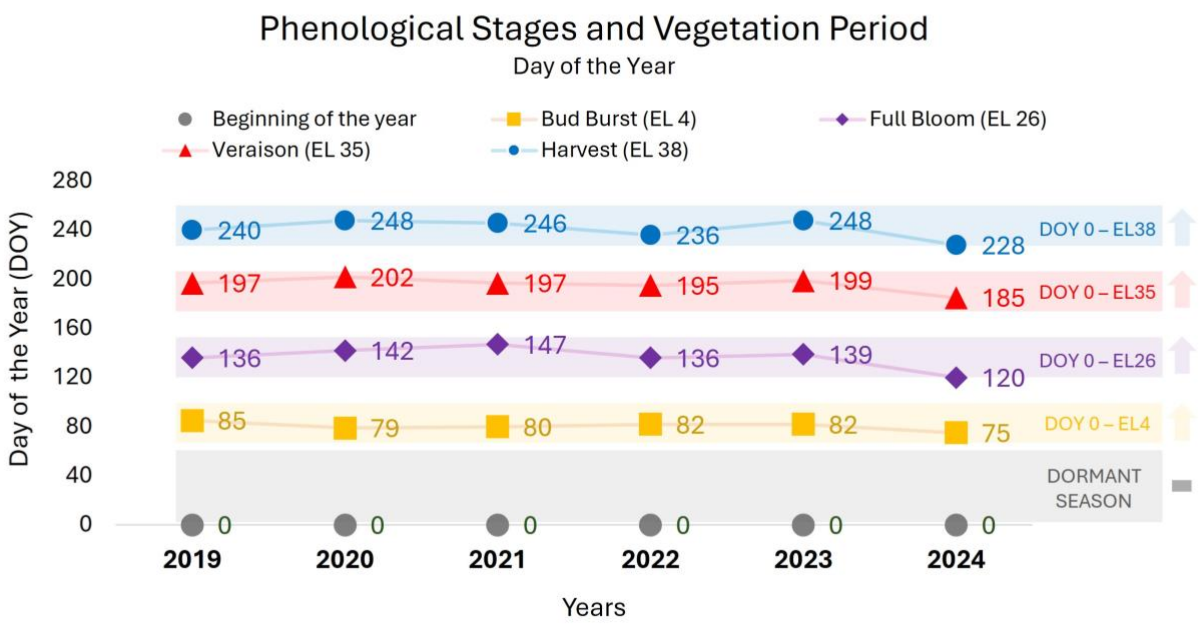

Figure 5. Illustration of the growing season length classified by phenological stages for 2019 to 2024. The grey line represents the entire dormant season; the yellow line indicates bud burst (EL4); the purple line shows full bloom (EL26); the red line marks veraison (EL35); and the blue line depicts harvest time (EL38), starting from the beginning of the year (DOY 0).

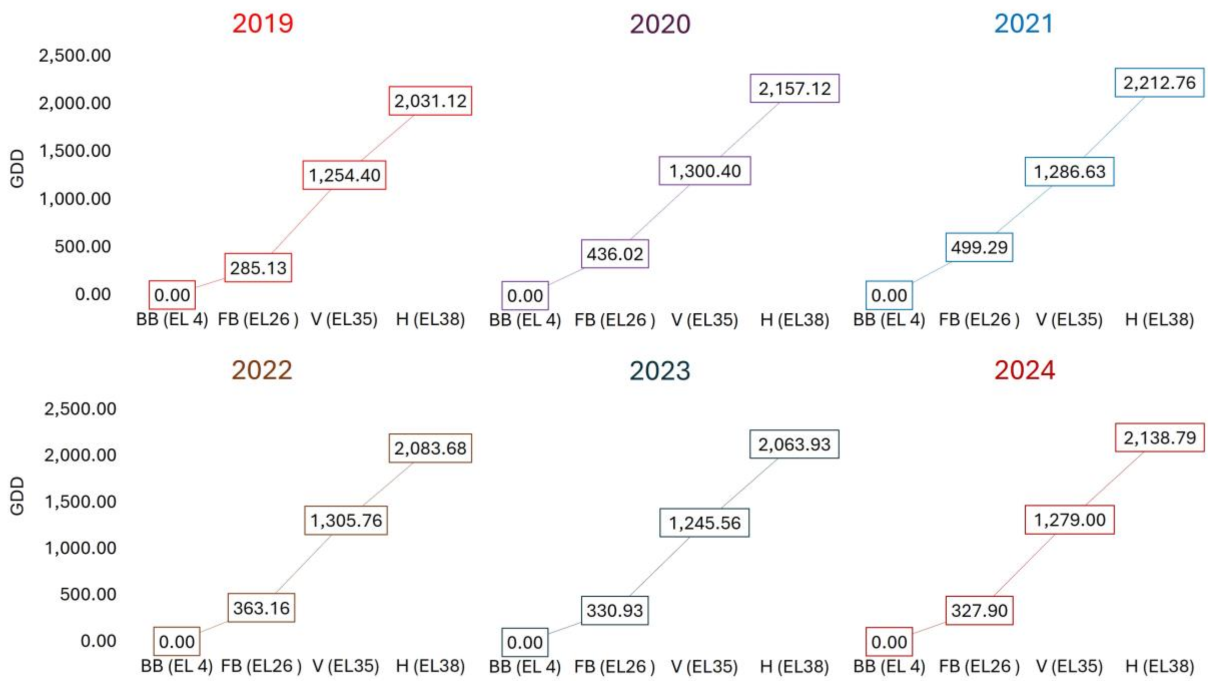

Figure 6. Illustration of the cumulative growing degree days classified by phenological stages of cv. Sultan 7 for 2019 to 2024. BB (EL4) represents the bud burst; FB indicates full bloom (EL26), V marks veraison (EL35), and H depicts harvest time (EL38).

The vegetation periods significantly influenced the effective heat summation of the variety each year (Figure 6). In 2020 (DOY 142) and 2021 (DOY 147), the late flowering times resulted in notably high effective temperature totals between bud burst and full bloom, with 436.02 GDD recorded in 2020 and 499.29 GDD in 2021. These figures were substantially higher than those observed in other years. Conversely, in the years 2019, 2023, and 2024, where flowering occurred earlier than in different years, it was observed that the GDD recorded between bud burst and full bloom were 285.13, 330.93, and 327.90, respectively. Notably, flowering in 2024 occurred on the 120th day, 16 days earlier than in 2019 and 2023. This early flowering was attributed to significantly high temperatures experienced before flowering in March and April. This study shows that the GDD value was higher than in 2019 in the same phenological phases in 2024, and the temperatures were higher in the same year (Figure 1). Therefore, the temperatures occurring before flowering in 2024 were relatively high compared to those in the last six years. On the other hand, despite a shorter vegetation period in 2024, it generated an effective heat summation value similar to 2020 and 2023. The study conducted by Templ et al. (2021) reveals a significant negative linear correlation (r = -0.62), indicating that as mean temperatures increase, the intervals within the DOY phenophase tend to shorten. This finding also underscores the impact of rising temperatures on phenological events.

CONCLUSION

Temperature distributions during the growing seasons in viticulture significantly influence the timing of phenological stages. Furthermore, variations in weather data across different years within a region can lead to changes in the monthly phenology of grapevines cultivated in that location. This study evaluates the monthly minimum, average, and maximum temperature values recorded over the past six years. It examines the Winkler Index and the changes in the vegetation period of the selected cultivar, cv. Sultan 7, and the distribution of these changes throughout the years and their respective phenological periods. Besides, the effective heat summation was calculated for the selected cultivar. As a result, the temperature data of the location in the last six years was higher in March, April, and June of 2024 compared to other years. In 2024, the flowering occurred earlier than in other years, and the harvest date was earlier than expected.

This study showed that an early bud burst and elevated temperatures in April led to a shorter interval between bud burst and flowering in the 2024 growing season. According to the Winkler Index calculation, the growing degree days value in April 2024 surpassed that of previous years between 2019 and 2023. In addition, June temperatures were unusually high, and July minimum temperatures were higher than those recorded in previous years. While the period (the number of days) between veraison and harvest has remained almost the same as in previous years, the harvest date occurred earlier than expected because both flowering and the beginning of veraison were determined earlier in the 2024 growing season.

Future studies should focus on short-term weather data in a specific unusual year, combined with comprehensive long-term research and potential climate scenarios, to enhance our understanding of recent changes in phenological stages due to elevated temperatures. These studies should examine the phenological phases of different grape cultivars over the coming years, particularly during warmer seasons and unusual weather events. The studies should also analyze these trends across various regions worldwide and compare them with previous seasons.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed.

Declaration of Interests

The author has no conflict of interest to declare.

Author contribution

TT designed the study and performed it. Wrote the paper and reviewed it.

REFERENCES

Alba, V., Russi, A., Caputo, A. R., & Gentilesco, G. (2024). Climate Change and Viticulture in Italy: Historical Trends and Future Scenarios. Atmosphere, 15(8), 885. https://doi.org/10.3390/atmos15080885

Alikadic, A., Pertot, I., Eccel, E., Dolci, 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. Agricultural and Forest Meteorology, 271, 73-82. https://doi.org/10.1016/j.agrformet.2019.02.030

Arias, L. A., Berli, F., Fontana, A., Bottini, R. & Piccoli, P. (2022). Climate change effects on grapevine physiology and biochemistry: Benefits and challenges of high altitude as an adaptation strategy. *Frontiers in Plant Science*, 13, 835425. https://doi.org/10.3389/fpls.2022.835425

Bartlett, M. K. & Sinclair, G. (2021). Temperature and evaporative demand drive variation in stomatal and hydraulic traits across grape cultivars. Journal of Experimental Botany, 72(5), 1995-2009. https://doi.org/10.1093/jxb/eraa577

Bock, A., Sparks, T., Estrella, N. & Menzel, A. (2011). Changes in the phenology and composition of wine from Franconia, Germany. Climate Research, 50(1), 69-81. https://doi.org/10.3354/cr01048

Cameron, W., Petrie, P. R. & Barlow, E. W. R. (2022). The effect of temperature on grapevine phenological intervals: Sensitivity of budburst to flowering. Agricultural and Forest Meteorology, 315, 108841. https://doi.org/10.1016/j.agrformet.2022.108841

Coombe, B. G. (1995). Growth stages of the grapevine: adoption of a system for identifying grapevine growth stages. Australian Journal of Grape and Wine Research, 1(2), 104-110. https://doi.org/10.1111/j.1755-0238.1995.tb00086.x

Copernicus Climate Change Service (CCCS), (2024). Surface air temperature for April 2024. Climate Bulletins. Retrieved in November, 20, 2024, from https://climate.copernicus.eu/surface-air-temperature-april-2024

Dalla Marta, A., Grifoni, D., Mancini, M., Storchi, P., Zipoli, G. & Orlandini, S., 2010. Analysis of the relationships between climate variability and grapevine phenology in the Nobile di Montepulciano wine production area. Journal Agriculture. Science, 148, 657–666. https://doi.org/10.1017/S0021859610000432.

Duchêne, E., Huard, F. & Pieri, P. (2014). Grapevine and climate change: what adaptations of plant material and training systems should we anticipate. Journal International des Sciences de la Vigne et du Vin, 3, 61-69.

Espinosa-Roldán, F. E., García-Díaz, A., Raboso, E., Crespo, J., Cabello, F., Martínez de Toda, F. & Muñoz-Organero, G. (2024). Phenological Evaluation of Minority Grape Varieties in the Wine Region of Madrid as a Strategy for Adaptation to Climate Change. Horticulturae, 10(4), 353. https://doi.org/10.3390/horticulturae10040353

Fraga, H., Malheiro, A. C., Moutinho-Pereira, J. & Santos, J. A. (2012). An overview of climate change impacts on European viticulture. Food and Energy Security, 1(2), 94-110. https://doi.org/10.1002/fes3.14

García de Cortázar-Atauri , I.,, Duchêne, E., Destrac, A., Barbeau, G., De Rességuier, L., Lacombe, T., Parker, A.K., Saurin, N. & van Leeuwen, C. (2017). Grapevine phenology in France: from past observations to future evolutions in the context of climate change. Oeno One, 51(2), 115-126. https://doi.org/10.20870/oeno-one.2016.0.0.1622

Jones, G. V. & Davis, R. E. (2000). Using a synoptic climatological approach to understand climate–viticulture relationships. International Journal of Climatology, 20(8), 813-837. https://doi.org/10.1002/1097-0088(20000630)20:8<813::AID-JOC495>3.0.CO;2-W

Jones G.V., White M.A.,Cooper O.R. & Storchmann K. (2005). Climate change and global wine quality. Climate. Change, 73, 319–343. https://doi.org/10.1007/s10584-005-4704-2.

Jones, G. V. (2007). Climate change: observations, projections, and general implications for viticulture and wine production. In: Climate and Viticulture Congress, Zaragoza, 10th – 14th April 2007.

Jones, G. V., Reid, R. & Vilks, A. (2012). Climate, grapes, and wine: structure and suitability in a variable and changing climate. In: P.H. Dougherty (Eds), The geography of wine: regions, terroir and techniques (pp. 109-133). Springer.

Kartschall, T., Wodinski, M., Von Bloh, W., Oesterle, H., Rachimow, C. & Hoppmann, D. (2015). Changes in phenology and frost risks of *Vitis vinifera* (cv Riesling). Meteorologische Zeitschrift, 24:189-200.

Malheiro, A. C., Campos, R., Fraga, H., Eiras-Dias, J., Silvestre, J. & Santos, J. A. (2013). Winegrape phenology and temperature relationships in the Lisbon wine region, Portugal. OENO One, 47(4), 287-299. https://doi.org/10.20870/oeno-one.2013.47.4.1558

Molitor D., Caffarra A., Sinigoj P., Pertot I., Hoffmann L. & Junk J. (2014). Late frost damage risk for viticulture under future climate conditions: a case study for the Luxembourgish winegrowing region. Australian Journal of Grape and Wine Research. 20, 160-168. https://doi.org/10.1111/ajgw.12059

Munoz-Organero, G., Espinosa, F. E., Cabello, F., Zamorano, J. P., Urbanos, M. A., Puertas, B., ... & Fernandez-Pastor, M. (2022). Phenological study of 53 Spanish minority grape varieties to search for adaptation of vitiviniculture to climate change conditions. Horticulturae, 8(11), 984. https://doi.org/10.3390/horticulturae8110984

Parker, L. E., Zhang, N., Abatzoglou, J. T., Kisekka, I., McElrone, A. J. & Ostoja, S. M. (2024). A variety-specific analysis of climate change effects on California winegrapes. International Journal of Biometeorology, 1-13. https://doi.org/10.1007/s00484-024-02684-8

Rafique, R., Ahmad, T., Ahmed, M., Khan, M. A., Wilkerson, C. J. & Hoogenboom, G. (2023). Seasonal variability in the effect of temperature on key phenological stages of four table grapes cultivars. International Journal of Biometeorology, 67(5), 745-759. https://doi.org/10.1007/s00484-023-02548-7

Ramos, M. C. & Yuste, J. (2023). Grapevine phenology of white cultivars in rueda designation of origin (Spain) in response to weather conditions and potential shifts under warmer climate. Agronomy, 13(1), 146. https://doi.org/10.3390/agronomy13010146

Rogiers, S. Y., Greer, D. H., Liu, Y., Baby, T. & Xiao, Z. (2022). Impact of climate change on grape berry ripening: An assessment of adaptation strategies for the Australian vineyard. Frontiers in Plant Science, 13, 1094633. https://doi.org/10.3389/fpls.2022.1094633

Santos, J. A., Fraga, H., Malheiro, A. C., Moutinho-Pereira, J., Dinis, L. T., Correia, C., ... & Schultz, H. R. (2020). A review of the potential climate change impacts and adaptation options for European viticulture. Applied Sciences, 10(9), 3092. https://doi.org/10.3390/app10093092

Teker, T. & Altindisli, A. (2021). Excessive pruning levels in young grapevines (Vitis vinifera L. cv. Sultan 7) cause water loss in seedless cluster berries. International Journal of Fruit Science, 21(1), 979-992. https://doi.org/10.1080/15538362.2021.1964416

Teker, T. & Soltekin, O. (2023). Berry shattering phenomena in vineyards: The influence of maximum temperatures during flowering period in an extreme year. Scientia Horticulturae, 321, 112278.

Teker, T. (2023). A study of kaolin effects on grapevine physiology and its ability to protect grape clusters from sunburn damage. Scientia Horticulturae, 311, 111824. https://doi.org/10.1016/j.scienta.2022.111824

Templ, B., Templ, M., Barbieri, R., Meier, M. & Zufferey, V. (2021). Coincidence of temperature extremes and phenological events of grapevines. OENO One, 55(1), 367-383.

TMS, (2024a). Turkish State Meteorological Service, Assessment of temperature and rainfall in April 2024 (In Turkish). Retrieved in October, 20, 2024, from https://www.mgm.gov.tr/FILES/iklim/yillikiklim/2024/Nisan-Sicaklik-Yagis-Degerlendirmesi.pdf

TMS, (2024b). Turkish State Meteorological Service, Assessment of temperature and rainfall in June 2024 (In Turkish). Retrieved in October, 20, 2024, from https://www.mgm.gov.tr/FILES/iklim/yillikiklim/2024/Haziran-Sicaklik-Yagis-Degerlendirmesi.pdf

TMS, (2024c). Turkish State Meteorological Service, official climate statistics (Manisa) (In Turkish). Retrieved in October, 20, 2024, from https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=A&m=MANISA

Tomasi, D., Jones, G. V., Giust, M., Lovat, L. & Gaiotti, F. (2011). Grapevine phenology and climate change: relationships and trends in the Veneto region of Italy for 1964–2009. American Journal of Enology and Viticulture, 62(3), 329-339. https://doi.org/10.5344/ajev.2011.10108

Winkler, A.J. (1974). General viticulture. University of California Press.

Wu, J., Abudureheman, R., Zhong, H., Yadav, V., Zhang, C., Ma, Y., ... & Wang, X. (2023). The impact of high temperatures in the field on leaf tissue structure in different grape cultivars. Horticulturae, 9(7), 731. https://doi.org/10.3390/horticulturae9070731