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The impact of heat units on the physical and chemical characteristics of two grape varieties in Egypt

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ABSTRACT

Purpose: Climatic circumstances are significant determinants in the formation and growth of the vine. Due to variations in climatic parameters, high-temperature affects phenology, the ripening period, and physicochemical characteristics are detrimental to the quality of the grapes produced and gradually decrease the yield. **Research method:** This investigation studies the effect of heat units on the yield and fruit quality of some grape cultivars in different regions of Egypt. This trial evaluates two grape cultivars (Flame Seedless and Crimson Seedless) grown in three distinct locations (El-Behira, El-Menoufia, and El-Minia governorates) during seasons (2021 and 2022). **Findings:** Heat units negatively affect the phenological dates of the grape growth cycle. However, the warmer regions (El-Minia governorate) accelerated various phases or stages in the phenological development of grapevines, including bud burst, full flowering, fruit set, veraison, and grape maturity as compared to the moderate regions (El-Behira and El-Menoufia governorates). Regarding yield and its attributes, the moderate regions (El-Behira and El-Menoufia governorates) had the highest yield. They improved the bunch physiochemical attributes of Flame Seedless and Crimson Seedless grapes compared to the warmer region (El-Minia governorate). **Research limitations:** There were no limits. **Originality/Value:** Heat units negatively affect the phenological stages of grape growth (bud break, full flowering, fruit set, veraison, and grape maturity) and physicochemical characteristics.

INTRODUCTION

Among all cultivated plants, grapevines are considered one of the most responsive to their environment (Jackson, 2001). Grapes (*Vitis vinifera* L.) are among the most important horticultural products and have high nutritional value. The most significant grape species used specially to make grapevines is *Vitis vinifera*, which is also commercially very valuable. Due to their extreme environmental sensitivity, these species are found in a rather small climatic niche, which is typically found between latitudes 30–50°N and 30–40°S (Wang et al., 2020). Difference in climate parameters is considered a main factor in inter-annual variability in plant development. All crops are affected by different heat stresses during the growing season and differential response to temperature changes across crops has been observed in various production environments (Kalra, 2008). Simple to complex temperature indices are the most commonly used measurements to assess which types of grapes can be grown in which weather (Jones et al., 2010). Any change in the ideal temperature during its differentiation negatively affects the initiation and duration of different phenological events and yields (Singh et al., 2007). Meteorological conditions exert a considerable influence on the phenology of fruit trees (Gupta et al., 2020). During the veraison-maturity stage, increased temperature can significantly affect the accumulation of sugar (Greer & Weedon, 2013). A decrease in the amount of anthocyanin production may also result from this occurrence (Conde et al., 2016). Grapes can also have low acidity and high sugar levels during this time. According to recent studies, there are negative correlations between anthocyanin temperature and berry weight at technical maturity (Gouot et al., 2019). Vines are a perennial crop that requires both adequate warm and cold conditions to complete their biological processes (high temperatures for berry ripening and low temperatures for fruiting and hardening). As a result, temperature can be thought of as one of the primary determinants of the vegetative cycle's evolution, the berries' ultimate maturity, and their composition. Conversely, the high-temperature regime during the ripening phase might be advantageous to the vine. On the other hand, high temperatures can stress plants and decrease their ability to photosynthesize. Thus, this investigation aimed to study the effect of heat units on the physiochemical of some grape cultivars in different regions of Egypt.

MATERIALS AND METHODS

This survey was conducted for two consecutive seasons (2021 and 2022) in three different regions located in the Arab Republic of Egypt, namely the El-Nubaria region of El-Behira governorate, El-Sadat city of the governorate of El-Menoufia and the district of Matai of the governorate of El-Minia Governorate, where the most grape-productive areas in Egypt are located, to study the impact of thermal units on the physical chemistry of Flame Seedless and Crimson Seedless grape cultivars. The Egyptian Meteorological Authority (Table 1) was recorded.

Table 1. List of study area locations for the Egyptian Meteorological Authority.

Region	Governorate	Latitude (N)	Longitude (E)	Elevation (m)
El-Nubaria	El-Behira	30.53	30.83	9.60
El-Sadat	El-Menoufia	31.03	30.53	17.90
Matai	El-Minia	28.41	30.77	34.20

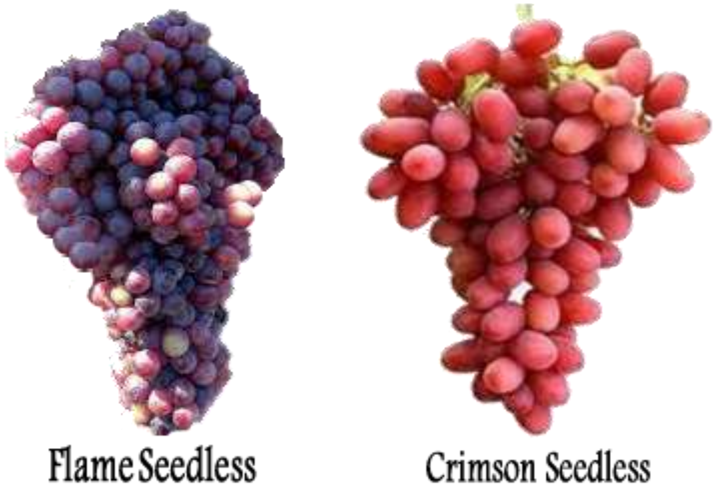

Fig. 1. Appearance of Flame Seedless and Crimson Seedless grape clusters.

Table 2. Climate data for the governorates of El-Behira, El-Menoufia, and El-Minia during the 2021 and 2022 seasons.

Governorate	El-Behira				El-Menoufia				El-Minia			
Month	Max Temp. (°C)	Min Temp. (°C)	Ppt (mm)	R.H. (%)	Max Temp. (°C)	Min Temp. (°C)	Ppt (mm)	R.H. (%)	Max Temp. (°C)	Min Temp. (°C)	Ppt (mm)	R.H. (%)
	Season 2021											
January	27.1	6.7	19.0	68.1	27.1	5.2	2.5	63.9	28.4	3.0	0.0	52.4
February	28.2	7.4	55.1	68.4	28.0	6.1	12.4	65.1	28.9	3.4	0.7	49.4
March	32.0	7.3	2.5	67.1	33.0	5.9	0.4	63.2	38.0	4.5	0.0	43.7
April	40.5	7.7	0.5	60.3	40.9	7.4	0.2	53.9	41.9	6.0	0.0	31.8
May	42.6	15.6	0.1	49.6	42.7	15.1	0.0	44.1	43.9	15.5	0.0	24.4
June	41.0	17.2	0.0	51.6	41.5	16.3	0.0	47.6	42.3	16.5	0.0	30.1
July	43.4	21.3	0.0	52.9	44.1	20.3	0.0	48.2	44.4	21.7	0.0	29.9
August	43.8	22.2	0.0	55.1	44.0	20.9	0.0	50.5	43.8	21.3	0.0	31.0
September	41.1	19.6	0.0	56.0	41.1	18.9	0.0	53.6	41.0	17.9	0.0	40.4
October	36.0	17.6	4.0	58.6	35.5	16.2	1.0	56.9	36.2	14.8	0.0	44.8
November	33.5	13.2	11.1	66.5	33.2	13.0	9.1	63.9	33.9	10.7	0.0	49.6
December	24.6	7.4	45.4	73.0	24.2	6.8	32.8	69.3	23.8	2.6	0.6	60.2
	Season 2022											
January	21.4	3.2	29.5	72.7	21.6	2.4	5.7	68.4	22.6	2.1	0.4	62.5
February	24.4	4.8	13.3	72.3	24.7	5.1	4.5	67.3	25.7	3.4	6.0	56.6
March	28.5	5.0	8.1	67.8	30.0	4.0	2.5	62.4	31.8	3.2	0.0	46.4
April	39.9	9.9	0.0	59.8	40.8	9.0	0.0	51.4	41.9	9.1	0.0	31.1
May	42.7	13.8	0.2	53.8	42.3	12.7	0.1	47.8	41.7	12.6	0.0	28.4
June	44.6	19.1	0.0	53.0	45.4	18.6	0.1	48.8	44.7	18.9	0.1	30.8
July	40.6	20.8	0.0	53.5	41.3	19.9	0.0	49.6	40.4	19.4	0.0	31.1
August	41.9	21.8	0.1	55.5	41.9	21.3	0.0	51.2	42.5	21.7	0.1	33.6
September	41.4	20.1	0.0	55.4	41.3	19.7	0.1	52.1	42.2	19.3	0.0	36.6
October	40.5	17.1	7.5	60.2	40.4	16.1	6.3	58.9	41.6	14.8	0.1	47.4
November	29.3	11.5	6.7	61.1	29.4	10.3	2.3	60.3	28.7	10.1	0.0	50.4
December	28.1	9.5	19.4	68.1	28.2	8.9	13.5	65.9	27.4	6.7	0.3	56.8

The grape is divided into early, medium, and late ripening. Climate plays an important role in phenological dates, yield, and characteristics of vine bunches (Spayd et al., 2002). Flame Seedless grapes were chosen as representative of early varieties and Crimson Seedless grapes as representative of late varieties to determine their degree of response to climatic elements (Fig. 1).

The governorates of Lower Egypt differ from the governorates of Upper Egypt in terms of climate. Behira and Menoufia governorates were chosen as representatives of Lower Egypt governorates, and Minia governorate was chosen as representative of Upper Egypt governorates in terms of climate in their influence on the studied vines (Table 2).

The selected vines were seven years old, planted in rows two by three meters apart, in sandy soil (Table 3), and received drip watering. The Spanish baron system was followed for pruning and trellising the vines. For both study seasons, the vines were trimmed in the second week of January to maintain a load of 84 buds/vine (7 canes × 12 buds/vine). Every cultivar was tested in three repetitions, with five vines in each replicate. The experimental vines were given the same horticultural treatments and had comparable growth vigor and health.

Heat units

Daily maximum temperature (Tmax), minimum temperature (Tmin), precipitation (Ppt), and relative humidity (RH) were recorded at the agro-meteorological observatory installed at the Central Agricultural Climate Laboratory of the Egyptian Research Center Agricultural (Table 2).

Growing degree days (GDD) for different grape phenologies were calculated using a base temperature of 10 °C (Tb) (Winkler et al., 1974) according to the following formulas (1) and accumulated from the date (i.e. January 1) until the date of appearance.

$$GDD=\sum \left(\frac{Tmax+Tmin}{2}\right) -T_b \qquad (1)$$

Grape phenology

The factors taken into account were: the first, known as the budburst date, which occurs when 50% of the buds open; the second, known as the full flowering date, which occurs when the calyptra falls on 70–80% of the flowers; the third, known as the fruit set date, which occurs when the fertilized flower starts to turn into a berry; the fourth date of veraison, which is when the berries attain the color stage or starts to soften as sugars build up and acids start to decrease; The berries achieve their full-color stage and the TSS reaches about 16–17% according to Hamie et al. (2023). Every calendar year, the number of days for phenological dates (Julian Day) was computed.

Yield

Yield/vine (kg) was determined as the number of bunches/vine × bunch weight (g).

Physical characteristics of the bunch

Average weight of bunch (g), average weight of the berries (g), and average volume of the berries (cm^3) were measured.

Chemical characteristics of the bunch

Total sugars were determined in (%) in the juice by Miller (1959) as described in A.O.A.C. (2005). Total acidity was determined in (%) according to the A.O.A.C. (2005). Total anthocyanin was determined in (mg/100g fresh berry skin) according to Hsia et al. (2006).

Table 3. Physical and chemical analysis of the soil of the vineyards of El-Behira, El-Menoufia, and El-Minia Governorates.

Characters	El-Behira Governorate	El-Menoufia Governorate	El-Minia Governorate
Sand (%)	74.3	71.6	78.2
Silt (%)	14.2	16.5	11.5
Clay (%)	11.5	11.9	10.3
Texture	Sandy	Sandy	Sandy
Organic carbon (%)	0.84	0.87	0.79
pH (1:25)	7.52	7.41	7.64
EC (Mmhos/cm)	0.96	0.91	0.93
Ca Co_3 (%)	1.33	1.37	1.31
Total N (%)	0.18	0.21	0.17
P (%)	0.12	0.14	0.11
K (%)	0.35	0.36	0.34

The following parameters were adopted for Flame Seedless and Crimson Seedless grape cultivars in three different regions.

Experimental design and statistical analysis

A completely randomized design was adopted for this experiment. The statistical analysis of the present data was carried out according to Snedecor and Cochran (1980). Averages were compared using the L.S.D. values at the 5% level.

RESULTS AND DISCUSSION

Heat units

Data in (Table 4) mentioned that Flame Seedless grapevines recorded the lowest heat requirements which led to faster ripening as compared to Crimson Seedless grapevines, which recorded heat requirements in both seasons. However, Flame Seedless grapevines required heat requirements (45422 and 46202 GDD) for the El-Behira governorate, (46827 and 47631 GDD) for the El-Menoufia governorate, and (42753 and 43487 GDD) for the El-Minia governorate in both seasons, respectively. In contrast, Crimson Seedless grapevines required heat requirements (66504 and 67646 GDD) for El-Behira governorate, (68561 and 69738 GDD) for El-Menoufia governorate, and (62596 and 63671 GDD) for El-Minia governorate in both seasons, respectively. These findings align with those of Karvonen (2020) who demonstrated that the apparent yearly temperature increase greatly sped up the Rondo vines' growth cycle (from budburst to harvest) by 11 days Regarding this, Ferretti et al. (2021) discovered that a consistent and regular rise in temperature, up to 4 °C, during the Gewürztraminer grape variety's growth season led a faster-growing cycle and ripening, resulting in a harvest that occurred three to five weeks early. The cumulative growth degree day range for ripening types was also mentioned by Gupta et al. (2020): 1303-1530 °C for early varieties, 1617-1712 °C for medium variations, and 1912-1959 °C for late kinds.

Grape phenology

Table 5 displays the data on the number of Julian days (days in a calendar year) for phenological dates. The data exhibited a significant degree of variation among the sites under investigation. When compared to other types, the Minia region had the fewest days for every phenological date in this regard. On the other hand, during both seasons, the El-Behira and El-Menoufia regions recorded the most days for every phenological date. In terms of the cultivar effect, in both seasons the Flame Seedless grape had fewer days than the Crimson Seedless grape for every phenological factor. There are various phases or stages in the phenological development of grapevines, including bud burst, full flowering, fruit set, veraison, and grape maturity. Climate plays a major role in determining these phases of the grapevine's vegetative and reproductive cycles (Fraga et al., 2012). Temperature series spanning several millennia have been reconstructed using harvest dates (Chuine et al., 2014). Varieties differ significantly in phenology (Parker et al., 2013). Local grape varietals may be subjected to high temperatures during grape ripening if they migrate beyond their optimal ripening window due to the presence of thermal units (Lereboullet et al., 2014). The vine's phenology advances with higher temperatures (Parker et al., 2013). As a result, grapes ripen in warmer climates earlier in the growing season (Molitor & Junk, 2019). In this sense, the outcomes align with the findings of (Molitor & Junk, 2019) conducted research in the Sopron and Zala districts (Western Carpathian Basin, northwest Hungary) on the phenological reaction of grapevines to temperature units. They demonstrated an 11-day early harvest and an approximate 7–8 days advance in bud break, flowering, and veraison, respectively, pointing to a substantial alteration in the vine's yearly vegetative cycle. The phenological intervals have also shortened, with 4.5 days now separating bud break from flowering. However, Biasi et al. (2019) found that there are differences between native and foreign grape types in the ripening date response, which is heavily influenced by genotype. Droulia and Charalampoulos (2022) reported that the Rondo variety's growth cycle (from bud break to harvest) was accelerated by an average of 11 days due to the apparent increase in yearly air temperature. Harvest frequency was earlier, with an average harvest start date six days earlier.

Table 4. Heat unit requirements (10 °C) for ‘Flame Seedless’ and ‘Crimson Seedless’ grape cultivars under three different regions during the 2021 and 2022 seasons.

Governorate	Stage	Flame Seedless		Crimson Seedless	
		Season 2021	Season 2022	Season 2021	Season 2022
El-Behira	Bud burst	5965	6372	6856	7324
	Full bloom	11108	11356	12768	13053
	Ripening	45422	46202	66504	67646
El-Menoufia	Bud burst	6149	6569	7068	7551
	Full bloom	11452	11708	13163	13457
	Ripening	46827	47631	68561	69738
El-Minia	Budburst	5614	5998	6453	6894
	Full bloom	10456	10689	12018	12286
	Ripening	42753	43487	62596	63671

Table 5. Impact of heat units on the number of days per calendar year (Julian day) for the phenological dates of the ‘Flame Seedless’ and ‘Crimson Seedless’ grape varieties during the 2021 and 2022 seasons.

Governorate	Budburst date		Full bloom date		Fruit set date		Veraison date		Ripening date	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
	Flame Seedless									
El-Behira	70	73	122	124	126	129	154	156	171	174
El-Menoufia	73	77	127	128	129	133	159	160	174	178
El-Minia	66	68	116	119	122	124	148	151	167	169
	Crimson Seedless									
El-Behira	86	88	126	129	134	135	169	170	246	248
El-Menoufia	92	93	130	134	140	139	174	174	252	253
El-Minia	79	82	121	123	127	130	163	165	239	242

Yield

Climate significantly affected Flame Seedless and Crimson Seedless grape productivity in both seasons, according to data in (Table 6). The hot region (El-Minia governorate) and the temperate regions (El-Behira and El-Menoufia governorates) differed significantly in productivity. El-Behira Governorate had the highest yield, followed by El-Menoufia Governorate. While El-Minia Governorate had the significantly lowest values in both seasons, there was no significant difference in effect between El-Behira and El-Menoufia governorates.

The effects of temperature on grapevine productivity were not uniform. Elevations beyond 35 °C interfere with the physiological functions of plants, like photosynthesis in grapevines, hence limiting overall yield (Drappier et al., 2019). Because of bud divergence, the period from April 15 to May 15 is critical for vineyard yield the following year. Over a few vital weeks, maximum temperatures have risen dramatically and now reach critical levels (>30°C). The outcomes are in line with those of Koch and Oehl (2018). Who found that a 2.1 °C temperature increase in Seinfeld, southwest Germany, caused a 15 tons/ha reduction in Pinot Gris output. Pinot Noir grapes yield 17 to 30 tons/ha, Riesling grapes yield 22 to 25 tons/ha, Sylvaner grapes yield 25 to 41 tons/ha, and Müller-Thorgau grapes yield 35 to 50 tons/ha. In a recent study, Gentilucci et al. (2020) revealed a rise in maximum values of 1.2 °C (showing an increase in extreme temperatures) and an increase in annual average temperatures from the past to the present, with a larger increase of more than 0.5 °C. With grape output declining with rising temperatures in every standard climatological mean period, a strong inverse relationship between temperature and productivity was shown. The average tons/ha of grape output during the years 1971-2000, 1981-2010, and 1991-2020 were 10.23, 9.84, and 9.21, respectively. A strong correlation was observed between the temperature increase from one period to the next and the decrease in grape yield, underscoring the challenges linked to rising temperatures.

Physical characteristics of the bunch

The data in Table 7 clearly shows that heat units remarkably affect the physical characteristics of the Flame Seedless and Crimson Seedless grape cultivars during the 2021 and 2022 seasons. Regarding average bunch weight, it is obvious that thermal units had a significant effect on the mean weight of Flame Seedless and Crimson Seedless grape bunches in both seasons. The highest mean weight of bunches was obtained in the El-Behira governorate, followed by the El-Menoufia governorate. There was no significant effect between the El-Behira and El-Menoufia governorates, while the El-Minia governorate significantly gave the lowest values of mean weight of bunches in both seasons. Concerning average berry weight, thermal units significantly affected the average weight of Flame Seedless and Crimson Seedless berries in both seasons. In general, grape berries from the El-Behira governorate significantly reached the highest values of average berry weight, followed by the El-Menoufia governorate. There was no significant effect between the El-Behira and El-Menoufia governorates, while the El-Minia governorate significantly reached the lowest values in both seasons. Concerning average berry volume, the data indicate that thermal units had a significant effect on the mean berry size of Flame Seedless and Crimson Seedless grapes in both seasons. The highest significant mean berry volume was obtained in the El-Behira governorate, followed by the El-Menoufia governorate. There was no significant effect between the El-Behira and El-Menoufia governorates, while the El-Minia governorate significantly gave the lowest values of mean berry volume in both seasons.

Table 6. Impact of heat units on the yield/vine (kg) of the 'Flame Seedless' and 'Crimson Seedless' grape cultivars during the 2021 and 2022 seasons.

Governorate	Flame Seedless		Crimson Seedless	
	Season 2021 yield/vine (kg)	Season 2022 yield/vine (kg)	Season 2021 yield/vine (kg)	Season 2022 yield/vine (kg)
El-Behira	16.49	17.25	15.08	15.57
El-Menoufia	14.57	15.23	13.32	13.75
El-Minia	12.28	12.84	11.23	11.59
LSD at 0.05	1.96	2.03	1.77	1.84

Table 7. Impact of heat units on physical characteristics of the 'Flame Seedless' and 'Crimson Seedless' bunches cultivars during the 2021 and 2022 seasons.

Governorate	Average bunch weight (g)		Average berry weight (g)		Average berry volume (cm3)	
	2021	2022	2021	2022	2021	2022
	Flame Seedless					
El-Behira	634.9	662.7	3.49	3.59	3.32	3.43
El-Menoufia	560.5	585.1	3.23	3.31	3.07	3.16
El-Minia	472.7	493.4	3.08	3.12	2.93	2.98
LSD at 0.05	74.9	78.3	0.27	0.29	0.26	0.28
	Crimson Seedless					
El-Behira	574.2	599.4	4.15	4.24	4.12	4.19
El-Menoufia	506.9	529.2	4.02	4.09	3.90	3.96
El-Minia	427.5	446.3	3.91	3.97	3.81	3.85
LSD at 0.05	71.2	71.5	0.15	0.18	0.23	0.26

Table 8. Impact of heat units on chemical characteristics of the 'Flame Seedless' and 'Crimson Seedless grape cultivars during the 2021 and 2022 seasons.

Governorate	Total sugars (%)		Total acidity (%)		Total anthocyanin (mg/g F.W.)	
	2021	2022	2021	2022	2021	2022
	Flame Seedless					
El-Behira	13.48	13.96	0.64	0.66	37.42	38.36
El-Menoufia	13.59	14.11	0.61	0.64	36.34	37.23
El-Minia	13.74	14.23	0.59	0.63	35.83	36.75
LSD at 0.05	0.13	0.16	0.04	0.03	1.17	1.23
	Crimson Seedless					
El-Behira	13.08	13.37	0.58	0.56	32.59	33.47
El-Menoufia	13.21	13.48	0.55	0.52	31.42	32.24
El-Minia	13.37	13.61	0.53	0.51	30.86	31.53
LSD at 0.05	0.15	0.17	0.04	0.05	1.31	1.39

Chemical characteristics of the bunch

The data in Table 8 clearly shows that heat units remarkably affect the chemical characteristics of the Flame Seedless and Crimson Seedless grape cultivars during the 2021 and 2022 seasons.

Regarding total sugars, it is evident that thermal units significantly affected the total sugar content of Flame Seedless and Crimson Seedless berries in both seasons. In general, grape berries from the El-Behira governorate had significantly lower levels of total sugars, followed by the El-Menoufia governorate. There was no significant effect between the El-Behira and El-Menoufia governorates, while the El-Minia governorate significantly reached the highest percentage of total sugars in both seasons. Concerning total acidity, the data clearly show that thermal units had a significant effect on the total acidity of Flame Seedless and Crimson Seedless berry juice in both seasons. The most significant berry juice in terms of total acidity was obtained in the El-Behira governorate, followed by the El-Menoufia governorate. There was no significant effect between the El-Behira and El-Menoufia governorates, while the El-Minia governorate significantly gave the lowest values of total acidity in both seasons. Concerning total anthocyanin, it is clear that thermal units significantly affected the skin of Flame Seedless and Crimson Seedless berries in terms of total anthocyanin in both seasons. In general, grape berries from the El-Behira governorate had significantly higher levels of total anthocyanin, followed by those from the El-Menoufia governorate. There was no significant effect between the El-Behira and El-Menoufia governorates, while the El-Minia governorate significantly reached the lowest values of total anthocyanin in both seasons.

Soil type, management practices, genotype, and climate all affect berry quality (Jackson & Lombard, 1993). Temperature is one of the environmental variables that have been found to have a significant impact on grapevine development and berry composition (Soar et al.., 2008). High temperature can have a considerable impact on sugar buildup (Greer & Weedon, 2013) and reduce the content of anthocyanin biosynthesis (Conde et al., 2016) during the veraison-ripening period. Recent research has demonstrated negative connections between temperature and anthocyanin and berry weight at technical maturity (Costa et al., 2020).

CONCLUSION

The previous results allow us to conclude that the beginning and end of the main phenological stages of the grape throughout the growing period and the chemical properties of the berries are negatively affected by the different thermal units since temperature is the atmospheric element that has the greatest influence on grape phenology. In general, temperature contributes to the harvest time and product quality for the Flame Seedless and Crimson Seedless grape varieties. It was also observed that high temperature had a positive effect on sugar accumulation and reduced the content of anthocyanin biosynthesis. The results of the current study may be useful for developing models to predict grape variety productivity based on temperature indicators, for expanding the cultivation of new varieties, and for establishing a map of grape varieties in regions suitable for their productivity.

Conflict of interest
The study presented in this publication, according to the authors, was not affected by any of their known financial conflicts or personal relationships. The authors declare that this article does not involve any conflict of interest.

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Data Availability
The authors acknowledge that the meteorological data are sourced from the Egyptian Agricultural Research Center and the Central Agricultural Climatic Laboratory, which approved the use of the data in this research paper.

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