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DETERMINATION OF GROWING DEGREE-DAY (GDD) VALUES: PISTACHIO (*PISTACIA VERA* L.) CASE

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Abstract

Pistachio is a drought-tolerant fruit that can be grown in arid areas under limited water conditions. Therefore, in our country, most of the cultivation is done in Southeastern Anatolia. Therefore, The Southeastern Anatolia Region was determined as the research area. Growing Degree Day Method (GDD) was also used as the method in this study. GDD values: Long-term daily maximum and minimum temperature values of the provinces in our region are used. Growing degree-day values are calculated according to the recommended temperature values for phenological periods of pistachio. According to GDD values, Kilis and Adıyaman were determined as the second most proper growth area after Şanlıurfa. It may be suggested due to the similarity between the geographical, soil, topographical and ecological structures of Kilis with those of Gaziantep that studies should be carried out for improving pistachio cultivation and that projects should be carried out for increasing yield per tree based on the consideration that it is not possible to increase areas of agriculture. Therefore, this and other similar studies will result in attaining higher yields by carrying out production activities in suitable areas while also contributing to the country economy.

Key words*: Growing degree-day, Southeastern Anatolia Region, temperature.*

INTRODUCTION

Pistachio grows in the Near East, Mediterranean Region and western parts of Asia in the world and its production is carried out in 56 provinces in our country the most predominant of which are Gaziantep and Şanlıurfa. These provinces are located in the Southeastern, Mediterranean, Aegean and even the Central Anatolia regions of our country with Gaziantep, Kahramanmaraş, Adıyaman, Şanlıurfa, Mardin, Kilis, Diyarbakır and Siirt standing out. Pistachio is widely grown in the aforementioned areas since they have suitable climate and ecological conditions (Anonymous, 2001). This agricultural product that is of significant importance for the economy of the region and the country has high potential with regard to domestic consumption and export incomes.

Climate is the most important factor that has an impact on the biological development and growth of plants as well as their biological distributions. Temperature and precipitation subject to standard climate data are among the most important climate parameters. However, temperature is an important limiting factor for plant growth at regions with a temperate climate as well as high latitudes (Forland et al., 2004).

Environmental variables and especially temperature are of significant importance with regard to plant growth, development and yield (Kaleem et al., 2011). Combined effects of environmental factors not only change plant phenologies but also result in significant changes in many physical and qualitative characteristics. Temperature is also among the critical factors that determines the growth areas for pistachio cultivars. Longer periods of high temperature is required in summer months for the proper development and maturing of the plant while lower temperature values for certain periods of time are required in winter months

(Anonymous, 2001). Temperature has four different effects on the distribution areas of Pistachio cultivars. These are winter frosts, late spring frosts, chilling requirement and total temperature demands. Southeastern Anatolia Region has suitable conditions for pistachio production with regard to summer temperature sum. In this regard, the long term mean summer temperatures (June-July-August) are above 30°C in Southeastern Anatolia. In case temperature sum is insufficient, the fruit cannot ripen well and the splitting percentage is quite low (Anonymous, 2001).

Growing degree-day method (GDD) is a very useful climate indicator for users that need to manage climate related risks and opportunities. Moreover, GDD provides information on temporal temperature trends and helps in estimating the impacts of climate fluctuations or changes (Grigoriva et al., 2010). Tekin (1993) carried out a study for determining the chilling requirements and Growing-Degree Day hours of pistachio cultivars. It has been determined with regard to the heat requirement among pistachio cultivars that Ohadi has the highest value with 11500 growing degree day hour (GDDH), while Kırmızı variety has the lowest temperature value with 10700 GDDH. Siirt variety is ranked in between these two values. Hence, Siirt region is suitable due to its climate conditions for the growth of the Siirt variety among pistachio cultivars.

The GDD method calculated using daily average maximum and minimum temperatures is used frequently in agricultural and phenologic studies (Grigorieva et al., 2010). GDD method is used for determining the crop maturity and flowering times, classification of plants and estimation of the time between two growth periods (Kaleem et al., 2011). It is known that there is a relationship between temperature and living organism (Birgücü & Karsavuran, 2009), as well as a linear relationship between GDD and plant growth ratio (Lu et al., 2001). Different methods such as average temperature method, sinusoidal method and integration (use of continuous data) are used for calculating GDD (Kaya, 2010).

In this study, climate data were used for examining the temperature limit values in phenological stages, the acquisition of related GDD values as well as the relationships between temperature and GDD for the Southeastern Anatolia Region, a popular pistachio production area with significant potential.

MATERIALS AND METHODS

Pistachio (*Pistacia vera* L.) is a fruit of the gum tree family. Pistachio is used as an ornamental tree in parks and gardens and is also used in many sectors including pharmacy, pastry, confectionery, ice cream industry. In our country, Pistachio is called "*golden tree"* or "*green gold*" (Anonymous, 2010). Due to these and similar features, pistachios were chosen as the research subject. In our country, the Southeastern Anatolia Region where pistachio is the most produced, and here, especially in Gaziantep and Şanlıurfa provinces are heavily cultivated (Aslan, 2017). Therefore, the Southeastern Anatolia Region was determined as the research area (Figure 1). Long-period daily maximum and minimum temperature (1950-2018) values, which are measured in meteorological stations belonging to 9 provinces in the study area and have different recording lengths, are used. Characteristics of meteorological stations in provinces are given in Table 1 (Anonymous, 2018a).

Figure 1. Map of Southeast Anatolia Region (Anonymous, 2019)

Table 1. Characteristics of Meteorological Stations

Meteorological stations	Period duration (years) (n)	Height (H, m)	Latitude-North	Longitude-East
Adıyaman	1962–2018 (57)	37°45	38°16	679
Batman	1952–2018 (67)	37°53	41°07	610
Diyarbakır	1960–2018 (59)	37°54	40°13	649
Gaziantep	1950–2018 (69)	37°04	37°29	854
Kilis	1959–2018 (60)	36°43	37°05	638
Mardin	1950–2018 (69)	37°18	40°46	1050
Siirt	1950–2018 (69)	37°55	41°56	896
Şanlıurfa	1950–2018 (69)	37°09	38°47	547
Şırnak	1970–2018 (49)	37°31	42°28	1381

The optimum temperature values used in the calculation of GDD values in different phenological periods of pistachio plant are given in Table 2 (Aktuğ et al., 2007; Anonymous, 2018a; Anonymous, 2018b).

Table 2. Optimum Temperature Values for Different Phenological Periods of Pistachio

Phenological period	Temperature (T_b, °C)	Date	Period Duration (Day)
Pre-flowering period	8–15	21 March – 1 April	11
Flowering period	9–19	1 April – 29 April	29
Leaf formation period	10–20	16 April – 30 April	15
Outer Shell development period	11–23	1 May – 15 May	15
Shell hardening period	16–30	16 May – 30 June	46
Shell splitting period	24–32	1 July – 31 August	62
Harvest period	17–26	1 Sept. – 30 Sept.	30
Total			208

Growing Degree-Day (GDD) Method: Growing-degree-days are defined as the integration of excess temperatures in days with maximum and minimum values limited by temperatures (Kaya, 2010). In order for plants to continue to develop in each phenological period, the sum of temperatures above the base temperature is defined as GDD (Kadıoğlu & Şaylan, 2001; Parthasarathi et al., 2013; Payero, 2017; Miller et al., 2018). GDD values can be calculated with the following equations:

$$Tave = \frac{T\max + T\min}{2} \quad (1)$$

$$GDD = \sum_{i=1}^{n} (Tave - Tb) \quad (2)$$

Where: T_{ave} stands daily average temperature (°C); T_{max} stands daily maximum temperature (°C); T_{min} stands daily minimum temperature (°C); T_b stands optimum temperature value recommended for different phenological periods of pistachio plant (°C) and n represents the yearly number of days. In the case of $T_{ave} > T_b$ in Equation 2, the GDD value is calculated (McMaster & Wilhelm, 1997; Rulm et al., 2010; de Souza, et al., 2011; Elnesr & Alazba, 2016).

Statistical Methods: The relationships between GDD values calculated for different phenological periods and optimum temperature values of pistachios were tested by regression analysis.

Regression Analysis: It is a statistical method used to determine the direction and amount of the relationship between two variables. In this method, one of the variables is considered as dependent and the other as independent. In trend studies, time (years) is taken as dependent variable and values such as temperature and precipitation are used as independent variables. Regression constant and regression coefficient are obtained from the analysis.

$$Y = a + b.x \quad (3)$$

Where: Y is the dependent variable, x is the independent variable, whereas a and b are equation regression coefficients (Gürtan, 1979; Helsen & Hirsch, 1993; Şahinler, 2000; Xu, 2002; Alpar, 2003; Shammugasundram, 2012; Kılıç, 2013).

RESULTS AND DISCUSSIONS

Long-term maximum (T_{max}), average (T_{ave}) and minimum (T_{min}) temperature values of the meteorological station in the research area are given in Figure 2.

Temperature is one of the important factors for determining the pistachio production locations. It requires longer periods of high temperature for growth and maturity during summer months, while lower temperature values for certain periods of time are required in winter months (Anonymous, 2001; Anonymous, 2010). It was determined upon examining Figure 2 that long term Tmax values are not below 30°C, while the T_{ave} values did not go below 15°C.

Thus, it can be stated that the Southeastern Anatolia region meets these temperature values. Figure 3 shows the GDD values calculated according to the optimum temperature values suggested for the different growth periods (showed in Table 2) of the pistachio plant as well as the changes in the daily maximum, minimum and mean temperature values throughout the growth periods.

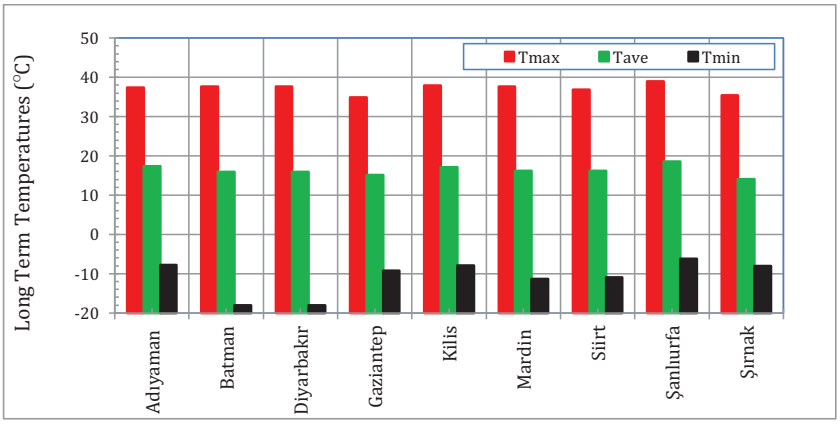
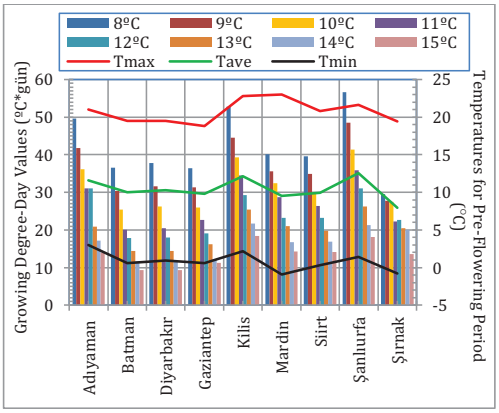
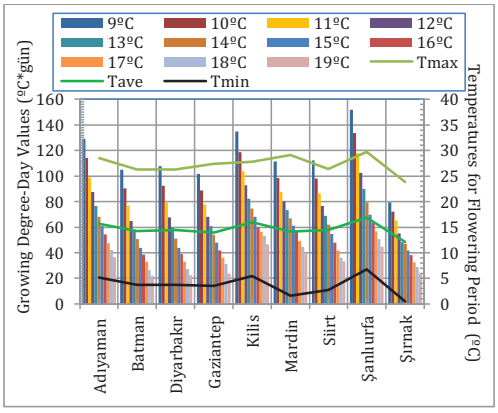


Figure 2. Long-term Period Temperature Values of Provinces





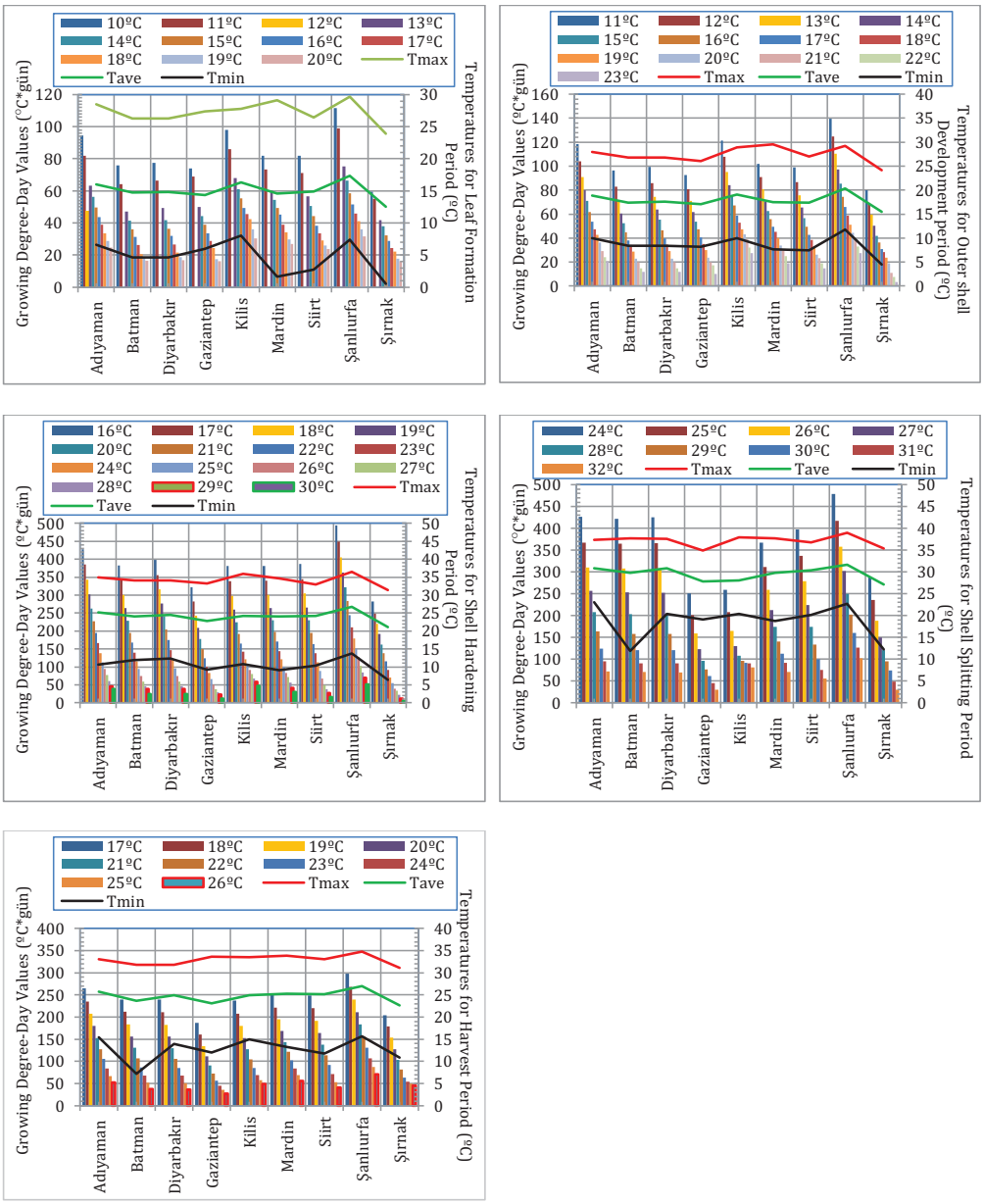


Figure 3. GDD values according to recommended optimum temperature values of pistachio

The GDD values for each development period of pistachio were calculated for each province. Highest GDD values during the pre-flowering phenological stage were observed in the provinces of Şanlıurfa, Kilis and Adıyaman while the lowest GDD values were determined in the Şırnak province. Şanlıurfa and Kilis were again determined as the provinces with the highest GDD values during the flowering period. Lowest GDD values were observed in the Şırnak province during this period. It can be seen from Figure 3 that the Şanlıurfa province had the highest GDD values in each phenological period of pistachio followed by Kilis. Highest GDD values were obtained in the Kilis province excluding only the shell splitting and harvest periods. According to TUIK (2019) data; Şanlıurfa 139216 ha, Gaziantep 136347.3

ha and Siirt 28207.1 ha were determined as the provinces with highest production. Based on GDD values, the locations that are most suited for growth were determined as Şanlıurfa, Kilis and Adıyaman with indicated as the city with the highest production which is also in accordance with our findings (TUIK, 2019). Therefore, Şanlıurfa province was determined as the best location with the largest area for growth.

The fact that Gaziantep followed Şanlıurfa as the province with the second highest production is not in accordance with our findings. Kilis comes after Şanlıurfa as the second most suited province for growth and Gaziantep is way back in this evaluation according to its GDD values. However, Kilis and Gaziantep have many similarities with regard to geographical location, topography, soil and vegetation, climate properties and elevations from sea level with no apparent differences between them. When the proximity of these provinces, similar ecologies and size of growth areas as well as their differences are taken into consideration, Gaziantep has higher potential with due to its production area and amount. On the other hand, if we consider that Kilis was a district of Gaziantep until June 10, 1995 it can be observed that the climate parameters used for evaluation are in accordance with the ecology of Gaziantep. Hence, the rise of Kilis in GDD rankings actually points out Gaziantep. Furthermore, Aslan (2017) states that the two most important cities in the production of pistachio in the GAP region are Gaziantep and Şanlıurfa. This is also support our comment on this issue. The production area of Kilis was determined as 6482.9 ha. According to TUIK (2019) data, pistachio yield for the provinces of Şanlıurfa, Gaziantep and Siirt was determined as 5 kg tree^{-1}. It was concluded due to the high yield of the pistachio trees in the Kilis province (6 kg tree^{-1}) and the fact that it is the second most suited location for pistachio growth that the production areas in the city of Kilis should be increased and that investments should be made for pistachio production in the region with opinions on increasing related works in the region. Determining proper locations for plant growth and carrying out plant production in these areas will increase the income of the producers while also contributing to the country's economy.

Statistical Method Results: The relationships between the optimum temperature (Tb) suggested for different phenological periods and the GDD values were examined via regression analysis after which a two-parameter parabolic equation was developed ($GDD=a+b.T+c.T^2$) with statistical values shown in Table 3. It was concluded based on the developed equality that temperature may be an effective factor during the growth periods of the pistachio plant.

Table 3. Statistical Results Between Calculated GDD Values and Recommended Temperature Values

Meteorological Stations	Equation Coefficients			r	s	$F_{calculated}$	p
	a	b	c				
Pre-flowering period							
Adıyaman	103,9	- 7,945	0,1284	0,989	2,16888	111,53	0,001
Batman	105,6	- 11,26	0,3242	0,998	0,582466	922,97	0,001
Diyarbakır	111,7	- 12,05	0,3496	0,999	0,557938	1119,18	0,001
Gaziantep	95,52	- 9,415	0,2519	0,998	0,596577	789,07	0,001
Kilis	126,6	- 11,74	0,3027	0,999	0,586796	1414,95	0,001
Mardin	79,56	- 5,542	0,07777	0,998	0,673076	653,98	0,001
Siirt	90,34	- 7,821	0,1833	0,9999	0,234432	5016,25	0,0001
Şanlıurfa	139,2	- 13,00	0,3290	0,9999	0,538335	2169,53	0,0001
Şırnak	32,40	0,478	- 0,1086	0,962	1,66383	31,32	0,001
Flowering period							
Adıyaman	311,4	- 25,77	0,6002	0,999	1,385290	2384,26	0,001
Batman	264,8	- 22,77	0,5305	0,998	1,96915	918,91	0,001
Diyarbakır	274,4	- 23,70	0,5541	0,998	1,55384	1581,80	0,001
Gaziantep	227,3	- 17,42	0,3598	0,998	1,59960	1182,77	0,001
Kilis	324,6	- 27,37	0,6772	0,998	1,62790	1540,36	0,001
Mardin	226,4	- 16,02	0,3292	0,998	1,62599	980,58	0,001
Siirt	256,6	- 20,27	0,4489	0,999	1,22021	2248,80	0,001
Şanlıurfa	375,7	- 31,84	0,7643	0,9999	1,18645	4440,06	0,0001
Şırnak	168,9	- 12,22	0,2455	0,995	1,94241	423,98	0,001

Leaf formation period							
Adıyaman	238,6	- 18,49	0,3922	0,999	1,06890	2236,67	0,001
Batman	213,5	- 18,04	0,4098	0,997	1,47747	864,91	0,001
Diyarbakır	220,5	- 18,65	0,4234	0,999	0,954591	2217,90	0,001
Gaziantep	186,7	- 13,90	0,2679	0,997	1,53238	817,79	0,001
Kilis	213,9	- 17,21	0,3628	0,997	1,66921	810,78	0,001
Mardin	174,9	- 11,38	0,1987	0,999	0,838783	2320,23	0,001
Siirt	206,2	- 15,89	0,3375	0,9999	0,610116	5033,59	0,0001
Şanlıurfa	295,3	- 23,76	0,5319	0,9999	1,00330	3447,50	0,0001
Şırnak	146,0	- 10,69	0,2094	0,999	0,745503	1955,08	0,001
Outer Shell development period							
Adıyaman	306,7	- 21,81	0,4094	0,999	1,52405	2511,82	0,001
Batman	275,0	- 21,12	0,4236	0,998	1,73218	1427,14	0,001
Diyarbakır	283,2	- 21,54	0,4256	0,999	1,23754	3088,05	0,001
Gaziantep	241,4	- 17,09	0,3105	0,999	1,31797	2293,65	0,001
Kilis	308,4	- 21,79	0,4212	0,998	1,66859	1888,57	0,001
Mardin	249,1	- 16,84	0,3019	0,998	1,59413	1585,78	0,001
Siirt	269,7	- 19,90	0,3859	0,999	1,22771	2869,73	0,001
Şanlıurfa	362,6	- 25,74	0,4889	0,9999	1,17687	5631,28	0,0001
Şırnak	211,4	- 15,09	0,2661	0,996	2,24744	672,82	0,001
Shell hardening period							
Adıyaman	1552,0	- 92,53	1,402	0,9999	1,55258	47378,53	0,0001
Batman	1432,0	- 86,91	1,336	0,9999	1,44959	44956,93	0,0001
Diyarbakır	1490,0	- 90,06	1,375	0,9999	2,03097	25346,93	0,0001
Gaziantep	1317,0	- 84,05	1,357	0,9999	2,35354	12499,78	0,0001
Kilis	1465,0	- 91,61	1,487	0,9999	3,55590	6335,41	0,0001
Mardin	1390,0	- 83,48	1,277	0,9999	2,39007	15579,06	0,0001
Siirt	1454,0	- 87,96	1,334	0,9999	1,52444	44180,97	0,0001
Şanlıurfa	1631,0	- 91,48	1,294	0,9999	2,28466	28010,45	0,0001
Şırnak	1113,0	- 68,86	1,066	0,9999	2,40053	9970,45	0,0001
Shell splitting period							
Adıyaman	3506,0	- 190,6	2,600	0,9999	2,62222	8983,41	0,0001
Batman	3572,0	- 195,6	2,689	0,9999	3,62241	4719,31	0,0001
Diyarbakır	3682,0	- 203,1	2,816	0,9999	3,19117	6191,44	0,0001
Gaziantep	2981,0	- 179,4	2,729	0,999	4,20877	1259,20	0,001
Kilis	3725,0	- 237,4	3,868	0,996	6,15797	402,09	0,001
Mardin	3452,0	- 197,2	2,862	0,9999	1,38126	22075,50	0,0001
Siirt	3892,0	- 222,1	3,193	0,9999	2,77728	7501,83	0,0001
Şanlıurfa	3581,0	- 190,1	2,541	0,9999	2,97382	7874,91	0,0001
Şırnak	2881,0	- 165,9	2,404	0,999	4,59335	1430,93	0,001
Harvest period							
Adıyaman	1076,0	- 63,15	0,9119	0,9999	1,48783	10775,14	0,0001
Batman	1057,0	- 64,52	0,9716	0,9999	1,19285	15171,46	0,0001
Diyarbakır	1072,0	- 66,00	1,005	0,9999	0,952306	23888,39	0,0001
Gaziantep	1065,0	- 73,79	1,303	0,9999	0,900429	16623,76	0,0001
Kilis	1210,0	- 80,47	1,376	0,9999	1,95349	5041,50	0,0001
Mardin	1050,0	- 63,55	0,9722	0,9999	0,762851	33946,11	0,0001
Siirt	1048,0	- 62,24	0,9007	0,9999	1,59249	9079,12	0,0001
Şanlıurfa	1065,0	- 57,63	0,7416	0,9999	1,58823	10894,57	0,0001
Şırnak	1248,0	- 89,15	1,646	0,998	3,85931	983,82	0,001

An equation was obtained which reflects the relationship between the suggested temperature for each growth period and GDD values after which correlation analysis at a significance level of 5%, F test and probability values were determined and presented in Table 3.

A statistically significant relationship was determined between the GDD and temperature values for the Şanlıurfa province during each phenological stage.

The fact that the city of Şanlıurfa is suited for pistachio production due to its GDD values is statistical proof that it matches our data with Şanlıurfa being the city with highest production in 2018.

CONCLUSIONS

The purpose of this study was to determine the best growth area for pistachio. For this purpose, GDD values were calculated for the temperature values suggested for each phenological stage and it was determined that the cities of Şanlıurfa, Kilis and Adıyaman are the best production areas. It was indicated based on 2018 data that Şanlıurfa, Gaziantep and Siirt are the locations with highest production. Our findings are not in full accordance with data on the cities with highest production. According to GDD values, Kilis and Adıyaman were determined as the second most proper growth area after Şanlıurfa. It may be suggested due to the similarity between the geographical, soil, topographical and ecological structures of Kilis with those of Gaziantep that studies should be carried out for improving pistachio cultivation and that projects should be carried out for increasing yield per tree based on the consideration that it is not possible to increase areas of agriculture. Therefore, this and other similar studies will result in attaining higher yields by carrying out production activities in suitable areas while also contributing to the country economy. In this way, it will be possible for the producers to use technological agriculture inputs for highly efficient and planned production while also carrying out more productive and planned agricultural applications with full knowledge on which products can be grown at which location.

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