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Research Article

Determination of effective heat requirements between full bloom to harvest dates of important Prunus salicina L. cultivars

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Abstract

Prunus salicina L. is the most common commercial plum species. Breeding and adaptation studies on Japanese plums have identified suitable varieties for specific regions. Heat requirements are defined as the total temperature required by plants between phenological stages, and problems in this section lead to serious quality losses on fruits. The study aimed to determine the effective heat requirements from full bloom (BBCH scale: Principal growth stage 6: Flowering, Code 65) to fruit ripening (harvest) (BBCH scale: Principal growth stage 8: Maturity of fruit and seed, Code 87) of four Japanese plum varieties in Ödemiş/İzmir conditions. Heat requirements were determined by the Growing Degree Days (GDD) and Growing Degree Hours (GDH) (Anderson and Richardson) methods, using 2-year-phenological data. When the years and varieties were examined together, the Julian days of full flowering and ripening were determined between 74 and 206, respectively. When we look at the number of days from full bloom to harvest, the difference between the varieties was found to be statistically significant and the average number of days from full bloom to harvest was determined as Black Diamond: 118.5, Black Splendor: 92, Fortune: 119,5, Show Time: 98,5 on the basis of varieties. GDD, GDH parameters were found to be statistically significant among the varieties. GDD was determined between 1,055–1,731 among the varieties. The results for GDH (Anderson and Richardson) methods were determined as 29,855–43,382 and 28,818–43,266, respectively. Additionally, correlations between days between full bloom and harvest, Anderson method, Richardson method and GDD were found to be statistically significant with R values in the range of 0.8456–0.998. It is thought that the results will provide significant contributions both to those who will grow plums in choosing the location where they will establish a plum orchard and to researchers in their studies on this subject.

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Introduction

Plum, a significant stone fruit crop globally, is primarily cultivated in tree species: Green plums (*Prunus cerasifera* Ehrh.), European plums (*Prunus domestica* L.) and Japanese plums (*Prunus salicina* L.) (Özçağıran et al., 2003). European plums are native to the Black Sea and Caspian Sea regions, green plums are native to Asia and Europe, while Japanese plums originated in China and were domesticated in Japan before spreading globally (Özçağıran et al., 2003; Okie and Hancock, 2008). Plum production quantities are given by FAO as a data set that includes all plum species (FAO, 2022). However, when looked at in terms of variety numbers and producers, the two most economically

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important species are the European and Japanese plums. World plum production is 12,391.467 tons in 2022, while Türkiye's plum production is 348,750 tons. China, Romania and Chile are the leading countries in production, respectively, and Türkiye ranks 6th (FAO, 2022).

The bloom date and harvest period of plums fluctuate from one year to the next, indicating that the environment plays a significant role. As with other fruit species, the most important factor in the successful cultivation of plum species is temperature. Understanding climatic conditions' impact on temperate fruit phenology is crucial for farmers to achieve optimal productivity and fruit quality (Gökkür and Şahin, 2024). Winter chilling and heat requirements are necessary for deciduous fruit trees to break the dormancy and reach full bloom, preventing incomplete dormancy or abnormal flowering. Studies on chilling and heat requirements for breaking dormancy in most of plant species and also varieties have been determined. Studies on chilling for breaking dormancy and heat requirements for flowering in most the plant species and also varieties have been determined (Kronenberg, 1988; Alburquerque et al., 2008; Ikinci et al., 2014; Boyacı, 2020).

Effective heat requirements for the stages included in the BBCH scale are determined on a variety basis at some fruit species (Kronenberg, 1988; Boyacı, 2020). The most important BBCH phase for producers and researchers in terms of heat requirements is the fruit ripening time. Determining the heat requirement between full bloom to harvest, allows for the successful selection of species and varieties suitable for regional conditions. When the studies conducted were examined, the relationship between full bloom and fruit maturity was determined as effective heat requirements (day/degree and day) in fruits such as apple, pear, mango, grape, highbush blueberry, pomegranate, and banana (Perry et al., 1987; Carlson and Hancock, 1991; Ikinci et al., 2014; Saniya et al., 2017; Abdurrohim et al., 2018; Lemos et al., 2018; Boyacı, 2020).

Aim of Study

In plum species, some studies on chilling for breaking dormancy and heat requirements for flowering were obtained but there is limited reports about heat requirement between full bloom to harvest. Therefore, the aim of this planned study was to determine the number of days from full bloom to harvest and temperature requirements in important Japanese plum varieties with different methods.

Method

Plant Material

In this study, four Japanese plum varieties; Black Diamond, Black Splendor, Fortune, and Show Time were used as a plant material. In order to minimize the error in the study, the experiment was carried out in the orchard grafted on the same age and the same rootstock. Fruit characteristics of the Japanese plum varieties used are given in Figure 1.

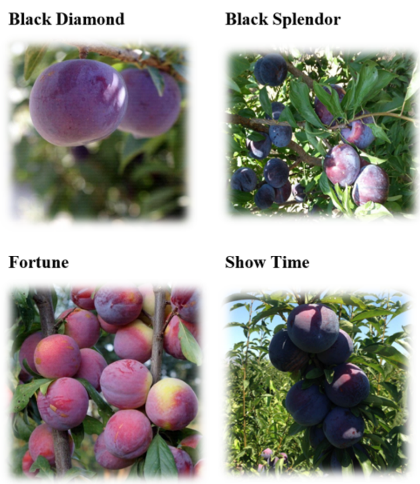


Figure 1. Fruit characteristics of the Japanese plum varieties (Anonymous, 2024)

Location and Data Collection

The experimental orchard was situated in the Ödemiş district of İzmir province, which is known for its Mediterranean climate in western Türkiye. The data logger was placed in a box with only the top and bottom closed to protect it from rain, at a height of 2 m, on a tree in the middle of the orchard. The hourly and daily minimum and maximum temperature values were recorded with the data logger between the flowering and harvest dates throughout the two years (2020-2021).

Phenological Stages

For two consecutive years (2020-2021), the two phenological stages of Japanese plum varieties were identified following the Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie (BBCH) Scale. This BBCH scale is a decimal code system used to identify plant phenological development stages (Meier et al., 1994), used in scientific disciplines and agriculture. The BBCH scale codes we examined in this study are given in Table 1.

Table 1. BBCH scale codes and explanations.

BBCH code	Description
Principal growth stage 6: Flowering	
65	Full flowering: at least 50% of flowers open, first petals falling
Principal growth stage 8: Maturity of fruit and seed	
87	Fruit ripe for picking

Determination of Heat Requirements

Growing Degree Hours (GDH)

The heat requirements of the Japanese plum cultivars were calculated as the growing degree hours (GDH) accumulated from BBCH 67 (full flowering: at least 50% of flowers open, first petals falling) to BBCH 87 (fruit ripe for picking) following the models proposed by Anderson et al. (1986) and Richardson et al. (1975).

Growing Degree Days (GDD)

In determining the effective heat requirements of the varieties, the daily temperature value was obtained by subtracting the threshold temperature from the daily average temperature above the threshold temperature (Tabuenca and Herrero,1966). The threshold temperature (T_{base}) was used as 7 °C suggested by Ünver and Çelik (1999) and the total effective temperatures (°C-day) were calculated as "Day-Degree" according to the number of days between BBCH 67-BBCH 87.

Statistics Analysis

The year was considered as a replication. Differences between the varieties examined were determined with the LSD test. Correlation analysis were determined with pairwise correlation analysis.

Results and Discussion

Effects of cultivars was found significant on harvest dates (JD), number of days full bloom to harvest, Growing degree days (GDD), growing degree hours (GDH) obtained by Anderson and Richardson methods.

Table 2. The F ratio and P levels derived from one-way analysis of variance.

Parameter	F ratio	Prob > F
Full bloom dates (JD)	1.3817	0.3695
Harvest dates (JD)	14.2759	*0.0133*
Number of days full bloom to harvest	25.3957	*0.0046*
Growing degree days (GDD	27.9618	*0.0038*
Growing degree hours (GDH) Anderson method	97.9766	*0.0003*
Growing degree hours (GDH) Richardson method	66.2119	*0.0007*

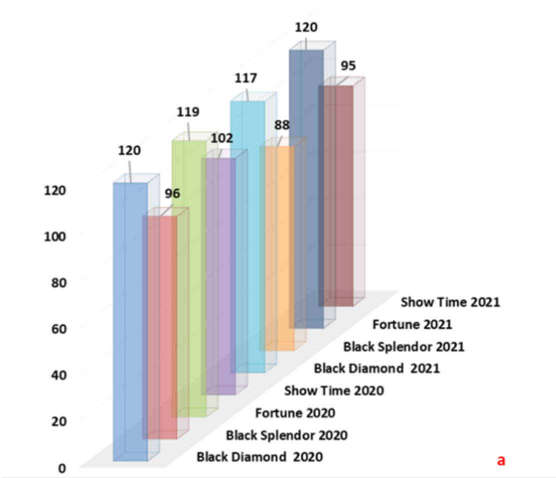
Full bloom dates of the Japanese plum cultivars ranged between 15.03.2020-25.03.2020 and 25.03.2021-16.04.2021. The earliest flowering date was 15th March (in 2020) for cv. Black Splendor, and the latest was 16th April (in 2021) for cv. Show Time (Table 3). Harvest dates of the Japanese plum cultivars ranged between 05.07.2020-21.07.2020 and 22.06.2021-26.07.2021 (Table 3). When the two years' data were examined together, the earliest harvest date was determined as 19th June for variety Black Splendor, and the latest harvest date was determined as 26th July for variety

Fortune. In a similar study conducted on *Prunus salicina* Lindl. cv. Horvin, significant differences were determined between years on fruit set and harvest dates, similar to our study (Orjuela-Angulo et all., 2022).

Table 3. Full bloom and harvest dates of Japanese plum cultivars.

Year	Varaity	Full bloom date	Harvest date
2020	Black Diamond	17.03.2020	15.07.2020
	Black Splendor	15.03.2020	19.06.2020
	Fortune	24.03.2020	21.07.2020
	Show Time	25.03.2020	05.07.2020
2021	Black Diamond	25.03.2021	20.07.2021
	Black Splendor	26.03.2021	22.06.2021
	Fortune	28.03.2021	26.07.2021
	Show Time	16.04.2021	20.07.2021

Number of days full bloom to harvest were given at Figure 2a on year basis. The differences between the varieties (year average) in terms of this feature were found to be statistically significant and the varieties were divided into two separate groups. Fortune and Black Diamond varieties were in the same group with an average of 119.50-118.50 days, while Show Time and Black Splendor varieties were in the second group with an average of 98.50-92.00 days, respectively (Figure 2b).



Varieties	Means of days to full bloom to harvest
Fortune	119.50±0.50 a
Black Diamond	118.50±1.50 a
Show Time	98.50±3,50 b
Black Splendor	92.00±4.00 b

b

Figure 2. Number of days from full bloom to harvest.

The time from full bloom to ripening varies greatly among fruit species and varieties and based on years. Harvest time of Pyrus pyrifolia and P. ussuriensis or P. bretschneider crossing combinations ranged from 159 to 185 days after full bloom in 200-2003 years (Shin et al., 2007). In the study conducted on 6 quince varieties, observations were made for 3 years and according to the annual averages, harvest time occurred 124-162 days after full flowering (Gunes and Dumanoğlu, 2005).

The differences between the varieties in terms of Growing Degree Days (GDD) between full bloom to harvest were given at Table 4. *Prunus salicina* L. cv. Fortune had the highest value with 1,731 °C-day while cv. Black Splendor had the lowest value with 1,055 °C-day.

Table 4. Yearly and average of GDD between full bloom to harvest

Variety	GDD between full bloom to harvest*		
	2020	2021	Mean
Black Diamond	1,589	1,649	1,619±30.00 ^{ab}
Black Splendor	1,057	1,054	1,055±1.70^{c}
Fortune	1,689	1,774	1,732±42.43^{a}
Show Time	1,350	1,549	1,449±99.20^{b}

*The difference between years was not statistically significant. Statistical analysis was performed only on year averages.

GDD has been calculated in several fruit trees such as; quince, pomegranate, apple, pear, peach, loquat, and plums (European and Japanese) (Gunes and Dumanoğlu, 2005; Hueso et al., 2007; Shin et al., 2007; Shivers et al., 2019; Cepeda et al., 2021; Pinzón-Sandoval et al., 2022). In study conducted on *Prunus cerasifera* Ehrh., *Prunus domestica* L. and *Prunus salicina* L. species, 2-year GDD observations were made and data varied between 281-1,952 oC-day and significant differences were determined between the years (Ünver and Çelik, 1999). Orjuela-Angulo et al. (2022), aimed to determine the base temperature of the phenological period between fruit set and harvest in Horvin plums and suggest Tbase as 2.9ºC. Results also showed a mean of 1,528 GDD and 81 days required to pass from fruit set to harvest. When the studies are examined, it is seen that Tbase, that is, the base temperature, varies based on regions and species. When interpreting the studies, the Tbase values of the relevant studies must be mentioned. In this study, the threshold temperature (Tbase) was used as 7 ºC suggested by Ünver and Çelik (1999) in calculating GDD.

The heat requirements from full bloom to harvest of the Japanese plum cultivars studied were approximately 29,855–43,382 GDH according to Anderson model, whereas using the Richardson model the values were between 28,818 and 43,266 GDH.

Table 5. Yearly and average of GDH calculated with Anderson and Richardson models between full bloom to harvest

Variety	Anderson model			Richardson model		
	2020	2021	Mean	2020	2021	Mean
Black Splendor	29,791	29,920	29,855±64[c]	29,099	28,538	28,818± 280[c]
Black Diamond	40,948	41,341	41,144±196[a]	40,776	41,445	41,110±334[a]
Fortune	42,851	43,914	43,382±531[a]	42,551	43,982	43,266±715[a]
Show Time	35,319	37,451	36,385±1,066[b]	34,878	37,545	36,211±1,333[b]

*The difference between years was not statistically significant. Statistical analysis was performed only on year averages.

In the study conducted on cherries, similar to our study, no significant difference was found between years. However, in the same study, the varieties showed similarity in this respect (Alburquerque et al., 2008). In our study, the differences between the varieties were found to be statistically significant in both the Anderson and Richardson models. Heat requirements of three pomegranate cultivars using Anderson and Richardson models from full bloom to fruit ripening were found between 47,400–53,267 GDH and 56,207–60,070 GDH, respectively (Ikinci et al., 2014).

Additionally, correlations between days between full bloom and harvest, Anderson method, Richardson method and GDD were found to be statistically significant with R values in the range of 0.8456–0.998.

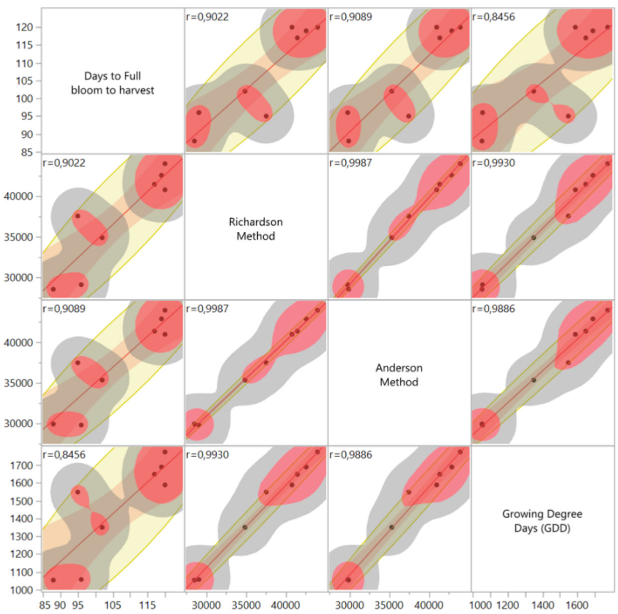


Figure 3. Correlations between the examined traits

Generally, studies suggest that there is a strong correlation between Growing Degree Hour (GDH) accumulation and various agricultural outcomes, including harvest date prediction and yield estimation (Mimoun and Dejong, 1999; Day et al., 2008). In addition to these, in our study, significant and positive correlations were found between days between full bloom and harvest, Anderson method, Richardson method and GDD, which have not been mentioned in most studies before.

Conclusion

The heat requirements of different fruit species and cultivars vary substantially from full bloom to harvest. This diversity can be taken into account in plant breeding and breeding studies to adapt to changing environmental circumstances. Heat accumulation models stand out as a key tool in forecasting and managing these processes. In this study, both GDD and GDH values of plum varieties were determined by different methods and in the light of the findings, important results were obtained regarding their adaptation in different regions. Black Splendor variety has the shortest number of days from full bloom to harvest so this variety can be recommended especially for its earliness. In addition, the fact that the GDH results determined by the Anderson and Richardson methods of plum varieties show a high correlation confirms that the study findings are consistent. The fact that there is no statistically significant difference between the years highlights the conclusion that the region is suitable for plum cultivation, but it would be more reliable to examine the region for longer years.

Recommendations

Black Splendor variety has the shortest number of days from full bloom to harvest so this variety can be recommended especially for its earliness. In addition, the fact that the GDH results determined by the Anderson and Richardson methods of plum varieties show a high correlation confirms that the study findings are consistent.

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