South Western Journal of Horticulture, Biology and Environment
P-Issn: 2067- 9874, E-Issn: 2068-7958

Vol.14, No.2, 2023
pp.124-136
Art.no. e23107

RIPENING TIME OF PEACH CULTIVARS IN THE CENTRAL PART OF HUNGARY IN A LONG-TERM OBSERVATION

László SZALAY [1,*], József László BAKOS [1], and Zsuzsanna BÉKEFI [2]

1. Department of Pomology, Institute of Horticultural Sciences, Hungarian University of Agriculture and Life Sciences, Budapest, Hungary
2. Fruit Research Centre, Institute of Horticultural Sciences, Hungarian University of Agriculture and Life Sciences, Budapest, Hungary
*Corresponding author: L. Szalay, E-mail: szalay.laszlo@uni-mate.hu

ABSTRACT. *The ripening time of peach cultivars is genetically determined, but it is greatly influenced by environmental factors. Prediction of ripening time is very useful from a scientific point of view and for practice as well. Generally, the sum of temperature and the days from flowering to ripening are used for prediction. Our work examined the phenological characteristics of 50 peach cultivars for 26 years in our experimental plantations in the central part of Hungary. We found that the number of days from flowering to ripening and the heat units (temperature sum units) vary greatly from year to year, so these values are not suitable for accurate prediction of the ripening time of cultivars. From a practical point of view, using reference cultivars is more effective for growers. The gradual shift towards earlier ripening time is proved during 26 years. Depending on the cultivar, the starting date of ripening of the investigated peach cultivars was 0.28 to 0.36 days earlier each year in our experimental plantations.*

KEYWORDS*: Prunus persica, harvest time, climate change, temperature, heat units*

INTRODUCTION

Knowing the ripening time of peach cultivars is very important from both a theoretical and practical aspect. The phenological characteristics are closely related to the exact description of the cultivars, including the ripening time

(Childers 1975, Okie 1998, Bellini 2007, Manganaris et al. 2023). Knowing the ripening time is essential for fruit growers to bring cultivars to the market (Manganaris et al. 2023, Bassi et al. 2023). The ripening time is genetically determined, but it is greatly influenced by environmental factors. For this reason, ripening occurs at different times every year in a certain growing area, but the sequence of ripening times of the cultivars is usually constant (Timon 2000, Layne and Bassi 2008, Bassi et al. 2023). The discovery of the genes that regulate the ripening processes and ripening time of peach cultivars has also begun (Farinati et al. 2021). Many other factors influence the ripening time of peach cultivars. The rootstock, the growing system, biotic and abiotic stresses, and the age of the trees can modify the time of ripening (Childers 1975, 1983, Faust 1989, Okie 1998, Jackson and Looney 1999, Timon 2000, Szabó 2002, Tromp et al. 2005). Therefore, to determine the ripening time of the cultivars, it is advisable to carry out observations on the same rootstock in the same growing system and technology over several years. Wild types of peach are late maturing, requiring 120-210 days from full bloom to maturity (Childers 1975, Childers and Sherman 1988, Layne and Bassi 2008). As a result of breeding, there are now very early and very late cultivars in practice, so the time from full bloom to maturity ranges from 55 to 270 days (Ramming and Tanner 1987, Caruso and Sottile 1999, Layne and Bassi 2008, Bassi et al. 2023). The ripening time of most of the hybrids created during crossbreeding is between the two parents, but there are always earlier and later ones due to the heterosis effect (Hesse 1975, Yamaguchi et al. 1984, Bassi et al. 1988, Layne and Bassi 2008). Flowering and ripening times are not correlated (Layne and Bassi 2008, Manganaris et al. 2023). There is a long tradition of peach cultivation in Hungary, and we have had data on the ripening time of the cultivars for a long time. In the past, the 'Mayflower' was the earliest cultivar in the peach orchards, which began to ripen around June 20 in the central part of Hungary, and the season was closed by the 'Shipley' which ripened at the end of September (Mohácsy 1954). During the 20th century, many foreign peach cultivars were introduced, and as early as 1959, the 'Springtime', which ripened a week earlier than the 'Mayflower', was described as a promising new season starter. The assortment of late ripening cultivars was also expanded, with now unknown cultivars such as 'Tropico' or 'Merrill Rodeo' (Mohácsy et al. 1959, 1963, 1967). From the 1960s, more and more cultivars were gradually cultivated in Hungary, some of which came from domestic breeding or selection, others from abroad. The list of cultivars recommended in 1992 also

starts with the 'Springtime' and ends with the 'Shipley', but are already 52 varieties on the list (Timon 1992). The assortment of cultivars used today also enables a harvest period from mid-June to the end of September in the central part of Hungary (Szabó 2001, Soltész 2013, Pernesz 2022). Prediction of the ripening time of cultivars would be very useful for practitioners; therefore, many researchers have tried to find the appropriate forecasting method. Heat units from flowering time to ripening were related to the date of ripening time. From the results of heat unit calculation models, the relationship appears less close than in the case of heat units required for flowering (Ryugo 1988, Faust 1989, Tromp et al. 2005). Heat units during the 30 days after flowering were more closely correlated with ripening time than those measured during the entire fruit development period (Grossman and DeJong 1994, Ben Mimoun and DeJong 1999, DeJong 2022). Despite the uncertainties, the estimated value of the number of days from flowering to maturity or the heat units (sum of mean daily temperatures) is often included in the cultivar descriptions, but these can only be considered informative data. Given the expected ripening time of a cultivar compared to a reference cultivar is more useful for practice (Childers 1975, Okie 1998, Timon 2000, Szabó 2001, Layne and Bassi 2008, Bassi et al. 2023). Climate change affects the phenological processes of fruit species (Zhang 2012, Haokip et al. 2020). We also have information about changes in the generative development processes of peach cultivars due to climate change. The gradually earlier blooming time is mainly highlighted and emphasized (Layne and Bassi 2008, Gariglio et al. 2012, Yong et al. 2016). The ripening time also changes due to climate change (Layne and Bassi 2008). In our present work, the tendency of the change in the ripening time of peach cultivars was investigated in our experimental plantations in the central part of Hungary. The possibility of predicting the ripening time by heat units was also observed.

MATERIALS AND METHODS

Our experimental work was carried out in the MATE gene bank cultivar collections, between 1995 and 2007 in Szigetcsép (northern latitude 47.25700; eastern longitude 18.96953), and from 2007 to 2020 in Soroksár (northern latitude 47.39768; eastern longitude 19.15101). Both locations are in the Budapest area, in the central part of Hungary; their climate characteristics are very similar, and the time course of the

phenological processes is almost the same at the two locations. Phenological observations were carried out at both places between 2004 and 2009. There were no significant differences between the two locations from the aspect of the phenological processes of peach cultivars. Fifty peach cultivars were observed, of which 3-4 trees were available in our experimental plantations.

The beginning of flowering and the beginning of ripening time were recorded in all 26 years on the trees of the tested cultivars. The day when 5% of the flowers on the trees opened was considered the beginning of flowering, BBCH 61 (Meier 2001). The beginning of ripening was considered the day when 5% of the fruits on the trees of the given cultivar reached 95% maturity, BBCH 85 (Meier 2001). In our work, the beginning of flowering and the beginning of ripening were used in the calculations. This is because the beginning of the phenological phases can be recorded most accurately.

Meteorological data were provided by meteorological stations located in the area of the plantations or their immediate vicinity. The heat units were calculated by summing up the average daily temperatures, maximum plus minimum temperatures divided by two (Ryugo 1988) between the BBCH 61 and BBCH 85 phenological stages. Statistical evaluations were performed with the Excel 365 program. Averages and standard deviations were calculated. The trend of the changing BBCH 85 phenological stage was calculated by linear regression analysis with significance level.

RESULTS

The ripening time data of the tested peach cultivars are shown in Table 1. The data of the earliest, the latest, and a medium-ripening cultivar can also be seen in Figure 1. The peach cultivars ripen from mid-June to mid-September in our garden. Each cultivar has a large annual fluctuation, and a gradual earlier shift in the ripening time can be observed. The earliest cultivar, 'Kraprim', had an average ripening date of June 19, but in 1996, its fruits began to ripen much later, on June 28, and in 2007, much earlier, on June 8. The medium-season 'Redhaven' started to ripen on July 27th in an average of 26 years. In the years with extreme ripening times, the ripening of its fruits started quite differently, in 1996 on August 4, and in 2007 and 2018 on July 17. The average ripening of the late 'Vérbarack' was on September 7. In 1996, its fruits began to ripen on September 15, and in 2007, on August 28. A gradual shift of the ripening time earlier for each observed cultivar over 26 years was observed. Overall, we could observe an earlier shift of between 0.28 and 0.36 days per year on average, which means 8

days during this period (Table 1). This tendency can be seen in the three featured cultivars (Figure 1).

Table 1. Ripening time of peach cultivars (1 - average day of onset of ripening BBCH 85 (Julian day) in 26 years and its standard deviation; 2 - the change in the date of the beginning of ripening during the 26 years, the slope of the trend line, calculated by linear regression analysis; 3 – the average length and standard deviation of the ripening time; significance levels: ***0.001, **0.01, *0.05, +0.1)

Cultivar	Start of ripening[1]	Changing[2]	Length of ripening[3]	Cultivar	Start of ripening[1]	Changing[2]	Length of ripening[3]
Kraprim	170.5 ± 5.3	-0.3118*	7.7 ± 1.0	Harko	211.3±4.8	-0.3402**	7.4 ± 1.0
Springtime	174.8 ± 5.0	-0.3097*	7.8 ± 1.1	Independence	211.7±5.0	-0.3651**	7.7 ± 1.1
Springcrest	180.8 ± 5.1	-0.2851*	7.8 ± 1.0	K8	213.5±5.0	-0.3405**	6.5 ± 1.0
Spring Lady	183.6 ± 5.3	-0.3238*	7.9 ± 1.0	Loadel	214.1±4.7	-0.3162**	8.8 ± 1.2
Manon	184.6 ± 4.8	-0.3145**	7.6 ± 1.2	Impero	217.8±4.9	-0.3056*	7.8 ± 1.0
Genadix 4	191.9 ± 4.7	-0.3097**	6.8 ± 1.0	Flavortop	218.7±4.6	-0.3190**	8.5 ± 1.0
Red June	192.0 ± 5.1	-0.3132*	6.9 ± 1.1	Incrocio Pieri	219.8±4.8	-0.3398**	7.8 ± 1.1
Aranycsillag	194.1 ± 4.8	-0.3053*	7.0 ± 1.2	Suncrest	224.6±4.7	-0.3480**	7.7 ± 1.0
Nectagrand 1	194.7 ± 4.9	-0.3326**	7.8 ± 1.1	Meystar	225.9±4.7	-0.3251**	7.8 ± 1.0
Early Redhaven	194.7 ± 4.9	-0.3368**	7.8 ± 1.0	Rome Star	229.4±4.9	-0.3368**	7.8 ± 1.1
Piroska	195.5 ± 4.8	-0.3190**	6.7 ± 1.1	Fantasia	229.7±4.7	-0.3128**	8.6 ± 1.1
Weinberger	195.7 ± 4.9	-0.3559**	7.8 ± 1.2	Fayette	229.8±4.7	-0.3094**	8.6 ± 1.1
Mariska	196.2 ± 5.0	-0.3111*	6.7 ± 1.2	Stark Redgold	230.8±4.9	-0.3289**	8.7 ± 1.2
Snow Queen	200.0 ± 4.6	-0.3087**	8.6 ± 1.2	Nectaross	232.6±4.8	-0.3446**	8.6 ± 1.1
Sunbeam	201.6 ± 4.9	-0.3412**	7.8 ± 1.3	Szegedi arany	234.6±4.7	-0.3477**	7.4 ± 1.0
Rich Lady	203.6 ± 5.0	-0.3562**	9.0 ± 1.2	Champion	235.6±4.6	-0.3194**	7.5 ± 1.1
Caldesi 2000	204.1 ± 4.6	-0.3190**	8.6 ± 1.2	Venus	236.5±4.9	-0.3446**	8.9 ± 1.1

(Table 1 – continued on the next page)

(Table 2 – continuation)

Cultivar	Start of ripening[1]	Changing[2]	Length of ripening[3]	Cultivar	Start of ripening[1]	Changing[2]	Length of ripening[3]
Troubador	204.6 ± 4.7	-0.3347**	8.8 ± 1.1	Zsoltüj	237.4±4.9	-0.3241**	7.7 ± 1.2
Redhaven Bianca	206.9 ± 5.0	-0.3450**	7.8 ± 1.0	Cresthaven	237.7±4.7	-0.3385**	7.8 ± 1.3
Redhaven	207.9 ± 4.9	-0.3169**	8.6 ± 1.2	Elberta	237.8±4.7	-0.3374**	7.6 ± 1.2
Olympio	208.4 ± 4.8	-0.3323**	8.7 ± 1.2	Padana	238.6±4.7	-0.3497**	8.6 ± 1.2
Pegaso	208.7 ± 4.8	-0.3258**	8.7 ± 1.1	August Red	240.9±4.7	-0.3374**	9.7 ± 1.4
Ford	208.9 ± 4.6	-0.3285**	7.5 ± 1.0	Michelini	243.0±4.4	-0,3005**	7.7 ± 1.1
Nektár H.	209.2 ± 4.6	-0.3128**	7.4 ± 1.1	Babygold 7	246.5±4.9	-0.3603**	9.5 ± 1.2
Orosz lapos	210.5 ± 4.7	-0.3426**	7.8 ± 1.2	Vérbarack	249.7±4.5	-0.3074**	7.8 ± 1.1

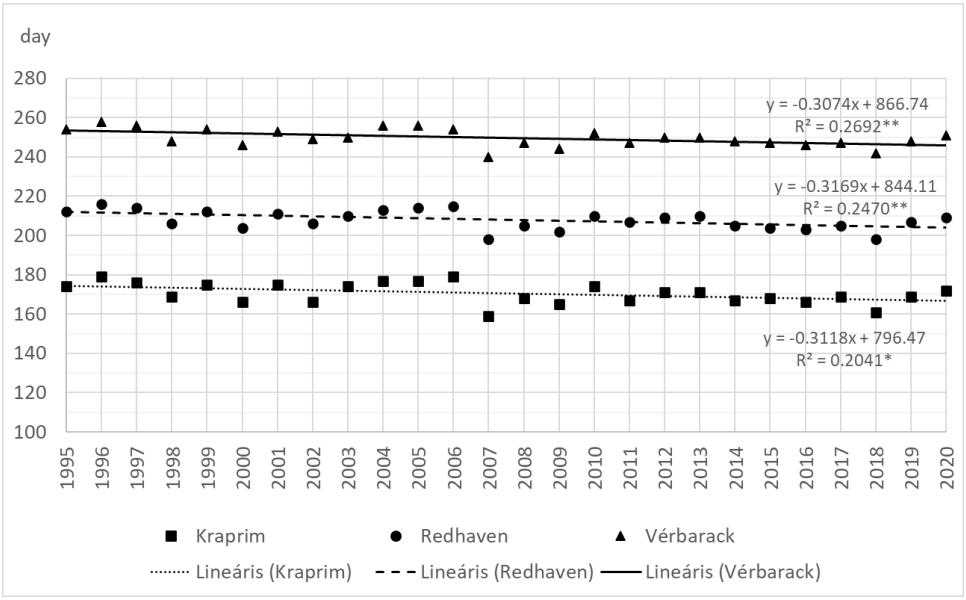

Figure 1. Starting days of the ripening time of selected peach cultivars (Julian day) in the 26 years of the study period (1995-2020) and the trend of the beginning of ripening, calculated by linear regression analysis; significance levels: *0.05, **0.01

There is no close correlation between the flowering time and the ripening time of the cultivars. Examples include the 'Venus', which is early flowering but late ripening, and the 'Genadix 4', which is late flowering but early ripening. The ripening period was 7-9 days on average, depending on the cultivar. It can also be observed that the ripening time of early ripening cultivars is usually shorter than that of late ripening ones. The cultivars with the shortest ripening time can be found among the early ripeners ('Genadix 4', 'Red June'), while the ones with the longest ripening time are found in the group of the latest ripeners ('August Red', 'Babygold 7'). The shortest ripening periods were observed in 2003, when ripening took 5-7 days, depending on the cultivar. The longest ripening period was in 2005; this year, the peach cultivars ripened for 9-12 days in our experimental plantation.

Each year, the number of days between the beginning of the flowering time and the beginning of the ripening time of the tested cultivars was determined. The results are shown in Table 2. In the average of 26 years, the values varied between 75.8 and 150.4 days, according to the cultivar. For each cultivar, there was a big difference between years; the standard deviation was greater than 6 days in all cases (Table 2).

From the list, 10 cultivars were selected, and the heat units of them were calculated from the beginning of flowering to the beginning of ripening (Table 3). The early ripening cultivar 'Red June' required 1683°C heat units for ripening in an average of 26 years. 'Redhaven,' which ripens in the middle of the harvest period, accumulated an average heat unit of 2024°C during the period between the beginning of flowering and the beginning of ripening. For the late-ripening cultivar 'Venus', this value was 2696°C. Each peach cultivar had a large interannual variation and interannual difference in the amount of temperature sum required for ripening (Table 3). The standard deviation of the calculated heat units was between 74 and 92 units. The largest differences from the average was between 5-13% during the 26 years of our study period, depending on the cultivar.

Our results showed that it is not possible to accurately predict the ripening time of the cultivars just by determining the temperature sums (by summing up the average daily temperatures) because fruit development and ripening time are influenced by other environmental factors as well, not just temperature. The heat units (temperature sum) calculation method contains a large uncertainty. With the number of days from flowering to ripening, we also cannot predict the expected ripening time of the cultivars since the differences between the years are large.

Table 2. Number of days between flowering and ripening of peach cultivars (1 the number of days between the beginning of flowering (BBCH 61) and the beginning of ripening (BBCH 85) in an average of 26 years and its standard deviation; 2 the smallest value of 26 years; 3 the highest value of 26 years)

Cultivar	Day[1]	Min.[2]	Max.[3]	Cultivar	Day[1]	Min.[2]	Max.[3]
Kraprim	75.8 ± 7.8	59	89	Harko	115.4 ± 7.8	100	129
Springtime	79.0 ± 7.5	61	91	Independence	113.1 ± 7.3	99	125
Springcrest	85.2 ± 7.6	68	99	K8	115.5 ± 7.1	102	128
Spring Lady	86.7 ± 7.6	70	100	Loadel	114.8 ± 7.0	100	124
Manon	88.2 ± 7.3	74	101	Impero	120.4 ± 7.7	106	134
Genadix 4	92.3 ± 6.9	81	103	Flavortop	121.2 ± 7.1	107	132
Red June	95.6 ± 7.3	80	107	Incrocio Pieri	122.4 ± 7.6	108	135
Aranycsillag	94.8 ± 6.9	80	105	Suncrest	128.2 ± 7.4	113	141
Nectagrand 1	97.3 ± 7.1	83	109	Meystar	127.0 ± 6.8	115	136
Early Redhaven	97.3 ± 7.3	81	108	Rome Star	133.0 ± 7.6	118	144
Piroska	96.4 ± 7.0	83	107	Fantasia	131.9 ± 7.2	118	144
Weinberger	98.6 ± 6.8	87	110	Fayette	133.7 ± 7.4	119	146
Mariska	98.4 ± 7.0	83	109	Stark Redgold	133.7 ± 7.3	120	145
Snow Queen	103.3 + 7.0	91	115	Nectaross	135.1 ± 7.0	123	146
Sunbeam	103.2 ± 7.3	89	114	Szegedi arany	137.1 ± 7.1	125	149
Rich Lady	108.2 ± 7.6	92	123	Champion	136.0 ± 7.3	123	148
Caldesi 2000	107.8 ± 7.6	94	121	Venus	141.2 ± 7.2	129	153
Troubador	107.8 ± 7.4	91	119	Zsoltüj	137.9 ± 7.4	124	153
Redh. Bianca	109.9 ± 7.2	94	121	Cresthaven	137.5 ± 6.9	124	148
Redhaven	110.5 ± 7.4	95	123	Elberta	139.5 ± 6.9	127	151
Olympio	109.7 ± 7.8	95	122	Padana	140.5 ± 7.3	128	154
Pegaso	112.3 ± 7.6	97	124	August Red	142.4 ± 7.2	129	154
Ford	111.2 ± 7.4	97	124	Michelini	143.9 ± 6.8	131	154
Nektár H.	110.5 ± 7.3	96	122	Babygold 7	148.1 ± 7.3	135	160
Orosz lapos	111.8 ± 7.3	97	123	Vérbarack	150.4 ± 7.6	136	163

Table 3. Heat units in °C between flowering and ripening of peach cultivars (1 - the average and standard deviation of the heat unit (sum of daily average temperatures) of the period between the beginning of flowering and the beginning of ripening during the 26 years of the study period; 2 - smallest value; 3 - largest value; 4 - the largest deviation from the average; 5 - the largest deviation from the average in %)

Cultivar	Heat unit[1]	MIN.[2]	MAX.[3]	Deviation[4]	Deviation %[5]
Red June	1682.9 ± 74.4	1465.0	1789.5	217.9	12.9
Piroska	1724.2 ± 64.9	1539.0	1825.5	185.2	10.7
Redhaven	2023.5 ± 81.7	1806.2	2146.5	217.3	10.7
Flavortop	2275.3 ± 84.5	2098.5	2411.0	176.8	7.8
Fantasia	2519.7 ± 87.6	2352.0	2660.0	167.7	6.7
Rome Star	2527.5 ± 86.9	2346.0	2660.5	181.5	7.2
Stark Redgold	2549.9 ± 82.8	2393.5	2686.0	156.4	6.1
Champion	2630.5 ± 88.4	2474.0	2771.0	156.5	5.9
Zsoltüj	2668.3 ± 91.5	2497.0	2820.5	171.3	6.4
Venus	2696.0 ± 81.3	2565.0	2833.0	137.0	5.1

DISCUSSION

Ripening time is an important part of the description and characterization of peach cultivars, both from a scientific and practical point of view (Okie 1988, Bellini 2007, Manganaris et al. 2023, Bassi et al. 2023). The prediction of the ripening time of cultivars has been a concern of researchers for a long time, although the methods for this have not been developed. The usability of the previously used methods was tested with our observations conducted for 26 years with 50 cultivars. During our investigations, the effect of climate change on the ripening time was also shown at our place of production. Fruit development and ripening of peach cultivars, which take a long time after flowering, are fundamentally genetically determined, but they are greatly influenced by environmental factors. The phenological and morphological characteristics of fruit development have been explored in detail in stone fruit species, such as peaches. Fruit growth over time can be described as a double-sigmoid graph (DeJong and Goudriaan 1989, Faust 1989, Timon

1992, 2000, Westwood 1993, Tromp et al. 2005, Layne and Bassi 2008, DeJong 2022).

The order of ripening time of the cultivars is mostly constant; the typical ripening time of the cultivars in a given growing area can be determined by several years of tests. The number of days from flowering to ripening does not provide adequate information about the expected ripening time, so determining the amount of heat required for ripening was among the goals of many researchers (Smith 1985, Ben Mimoun & DeJong 1999). Average daily temperatures from flowering to ripening were summed. However, this also does not give accurate results, since fruit development, like any other developmental process, is influenced by numerous other environmental factors besides temperature (Childers 1975, 1983, Ryugo 1988, Faust 1989, Janick & Moore 1996, Tromp et al. 2005, Layne and Bassi 2008, Sansavini et al. 2019, DeJong 2022). Our research results confirmed this by examining selected cultivars. In the case of peach cultivars, the heat units showed a 5-10% deviation from the average in different years. Therefore, we cannot accurately predict the ripening time of the cultivars by calculating the heat unit. In practice, it is customary to specify the expected ripening time of cultivars by comparing them to a reference cultivar, which provides more useful information than heat units (Okie 1998, Soltész 1998, Timon 2000, Szabó 2001, Bellini 2007, Layne and Bassi 2008, Bassi et al. 2023).

Based on long-term observations, the official meteorological data describe a clear warming of the climate in Hungary. The country's annual average temperature rose by 1.1°C from 1901 to 2018, and the climate models predict further warming (Izsák and Szentimrey 2020). During 26 years at our study site, the ripening time of the peach cultivars gradually occurred earlier and earlier. During this period, the starting date of ripening of the investigated peach cultivars shifted to different extents per cultivar, on average 0.28 and 0.36 days per year. The effect of climate warming on phenological processes can, therefore, also be observed during this quarter of a century at our production site in central Hungary. Similar effects of climate change on the phenological processes of fruit species have already been reported in many literature sources (Chuine et al. 2010, Zhang 2012, Ramírez and Kallarackal 2015, Haokip et al. 2020, DeJong 2022). In addition to the old cultivars, we can also provide information on the expected ripening time of the recently cultivated cultivars in our country. This information is primarily useful for production sites around Budapest.

In conclusion, the days and heat units between flowering and ripening of

peach cultivars vary from year to year, as phenological processing is determined by many environmental and technological factors, of which temperature is only one. The ripening time of cultivars compared to a reference cultivar provides more useful information than the time between blooming and ripening and heat units.

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