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Analyses of long-term and multi-site floral phenological observations of apple cultivars in comparison with temperature datasets

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Abstract—Three flowering stages were available for seven old apple cultivars in the database of Hungarian Meteorological Service. These old apple cultivars have more and more important role in the fruit production. The aim of this work is to describe the main flowering characteristics of these cultivars. Understanding the temporal nature and causes of phenological changes of such fruit trees is potentially valuable in the context of local climate change and associated yields, and more particularly for establishing appropriate horticultural management structures to ensure suitable future yields under changing orchard formation processes.

Key-words: apple cultivars, weather impact, phenology, flowering, heat accumulation

1. *Introduction*

1.1. Importance of old apple cultivars

In the Carpathian basin, a highly diverse fruit cultivar assortment could by enjoyed for a long time. Commercial fruit production, monocultures threatens biodiversity. In order to preserve biodiversity, cultivar collections are maintained in gene banks. Old cultivars are getting more and more attention for several reasons (*Tóth,* 2013).

Nowadays, people have nostalgic feeling about old apple cultivars. Old varieties have historical and cultural importance, they are part of the natural treasures and cultural heritage. They also have an important role in landscape aesthetic and nature protection.

Breeders use them as parent cultivars in order to reach their breeding purposes. Some of the old cultivars have exceptional size, shape, surface, or not light colored flesh. They have an important role to increase nutritional content, consuming values, and health benefits of future cultivars.

Other aim of selection is to increase resistance and tolerance to the most dangerous diseases (*Hevesi, et al.,* 2004; *Tóth et al.,* 2012). Several cultivars shows sufficient tolerance to the most biotic and abiotic stress factors (*Tóth, et al.,* 2005).

Old cultivars are suitable for growing systems with closed or opened plantation, self-supporting house gardens, complex agroforestry systems, furthermore, in traditional orchards or in tree lines.

1.2. Description of examined cultivars

For this study, the phenological observations of old apple cultivars (*Table 1*) (‘Nyári fontos’, ‘Asztraháni piros’, ‘Téli aranyparmen’, ‘Batul’, ‘Húsvéti rozmaring’, ‘Jonathan’, ‘Starking’) from the Hungarian Meteorological Service (OMSZ) were used. Data were available from 1952 to 1964. At that time, they used traditional growing and training methods in the orchards, trees were planted in large spacing. Apple trees were mostly grown on seedlings or in some cases on M.4 rootstock.

1.3. Spring phenology

The growth cycle of the apple trees includes all events occurring normally every year. The main processes - budburst, flowering, extension growth, fruit set and development, extension growth cessation, flower-bud formation, leaf abscission, and winter dormancy - are interrelated and synchronized with the growth season.

Table 1. Examined old apple cultivars

	Blooming	Ripening	Harvest	Edible maturity	Production region
Asztrahháni piros	early-mid	July	early-season	July-August	Northern Transdanubia, Southern Transdanubia, Danube-Tisza Plain, Transtisza, Nyírség
Batul	late-mid	October	late-season	November-March	Nyírség, Upper Hungary
Húsvéti rozmaring	early-mid or late-mid	October	late-season	December-June	Western Transdanubia, Southern Transdanubia, Danube-Tisza Plain, Transtisza, Nyírség
Jonathan	late-mid	September	late-season	October-March	Northern Transdanubia, Western Transdanubia, Southern Transdanubia, Danube-Tisza Plain, Transtisza, Nyírség
Nyári fontos	early	August	early-season	August	Southern Transdanubia, Danube-Tisza Plain, Transtisza, Nyírség
Starking	late-mid	September-October	late-season	November-March	Northern Transdanubia, Western Transdanubia, Southern Transdanubia, Danube-Tisza Plain, Transtisza, Nyírség
Téli aranyparmen	early-mid or late-mid	August-September	mid-season	September-January	Western Transdanubia, Transtisza, Nyírség, Upper Hungary

In early spring, as a response to chilling temperatures during the preceding winter, high proportion of buds emerge from dormancy (*Webster,* 2005). As the air temperature reaches a certain level, these buds are ready to develop (*Faust,* 1989). Buds with flower primordia normally open first and develop flower clusters that pass through a series of phenological stages.

Flowering in apple trees comprises floral induction, initiation, differentiation, and anthesis (*Hanke et al.,* 2007).

Temperature has direct and indirect effects on flowering. Warm temperatures advance flower initiation, cool temperatures retard it (*Abbott,* 1984). Indirectly, high temperatures stimulate shoot growth and so influencing flowering negatively *(Tromp, 1984)*.

2. *Materials and methods*

2.1. Phenology data

Stages in the developments from flowers to fruitlets were recorded in various locations in Hungary (*Figs. 1–7*) between 1952 and 1964. The assessments of floral dates was made by experienced observers.

Phenological database covers three stages during the flowering period: beginning of flowering, full flower, and petal fall.

The beginning of flowering can be defined several ways. *Maliga* (1958), *Singh, et al*. (2002), and *Soenen et al.* (1978) describe as the time in the year, when at some places of the plant, the first flowers have opened completely. According to *Faust* (1989), it is defined as the time when the rate of opened flowers is 12–15%.

The stage of full flower can be defined as the time when about 80% of the flowers are flowering, petal fall signals the end of flowering period, followed by the early fruitlet (*Wertheim,* 1996).

Soltész (1992) describes the end of flowering period when the pistils are not able to function anymore. *Faust* (1989) and *Nyéki* (1989) mentioned the 95–100% rate of overblown flowers as the end of flowering period.

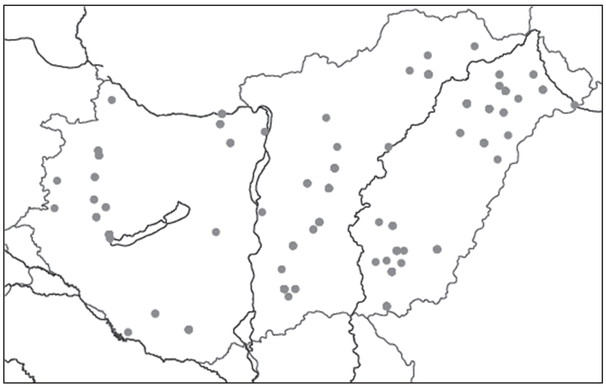

Fig 1. Phenological observations 'Asztraháni piros'.

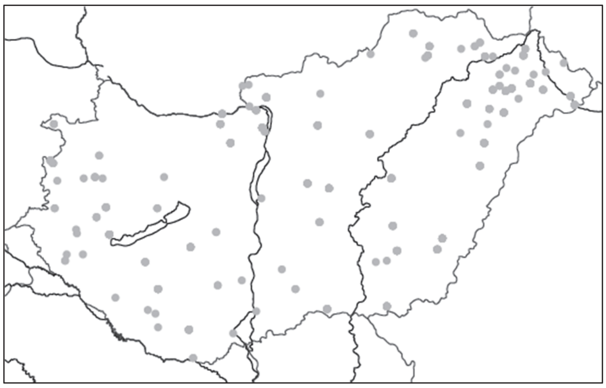

Fig 2. Phenological observations 'Batul'.

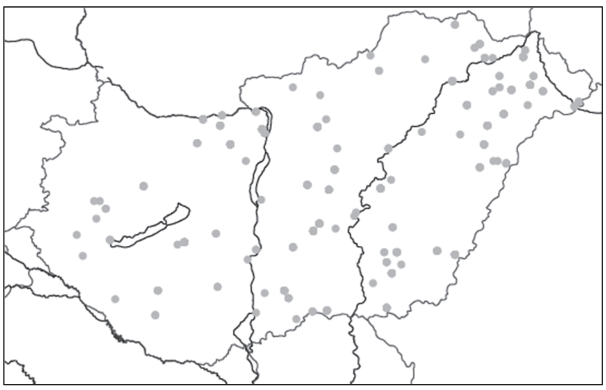

Fig 3. Phenological observations'Húsvéti rozmaring'.

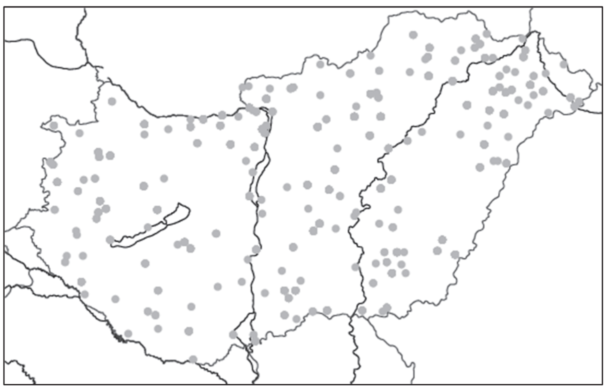

Fig 4. Phenological observations 'Jonathan'.

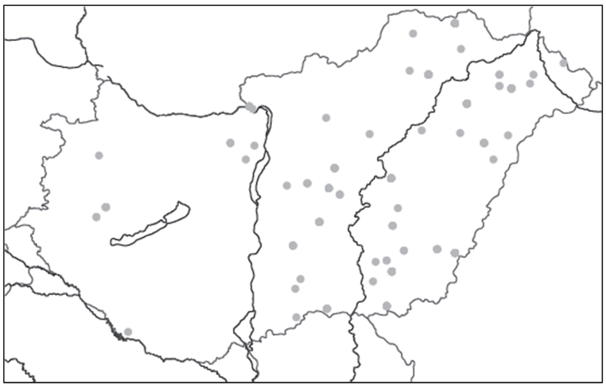

Fig 5. Phenological observation ‘Nyári fontos’.

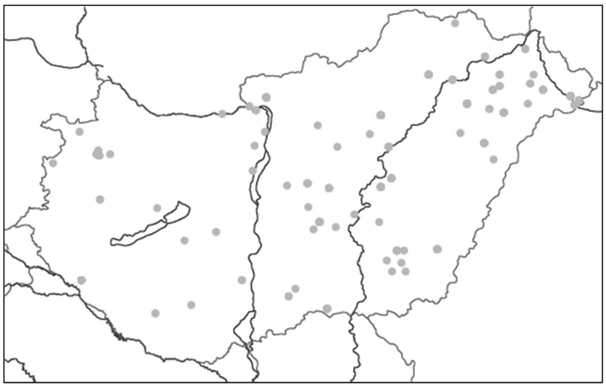

Fig 6. Phenological observations ‘Starking’.

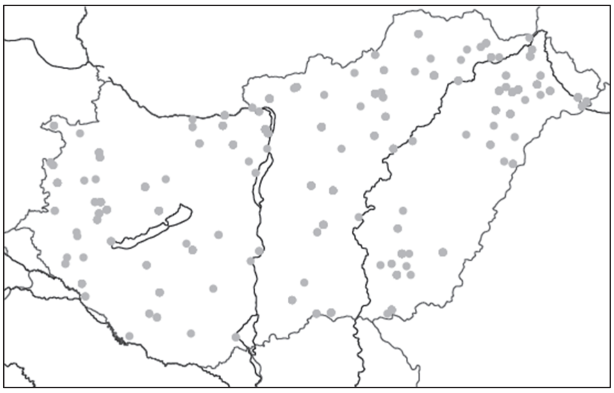

Fig 7. Phenological observation ‘Téli aranyparmen’.

2.2. Temperature data

Temperature database stems from the meteorological observational stations in Hungary during 1952–1964. At that time, synoptic measurements were carried out in 19 weather stations (*Fig. 8*).

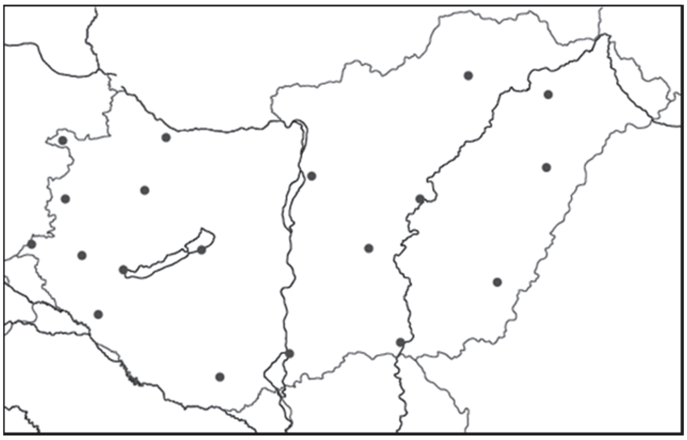

Fig 8. Synoptic stations.

Temperature data from the station closest to each phenological observation point were taken into account during the calculation of growing degree days.

Meteorological database was checked to detect errors due to missing observational data. Daily gaps in the temperature database were filled by linear interpolation between existing records. In case of significant gaps and missing periods, the closest stations were taken into account with different weight.

2.3. Calculation of growing degree days (GDD)

The accumulation of the active temperature values above the base temperature is a widespread method to classify the environmental conditions in phenological analysis (*Szász,* 2013).

In order to evaluate the relationship between the different developmental processes in the tree's annual growth cycle and temperature, in terms of accumulation of heat, growing degree days were calculated by the following formula:

$$GDD = \frac{T_{max}+T_{min}}{2} - T_{base},$$

where T_{max} and T_{min} are the mean daily maximum and minimum temperature, and T_{base} is the threshold temperature below which development does not progress.

2.4. Statistical analyses

All statistical analyses were performed using IBM SPSS Statistics 22.0 software.

For identifying univariate outliers, z score method was used (*Schiffler,* 1988). Any observation with a z score less than -1.96 or greater than +1.96 is considered an outlier.

Detection of multivariate outliers was performed by calculating Mahalanobis' distances (*Mahalanobis,* 1936), which identifies observations that lies far from the center of the data cloud. Less weight was given to those variables with large variances or to groups of highly correlated variables.

Data were analyzed using one-way analysis of variance (ANOVA) for the separation of means with a confidence interval of 95%. Grouping information was obtained by comparing means using Tukey's method in case of homogeneity of variance.

In cases flowering period, the strength of relationships between beginning of the flowering and the time of petal fall was measured by Pearson correlation analysis.

2.5. *Mapping*

Generic Mapping Tools (GMT) was used for creating maps with contours. The optimal Delaunay triangulation is performed (using *Shewchuk's* (1996) method). After eliminating outliers, for all sites the average dates were calculated. Maps are based on these average phenological data.

3. Results

3.1. *Beginning of flowering*

In the database, 2538 observations were available for beginning of flowering. After eliminating the outliers (61 data), maps were designed with 2477 data. In the examined period, the average date of beginning of flowering was in the second half of April. In general, it was the 117th day of the year (April 26). The standard deviation was 8.911, and the range was 38. Significant spatial differences can be observed in the start date (*Fig. 9*).

After splitting the dataset by cultivars, another outlier detection was carried out. In this case, 2.52% of the data was marked as outlier. ANOVA showed significant cultivar effect ($F(6, 2467) = 3.337$, $p = 0.003$). The results of post hoc test can be seen in *Table 2*. Significant differences were detected between the cultivars ($p<0.05$). Summer cultivars ('Asztraháni piros' and 'Nyári fontos') flowered exceptionally early.

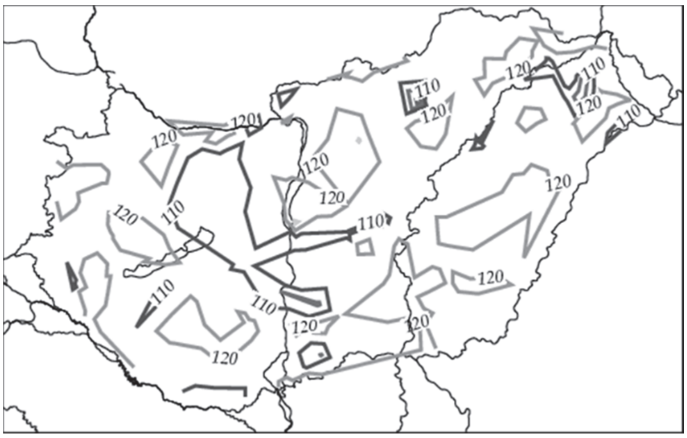

Fig 9. Spatial distribution of beginning of flowering.

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test can be seen in *Table 2*. Significant differences were detected between the cultivars ($p<0.05$). Summer cultivars ('Asztraháni piros' and 'Nyári fontos') flowered exceptionally early.

Table 2. Average date of beginning of flowering by cultivars and the results of the post hoc test

Cultivar	DOY	Date	Sample size	Post hoc test*
Asztraháni piros	113.63	April 22.	183	a
Batul	115.56	April 24.	342	ab
Húsvéti rozmaring	116.56	April 25.	364	bc
Jonathan	117.52	April 26.	782	bc
Nyári fontos	113.39	April 22.	167	a
Starking	118.13	April 27.	201	c
Téli aranyparmen	117.43	April 26.	435	bc

*: means marked with the same letter are not different from each other at p<0.05 significance level

3.2. Full bloom

In the database, 2544 observations were available for full bloom. After eliminating the outliers (65 data), maps were designed with 2468 data. In the examined period, the average date of full flower was at the end of April or in the very beginning of May. In general, it was the 122nd day of the year (May 1). The standard deviation was 8.437, and the range was 35. Significant spatial differences can be observed in the start date (*Fig. 10*).

Fig 10. Spatial distribution of full bloom.

After splitting the dataset by cultivars, another outlier detection was carried out. In this case, 3.04% of the data was marked as outlier. ANOVA showed significant cultivar effect ($F(6, 2449) = 20.502$, $p < 0.001$). The results of the post hoc test can be seen in *Table 3*. Significant differences were detected between the cultivars ($p < 0.05$). Like beginning of flowering, full flower can be observed earlier in the case of summer cultivars (‘Asztraháni piros’ and ‘Nyári fontos’).

Table 3. Average date of full bloom by cultivars and the result of post hoc test

Cultivar	DOY	Date	Sample size	Post hoc test*
Asztraháni piros	118.04	April 27.	182	a
Batul	120.82	April 29.	340	b
Húsvéti rozmaring	121.72	April 30.	366	bc
Jonathan	123.02	May 2.	779	cd
Nyári fontos	117.67	April 26.	165	a
Starking	124.05	May 3.	196	d
Téli aranyparmen	122.91	May 1.	428	ab

*: means marked with the same letter are not different from each other at p<0.05 significance level

3.3. Flowering period

The average length of flowering period can be calculated in 2524 cases. Outlier detection marked 98 cases as outlier. The average length of flowering period was 15 days. The standard deviation was 4.875, the range was 23.

After splitting the dataset by cultivars, another outlier detection was carried out. In this case, 4.08% of the data was marked as outlier. ANOVA showed significant cultivar effect ($F(6, 2414) = 4.026$, $p < 0.001$). The results of the post hoc test can be seen in *Table 4*. Significant differences were detected within the cultivars ($p < 0.05$).

Table 4. Average length of flowering period by cultivars and the results of the post hoc test

Cultivar	Mean	Sample size	Post hoc test*
Asztraháni piros	14.43	178	ab
Batul	14.89	330	ab
Húsvéti rozmaring	15.22	359	ab
Jonathan	15.42	767	b
Nyári fontos	14.11	161	a
Starking	14.04	198	a
Téli aranyparmen	14.63	428	ab

*: means marked with the same letter are not different from each other at p<0.05 significance level

3.4. *Relationship between beginning of flowering and petal fall dates*

In the database, there were 2524 cases when both beginning of flowering and petal fall dates were available. Outliers were detected based on Mahalanobis' distances. 26 cases were eliminated. The relationship between the two phenological stages can be seen in *Fig. 11*. Strong correlation was observed ($r=0.818$, $p<0.001$). If the flowering begins later, it also ends later.

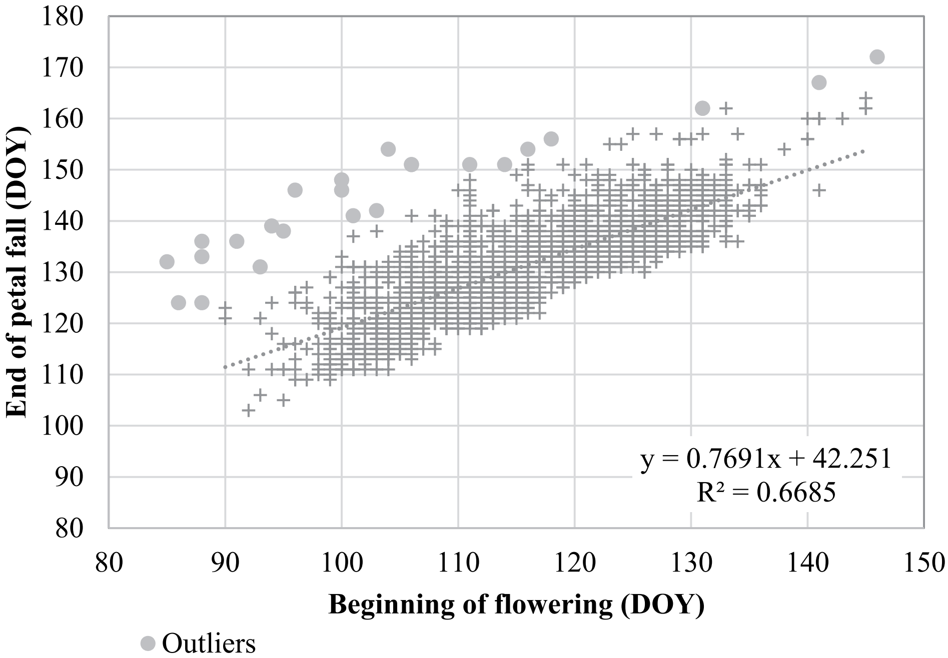

Fig 11. Relationship between beginning of flowering and end of petal fall.

3.5. *The role of temperature indices in the timing of the beginning of flowering and the duration of flowering*

For the entire database, four temperature indices were examined before the date of beginning of flowering. Significant relationship was observed (*Table 5*). The average minimum temperature and average temperature amplitude have remarkable impact on the timing of beginning of flowering.

These above mentioned indices were calculated during the flowering period (*Table 6*). Significant connection was found in this case, too.

Table 5. Temperature indices before the flowering period and correlations between these indices and the timing of beginning of flowering

Period	**10-day**		**20-day**		**30-day**	
	Average	**Pearson correlation**	**Average**	**Pearson correlation**	**Average**	**Pearson correlation**
Mean temperature	12.70 °C	0.213**	11.38 °C	0.152**	10.28 °C	0.163**
Maximum temperature	18.78 °C	0.109**	17.30 °C	–0.004**	16.17 °C	–0.096**
Minimum temperature	6.75 °C	0.348**	5.70 °C	0.310**	4.71 °C	0.384**
Temperature amplitude	12.03 °C	–0.176**	11.60 °C	–0.333**	11.47 °C	–0.458**

**: at p<0.001 significance level

Table 6. Temperature indices during the flowering period and the correlations between these indices and flowering duration

	Average	**Pearson correlation**
Mean temperature	13.90 °C	–0.389**
Maximum temperature	19.83 °C	–0.403**
Minimum temperature	8.10 °C	–0.343**
Temperature amplitude	11.73 °C	–0.271**

**: at p<0.001 significance level

Growing degree days were determined for the period before the bud break: for the 10-day-long period the value was 67.74 °C, for the 20-day-long one it was 112.06 °C, and finally, for 30-day-long period it was 141.10 °C. The effect of these values was measured by the linear correlation coefficient between the timing of beginning of flowering and the growing degree days (*Fig. 12*). The role of the 30-day-long period is the highest. The optimal choice of base temperature is 5.1 °C.

During the flowering period, the average value of growing degree days calculated with 5.1 °C base temperature was 126.21 °C. In case of markedly longer flowering period, this value was larger.

These findings indicate that the relationship between phenology and temperature is significant, but may not necessarily be linear, and thus, apple cultivars may respond differently to temperature change.

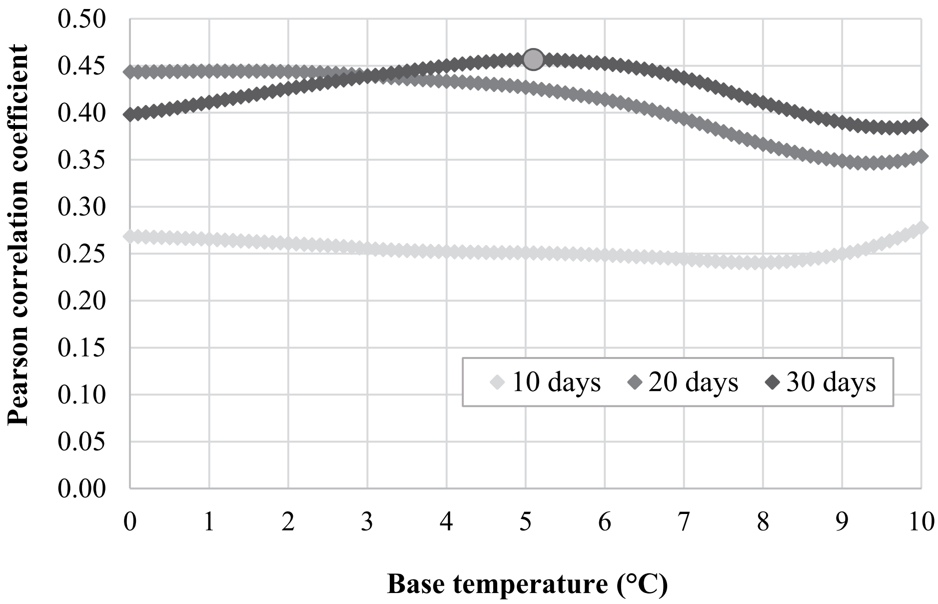

Fig. 12. Correlation between the timing of beginning of flowering and growing degree days.

4. Summary and conclusion

The time required for a crop to pass through its various stages of development is useful in estimating yield (*Hunkár et al.,* 2012) and in describing the effects of climate change. This interval is effected by the weather conditions. Our results prove the importance of temperature on timing of phenological phases. Newertheless, GDD calculation disprove the long-standing statement that the higher amount of heat accumulation shortens the flowering period.

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