SZENT ISTVÁN UNIVERSITY

Doctoral (PhD) thesis

INFLUENCE OF TEMPERATURE AND PRECIPITATION ON APPLE PHENOLOGY BASED ON HISTORICAL DATASETS

SEPSI PANNA

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PhD School

Name: **Doctoral School of Horticultural Sciences**

Field: Crop Sciences and Horticulture

Head of Ph.D. School: **Prof. Dr. Éva Németh Zámboriné**
Doctor of the Hungarian Academy of Sciences
Head of Department of Medicinal and Aromatic Plants
Szent István University,
Faculty of Horticultural Sciences

Supervisor: **Prof. Dr. Magdolna Tóth,**
DSc Head of Department of Pomology
Szent István University,
Faculty of Horticultural Sciences,
Department of Pomology

Dr. László Tőkei†,
CSc, Head of Deapartment of Soil Science and Water Management
Corvinus University of Budapest,
Faculty of Horticultural Science,
Department of Soil Science and Water Management

The applicant met the requirement of the PhD regulations of the Szent István University and the thesis is accepted for the defence process.

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Head of Ph.D. School Supervisor

1 Introduction

Apples are the most widely cultivated fruit in the temperate zone. Among any other fruits, only the banana and citrus fruit production precedes it. Although the number of grown apple varieties is enormous, only a small fraction of the selection is grown under industrial conditions. The local and regional varieties are gradually squeezed out of production, spreading of new varieties is halting. Narrowing of variety usage pose risk on selection, production safety and profitability.

The old and new apple varieties have an outstanding role in preserving biodiversity. In addition, they can play a key role in creating the conditions for multifarious fruit consumption.

In recent decades, the assessment of usage and characteristics of varieties can be found in gene banks have begun. It provides useful information on former variety usage in a specific region.

The effectiveness of temperate zone fruit tree production is essentially determined by the coincidence of ecological needs and natural-geographical habitat of the region. Climate and weather conditions are excelled from these factors. However certain weather conditions, especially temperature has an impact on all aspects of production, due to its fairly high adaptability, apples belong to the cosmopolitan species. Temperature affects the realization of physiological process, in particular the annual occurrence of phenological phenomena.

The success of production is fundamentally influenced by the fact whether the agro-biotechnical works are suited to the phenological phases.

In the fruit-growing sector only schematic or approximate findings are known about the relationship between the phenological events and the temperature and precipitation conditions of the production site. In domestic context extensive analysis based on reliable data doesn't exist.

The results of this study give a detailed description on formerly prevalent varieties, particularly the relationship between phenological events and weather conditions.

2 Research aim

The main goal of this study was to evaluate and assess a 13-year-long phenological dataset, and to get a wider knowledge of the relationship between phenology and meteorological variables with performing the followings:

- Processing flowering phonology data
    - Analysis of flowering data split up by varieties and years, and determination of dependency from weather conditions (daily mean temperature, maximum and minimum temperature, temperature amplitude, growing degree days and precipitation)
    - Analysis of flowering duration by varieties and years, and the dependency from the timing of beginning of flowering and weather indices
- Processing of maturity data
    - Analysis of the harvest maturity data split up by varieties and years
    - Determination of the length of the period from full bloom to the picking date by varieties and years
- Processing of data about the length of vegetation period
    - Determination of the length of the period from bud break to end of leaf drop by varieties and years
    - Calculation of growing degree days and precipitation amount during the vegetation period
- Determination of the spatial variation of phenological events

3 Materials and methods

3.1 Phenological data

Phenological data were provided by the Hungarian Meteorological Service. Observations were recorded from 1952 to 1964 for widely grown varieties like 'Asztraháni piros', 'Batul', 'Húsvéti rozmaring', 'Jonathan', 'Nyári fontos', 'Starking' and 'Téli aranyparmen'.

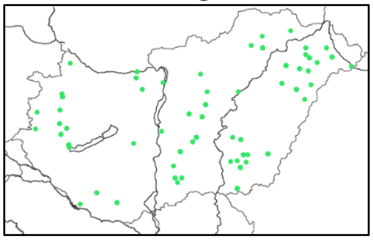

Fig 1. Phenological observation of 'Asztraháni piros' – 61 sites

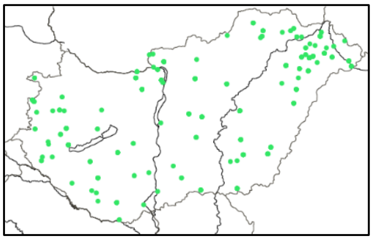

Fig 2. Phenological observation of 'Batul' – 96 sites

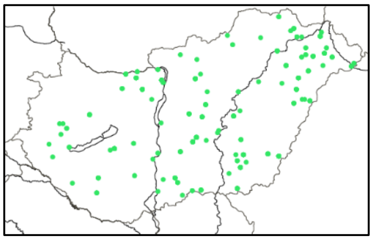

Fig 3. Phenological observation of 'Húsvéti rozmaring'– 93 sites

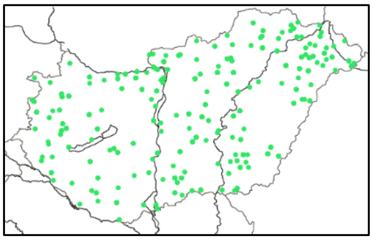

Fig 4. Phenological observation of a 'Jonathan' – 190 sites

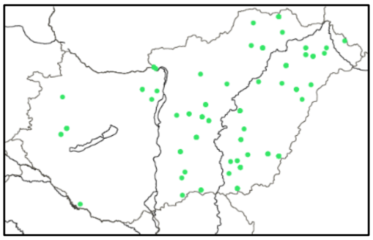

Fig 5. Phenological observation of 'Nyári fontos' – 50 sites

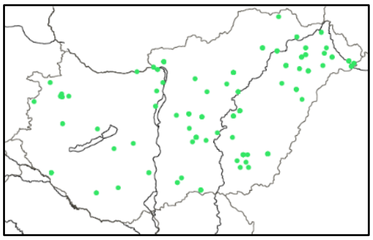

Fig 6. Phenological observation of 'Starking' – 69 sites

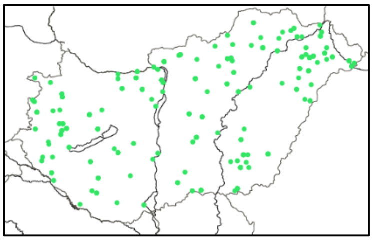

Fig 7. Phenological observation of 'Téli aranyparmen' – 126 sites

Although 13 years of observations were included in the database, it doesn't mean that we can find data for each and every season and orchard. The dataset usually covers a shorter period.

The age of the plantations, the orientation of the lines and the technology were not involved into the topic of observations. The rootstocks were also recorded only in a few cases. In these cases seedlings were mentioned, or rarely M.4 rootstocks.

Although provisions were available for phenological observations, the monitoring is relatively subjective due to the different observer experience.

The first step of data processing was digitalization. This was followed by the elimination of incorrect data. If the phenological phases were not in chronological order, data were deleted. The next step was the searching for outliers. Univariate outliers were detected with one dimensional method. When the goal was to describe the connection of two variable, multivariate method was used.

3.2 Temperature data

Temperature data were provided by the Hungarian Meteorological Service. Daily mean temperature, maximum and minimum temperature and temperature amplitude were used during the calculations. Missing data were replaced by the average of adjacent stations.

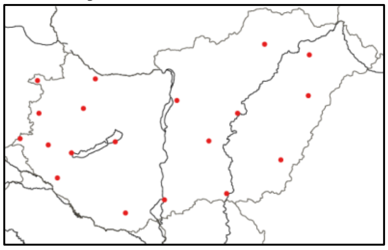

Fig 8. Temperature data – 19 synoptic stations

Phenological observations was paired with temperature data from the nearest synoptic station. Growing degree days were calculated with the available daily data. During the analysis the conventional method was used (McMaster & Wilhelm, 1997):

$$GDD = \sum_{i=1}^{n} \left(\frac{T_{i,min} + T_{i,max}}{2} - T_b \right),$$
$$\text{if } \left(\frac{T_{i,min} + T_{i,max}}{2} - T_b \right) > 0,$$
$$\text{otherwise } 0,$$

where $T_{i,max}$ is the daily maximum temperature [°C], $T_{i,min}$ is the daily minimum temperature [°C], T_b is the start temperature [°C] and n is the length of the phenological stage.

3.3 Precipitation data

Precipitation data were provided by the Hungarian Meteorological Service. The daily precipitation amount was used during the calculations.

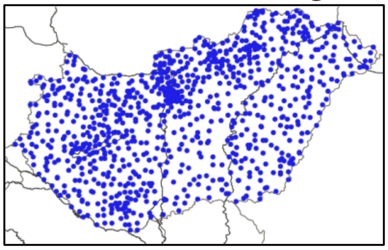

Fig 9. Precipitation data – 944 synoptic and precipitation station

For the examined period, precipitation data from the nearest place were sum up. Usually the nearest station was located within the 10 km surroundings.

3.4 Mapping

For mapping purpose GMT (The Generic Mapping Tools) software was used. Optimal triangulation was performed in order to draw contours.

3.5 Statistical analysis

The relationship between the phenological phases, or a phenological phase and the weather conditions was investigated by the calculation of correlation coefficient.

When the linear relationship was strong enough, the regression equation was determined.

Variance analysis was carried out in order to determine the differences between the mean values of the examined varieties. In case of identical variances, Tukey method was performed, in other cases Games-Howell method was carried out.

Statistical analysis were performed by using IBM SPSS Statistics 22 software package.

4 Results

During the examinations data were evaluated according to several aspects. First of all global outliers were detected, the search for outliers was repeated after splitting the dataset by varieties, years and finally climatic regions. Climatic regions were determined by the results of Réthly (1933). In this classification system *C* represents the temperate climate, *D* means the cold climate zone. Hot summers (average temperature in July is higher than 22 °C) are indicated by *a*, warm summers (average temperature in July is less than 22 °C) by *b*. Those areas where the highest monthly precipitation falls in the early summer are marked by *x*, if the highest amount falls in the middle of summer, it is indicated by *x''*. When the secondary precipitation maximum can be observed, it is marked by *z*.

4.1 Bud break

2533 observations were available in the database about the timing of bud break. 105 data were claimed as outlier.

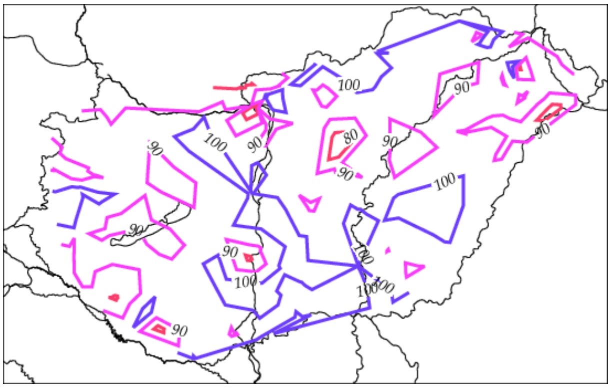

Fig 10. The average date of bud break

The timing of bud break is unevenly distributed in space (Fig. 10.). Its pattern does not resemble to the spatial distribution of temperature in spring. Although the spring comes earlier in the southwestern part of Hungary, similarly late dates were observed at the northern part of Great Hungarian Plain.

4.1.1 Differences between varieties

Before this examination 3.83% of the data was marked as outlier. According to the results of ANOVA the effect of variety is significant ($F(12,2526) = 3.337$, $p = 0.003$).

Only a few days of difference can be observed between the bud break dates of examined varieties. Early dates can be found in case of summer varieties, the bud break of all the other varieties happens 2-3 days later.

4.1.2 Annual variety

Before the examination of annual variety 5.49% of the data was marked as outlier. According to the results of ANOVA the effect of vintage is significant ($F(12,2520) = 222.617$, $p < 0.001$).

Table 1. Annual variety of bud break

Year	Mean	Date	Spread	Range	Case number	Post hoc test*
1952	94	April 3.	7.8	33	62	d
1953	88	March 28.	4.4	22	193	b
1954	100	April 9.	7.4	36	217	ef
1955	98	April 7.	8.7	36	219	e
1956	103	April 12.	5.2	24	234	g
1957	86	March 26.	6.8	30	196	b
1958	102	April 11.	6.3	27	200	efg
1959	85	March 25.	5.3	24	189	b
1960	91	March 31.	7.1	30	194	c
1961	81	March 21.	6.5	28	200	a
1962	102	April 11.	5.6	27	161	fg
1963	103	April 12.	4.1	20	156	g
1964	100	April 9.	4.4	19	173	ef

*: averages marked by the same letters are not differ from each other at $p<0.05$ significance level

Significant differences can be observed between the seasons in the timing of bud break (Table 1.). Extremely early dates were recorded in 1961, when the average bud break was on 21. March. In some specific regions (like the surroundings of the western basin of Lake Balaton) bud break happened on 10. March.

Late bud breaks were dated in 1956 and 1963. In these years we can hardly find an area where the bud break was observed before April. In 1956 in the Transdanubia region late dates were observed.

4.1.3 Differences between climatic regions

Before the calculations 4.50% of the data was marked as outlier. According to the results of ANOVA the effect of region is significant ($F(5,2527) = 5.925$, $p < 0.001$).

Only 4 days of difference can be observed between the climatic regions in the timing of bud break.

The earliest observations were recorded in the southwestern part of the country, and contrary to the expectations the latest timing can be found in the southern part of Great Hungarian Plain.

4.1.4 Weather conditions prior the bud break

If we examine the effect of temperature for the timing of bud break, the role of the 20-day-long period seems to be the most important. Moderately strong positive connection can be found between the dates and the minimum temperatures prior the bud break (Table 2). Considering the temperature amplitude, the 10-day-long period is the determinative. The timing is weakly connected to the mean temperature. In case of early bud break, the temperature amplitude is usually larger, which refers to dry, mostly warm, sunny weather conditions in advance.

Considering the precipitation data, the influence of the 20-day-long period is remarkable. If the amount of precipitation is larger, the bud break is usually late. This finding is in agreement with the effect of the temperature amplitude, since cloudy, rainy weather causes smaller temperature amplitude

Table 2. Relationship between the date of bud break and the weather conditions in the preceding periods

Pearson correlation coefficient	10 days	20 days	30 days
Mean temperature	0.290**	0.457**	0.290**
Maximum temperature	0.102**	0.316**	0.273**
Minimum temperature	0.406**	0.514**	0.437**
Temperature amplitude	-0.291**	-0.164**	-0.096**
Precipitation	0.331**	0.414**	0.393**

**: at p<0.01 significance level

4.1.4.1 The role of growing degree days before bud break

Considering the role of the growing degree days in the timing of bud break, the preceding 30-day-long period has the most prominent influence (Fig. 11). The strongest connection can be observed when the start temperature was chosen to be 5.1 °C. This value can be used as the base temperature of apples.

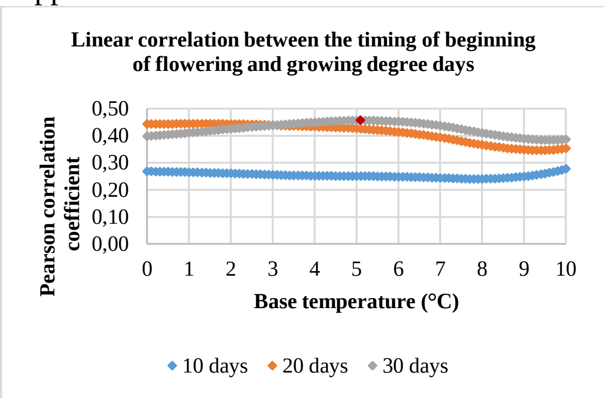

Fig. 11. The connection between the timing of bud break the growing degree days prior the bud break

4.2 The beginning of flowering

2538 observations were available in the database about the beginning of flowering. 2.40% of the data was claimed as outlier.

The beginning of flowering can be described with diverse values in the different region of the country (Fig. 12.). No similarities can be discovered between the spatial distribution of timing and spring temperature.

In some specific regions of North Hungarian Mountains extremely early dates were recorded. It can be possibly explained by the location of the orchard (southern orientated slopes, probably frost-free area). The soil type could give a reason for the markedly early dates in the northeast part of the country.

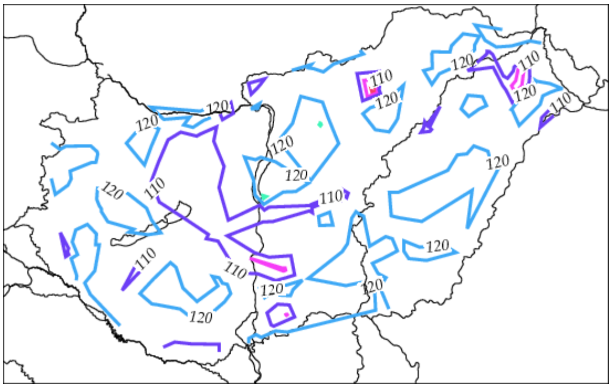

Fig 12. The average time of beginning of flowering

4.2.1 Differences between varieties

Before the examination of differences between varieties 2.52% of the data was marked as outlier. According to the results of ANOVA the effect of variety is significant ($F(6,2467) = 11.025$, $p < 0.001$).

Table 3. The beginning of flowering for each variety

Variety	Mean	Date	Spread	Range	Case number	Post hoc test*
Asztraháni piros	114	April 23.	9.2	35	183	a
Batul	116	April 25.	9.2	36	342	ab
Húsvéti rozmaring	117	April 26.	8.9	37	364	bc
Jonathan	118	April 27.	8.7	36	782	bc
Nyári fontos	113	April 22.	8.6	32	167	a
Starking	118	April 27.	8.0	32	201	c
Téli aranyparmen	117	April 26.	8.8	36	435	bc

*: averages marked by the same letters are not differ from each other at p<0.05 significance level

Significant differences can be found between the timing of the beginning of the flowering of the varieties (Table 3.). Summer varieties (‘Asztraháni piros’ and ‘Nyári fontos’) can be described with early timing of the beginning of flowering, late timing was observed in the case of ‘Starking’ and ‘Jonathan’. Extremely late dates were recorded from the surroundings of Lake Balaton.

4.2.2 Annual variety

Before the examination of annual variety 9.15% of the data was marked as outlier. According to the results of ANOVA the effect of vintage is significant ($F(12,2369) = 750.530$, $p < 0.001$).

Significant annual differences can be observed in the date of beginning of flowering (Table 4.). According to the result of Brózik and Regius (1957) 1953 is considered as a year, when the beginning of flowering was unusually early based on examination of 250 varieties. In contrast, in 1954 late dates were recorded. The records of the examined database support these findings. Similarly to 1954, data recorded in 1958 shows markedly late timing.

In the examined 13 years 23 days of difference can be found in the timing of the beginning of flowering. Soltész observed 20 days of differences based on the records of 300 varieties from 20 years (Soltész, 1992). Grausland (1996) found 25 days of difference between the data of 11 varieties from 10 years. According to Blasse and Hoffmann (1992) the timing of the beginning of flowering of 'Golden Delicious' had 35 day variety in the surroundings of Berlin based on 22 years of observation.

Table 4. Annual variety of the beginning of flowering

Year	Mean	Date	Spread	Range	Case number	Post hoc test*
1952	114	April 23.	3.6	22	75	e
1953	108	April 17.	4.6	24	201	c
1954	126	May 5.	4.3	25	202	i
1955	124	May 3.	2.8	16	219	h
1956	124	May 3.	4.2	20	236	h
1957	110	April 19.	5.5	23	198	d
1958	127	May 6.	4.2	20	199	i
1959	107	April 16.	3.2	15	188	b
1960	112	April 21.	4.1	20	184	e
1961	103	April 12.	2.5	11	196	a
1962	117	April 26.	3.6	18	154	f
1963	118	April 27.	3.6	17	157	f
1964	121	April 30.	5.1	23	173	g

*: averages marked by the same letters are not differ from each other at $p<0.05$ significance level

4.2.3 Differences between climatic regions

Before the calculations 2.72% of the data was marked as outlier. According to the results of ANOVA the effect of region is significant ($F(5,2463) = 10.708$, $p < 0.001$).

5 days of differences can be observed between the climatic regions. The earliest dates were recorded in the southern part of Great Hungarian Plain, in contrast the latest dates were observed in the Little Hungarian Plain.

In their research Illés et al. (2010) compared several data from the southwestern and the northeastern part of the county in the case of four different varieties. According to their results the earlier flowering dates in the southwestern part of Hungary can be explain by the different soil types and the dissimilarities of technology.

Based on my examinations only 1 day difference can be seen in the average timing of the beginning of flowering between the above mentioned regions.

4.2.4 Weather conditions prior the beginning of flowering

Although according to Sunley et al. (2006) the warm periods before the flowering usually causes early timing, based on the data from the 1950's and 1960's this relation can't be proven (Table 5.).

Table 5. Connection between weather conditions and the timing of the beginning of flowering

Pearson correlation coefficient	10 days	20 days	30 days
Mean temperature	0.213**	0.152**	0.163**
Maximum termperature	0.109**	-0.004**	-0.096**
Minimum temperature	0.348**	0.310**	0.384**
Temperature amplitude	-0.176**	-0.333**	-0.458**
Precipitation	0.277**	0.384**	0.530**

**: at $p<0.01$ significance level

Weak positive connection can be found between the minimum temperatures and the timing of the beginning of flowering, the correlation coefficient is negative in the case of temperature amplitude. If the temperature amplitude is large in the preceding period, it usually refers to dry, mostly warm, and sunny weather.

Moderately strong positive connection was observed between the timing of the beginning of flowering and the precipitation of the preceding 30-day-long period. According to this result, the higher precipitation amount causes later beginning of flowering. In this specific 30-day-long period the average rainfall was 39 mm.

4.3 Full bloom

In the database 2533 observations were available about the timing of full bloom. 2.57% of these data was eliminated during the calculations.

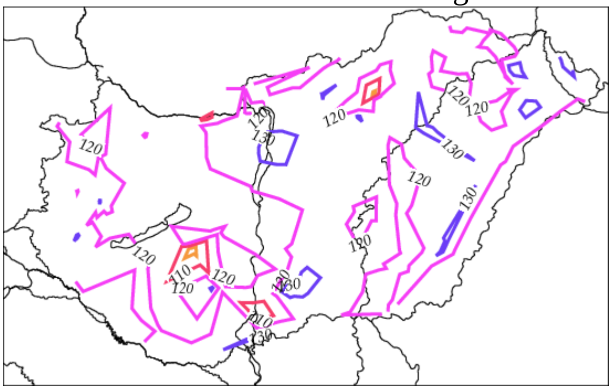

Fig 13. The average timing of full bloom

In some specific regions of North Hungarian Mountains extremely early dates were recorded (Fig. 13.). Similarly early dates can be seen southeast from Lake Balaton, although this anomaly can't be observed in the timing of beginning of flowering.

Brózik és Nyéki (1974) showed 14 days of difference in the timing of full bloom with the examination of data from 1954 and 1957.

4.3.1 Differences between varieties

Before the examination of differences between varieties 3.04% of the data was marked as outlier. According to the results of ANOVA the effect of variety is significant ($F(6,2449) = 20.502$, $p < 0.001$).

For the full bloom the order of varieties is similar to the beginning of flowering. The earliest timing can be observed in the case of summer varieties. It is followed by the full bloom of 'Batul', finally the American varieties come. In the central part of Great Hungarian Plain early timing was recorded for some varieties.

Varieties were divided into four groups by Soltész (1992). Early, mid-early, mid-late and late groups were determined. In this classification 'Batul' was considered as a mid-early flowering variety. These findings are in agreement with the results of Király (2013).

4.3.2 Annual variety

Before the examination of annual variety 5.45% of the data was marked as outlier. According to the results of ANOVA the effect of vintage is significant ($F(12,2382) = 627.031$, $p < 0.001$).

In 1961 the timing of the full bloom was unusually early. This year was considered as an extremely warm one, since the spread of the data is the smallest in this case. Markedly late timing was recorded in 1954 and 1958.

4.3.3 Differences between climatic regions

Before the calculations 3.47% of the data was marked as outlier. According to the results of ANOVA the effect of region is significant ($F(5,2439) = 20.892$, $p < 0.001$).

The earliest full bloom was observed in the warmest region of the country, the latest dates were recorded on those part of Little Hungarian Plain where a secondary maximum can be seen in the annual distribution of precipitation.

4.4 Flowering duration

The flowering duration can be calculated in 2524 cases based on the beginning of flowering and the end of petal fall data. 3.88% of these values was marked as outlier before the calculations.

The average flowering duration was 15 days long. Almost 2-weeks of difference can be found between the shortest and longest flowering periods.

4.4.1 Differences between varieties

Before the examination of differences between varieties 4.08% of the data was marked as outlier. According to the results of ANOVA the effect of variety is significant ($F(6,2414) = 4.026$, $p = 0.001$).

Only 1 day of difference was showed between the flowering duration of the examined seven old apple varieties. The shortest period was observed in the case of 'Starking', the longest in the case of 'Húsvéti rozmaring' and 'Jonathan'. According to Pethő (1984) the flowering duration of 'Starking' shorter compared to the other varieties, so the effective pollination period is also shorter.

4.4.2 Annual variety

Before the examination of annual variety 5.35% of the data was marked as outlier. According to the results of ANOVA the effect of vintage is significant ($F(12,2376) = 74.036$, $p < 0.001$).

During the 1950' and 1960's the flowering period usually lasted from 10 to 19 days (Table 6.). The smaller durations were recorded in 1958, the larger ones in 1959 and in 1960.

Table 6. Annual variety of flowering duration

Year	Mean	Spread	Range	Case number	Post hoc test*
1952	10,6	2.23	10	77	a
1953	18,0	5.31	24	200	c
1954	14,5	4.27	22	204	cd
1955	12,9	3.43	15	214	b
1956	13,3	3.72	18	239	bc
1957	15,5	4.71	23	195	d
1958	10,1	3.98	20	195	a
1959	18,6	4.65	23	192	e
1960	18,9	4.73	20	192	e
1961	14,5	3.85	18	199	cd
1962	14,7	3.47	16	156	cd
1963	14,1	3.49	16	153	bcd
1964	14,4	4,03	17	173	bcd

*: averages marked by the same letters are not differ from each other at $p<0.05$ significance level

4.4.3 Differences between climatic regions

Before the calculations 4.40% of the data was marked as outlier. According to the results of ANOVA the effect of region is significant ($F(5,2407) = 12.532$, $p < 0.001$).

The shortest periods were recorded in the coldest region of the country. It is noteworthy that the statistical analysis couldn't be able to detect differences between this above mention area and the warmer regions. The longest periods were observed in the Little Hungarian Plain.

4.4.4 Weather conditions during the flowering period

Table 7. Weather conditions during the flowering period

	Mean temperature	Maximum temperature	Minimum temperature	Temperature amplitude	Precipitation amount
Average value	13.90 °C	19.83 °C	8.10 °C	11.73 °C	28.82 mm
Pearson correlation coefficient	-0.389**	-0.403**	-0.343**	-0.271**	0.442**

**: at $p<0.01$ significance level

Weak negative connection was found between the duration of flowering and the mean temperature (Table 7.). The maximum and minimum temperature have a similar role. The relation is weak and negative with the precipitation.

4.4.4.1 Growing degree days during the flowering period

No matter which base temperature was chosen, positive connection can be observed in each cases between flowering durations and growing degree days. If the flowering period is long, usually higher amount of heat accumulated.

Using 5.1 °C as a base temperature, the calculated value of growing degree days was 136.04 °C and the linear correlation coefficient was 0.625.

4.4.5 Connection between beginning and end of flowering dates

Very strong positive correlation was observed between the beginning of flowering and the end of petal fall ($r=0.818$, $p<0.01$). The later the flowering begins, the later it ends.

4.5 Harvest maturity

2169 observations were available in the database about the harvest maturity.

4.5.1 Differences between varieties

Before the examination of differences between varieties 4.79% of the data was marked as outlier. According to the results of ANOVA the effect of variety is significant ($F(6,2058) = 1050.568$, $p < 0.001$).

The optimal harvest (Table 8.) of ‘Asztraháni piros’ is the earliest among the seven old cultivars. It is followed by the other summer variety, namely ‘Nyári fontos’. ‘Téli aranyparmen’ can be picked in early September, then ‘Batul’, and in the end of September ‘Húsvéti rozmaring’. The two variety with American origins can be harvested at the latest.

Table 8. Harvest maturity of varieties

Variety	Mean	Date	Spread	Range	Case number	Post hoc test*
Asztraháni piros	210	July 28.	11.2	53	160	a
Batul	263	September 19.	13.2	55	274	d
Húsvéti rozmaring	273	September 29.	13.9	63	310	e
Jonathan	276	October 2.	10.6	46	646	f
Nyári fontos	223	August 10.	12.3	59	140	b
Starking	275	October 1.	9.0	39	175	ef
Téli aranyparmen	254	September 10.	11,5	54	360	c

*: averages marked by the same letters are not differ from each other at p<0.05 significance level

4.5.2 Average weather conditions from the full bloom to the harvest maturity

Previous studies have shown strong connection between growing degree days and the length of period from full bloom to harvest maturity (Warrington, et al., 1999).

Table 9. Growing degree days from full bloom to harvest maturity and their connection with the timing of harvest

Variety	Growing degree days	Pearson correlation coefficient
Asztraháni piros	1196.68 °C	0.819**
Batul	1918.18 °C	0.773**
Húsvéti rozmaring	2007.40 °C	0.813**
Jonathan	2025.14 °C	0.548**
Nyári fontos	1429.73 °C	0.859**
Starking	2029.18 °C	0.477**
Téli aranyparmen	1792.49 °C	0.763**

**: at p<0.01 significance level

The value of growing degree days for each variety can be seen in the Table 9. Very strong relationship can be found between the timing of the harvest and the growing degree days in the case of summer varieties. Weak relation can be observed for the late-maturing ‘Starking’ variety.

A possible way of predict the date of harvest maturity is counting the days from full bloom. For the seven varieties in the database the length of period from full bloom to maturity was counted. The result can be seen in the Table 10. For the summer varieties this period is 90 – 110-days-long, for the varieties with American origins it can be more than 150 days.

Table 10. Number of days from full bloom the harvest maturity

Variety	Number of days
Asztraháni piros	90.6
Batul	142.4
Húsvéti rozmaring	150.2
Jonathan	153.8
Nyári fontos	106.1
Starking	152.1
Téli aranyparmen	131,2

According to some research the optimal harvest is affected by the temperature conditions after full bloom (Tóth, 2013). Eggert (1960) found strong connection between maturity and the value of growing degree days for 40 days after petal fall in the case of 'McIntosh'.

The average value of growing degree days for the 40-day-long period after full bloom was 454.97 °C. The numbers for each varieties can be seen in Table 11. In all cases weak negative connection can be observed, so the warmer the period after full bloom is, the earlier the maturity happens.

Table 11. Growing degree days from full bloom for 40 days and their connection with the timing of harvest

Variety	Growing degree days	Pearson correlation coefficient
Asztraháni piros	439.65 °C	-0.479**
Batul	449.53 °C	-0.341**
Húsvéti rozmaring	456.27 °C	-0.416**
Jonathan	459.66 °C	-0.430**
Nyári fontos	432.09 °C	-0.312**
Starking	468.97 °C	-0.446**
Téli aranyparmen	458.71 °C	-0.415**

**: at $p<0.01$ significance level

4.6 The vegetation period

The length of vegetation period can be calculated in 1992 cases based on the beginning of flowering and the end of leaf drop. 4.96% of these values was marked as outlier before the calculations.

The average length of vegetation period was 222 days, but a 2-month-difference can be found between the shortest and longest vegetation periods.

4.6.1 Differences between varieties

Before the examination of the differences between varieties 4.87% of the data was marked as extreme value. According to the results of ANOVA the effect of variety is significant ($F6,1888) = 4.853$, $p < 0.001$).

Only some days of differences can be observed in the average length of vegetation period of the varieties. The shortest period was found in the case of a 'Nyári fontos', in the case of 'Asztraháni piros' this period is 1 day longer, and approximately 5 day longer for 'Starking' and 'Jonathan'.

4.6.2 Annual variety

Before the examination of annual variety 5.37% of the data was marked as outlier. According to the results of ANOVA the effect of vintage is significant ($F(12,1872) = 56.398$, $p < 0.001$).

The shortest period was recorded in 1962, when 214 days passed from the bud break till the end of leaf drop. In the preceding year the length of the vegetation period was 235 days. In the 1950's and 1960's the variance of average length of vegetation period was 21 days (Table 12).

Table 12. Annual variety of the length of vegetation period

Year	Mean	Spread	Range	Case number	Post hoc test*
1952	228,5	15.70	38	8	de
1953	230,9	9.15	41	109	ef
1954	218,6	12.66	55	153	abc
1955	222,0	12.66	55	163	cd
1956	215,3	13.80	60	168	ab
1957	230,5	10.47	45	170	ef
1958	217,7	9.21	42	181	abc
1959	221,7	10.69	48	183	bc
1960	229,3	12.36	54	179	ef
1961	235,2	13.38	61	160	f
1962	214,0	8.73	40	145	a
1963	215,2	8.87	41	140	ab
1964	219,4	11,50	49	126	abc

*: averages marked by the same letters are not differ from each other at $p<0.05$ significance level

Brózik és Nyéki (1974) was calculated 19 days of difference between the data from 1954 and 1957. According the examined data, only 12 days of difference can be determined. Although the numbers are not equal, statistical analysis shows significant disparity.

4.6.3 Differences between climatic regions

Before the calculations 5.17% of the data was marked as outlier. According to the results of ANOVA the effect of region is significant ($F(5,1883) = 12.275$, $p < 0.001$).

The shortest period was found in the southern part of Great Hungarian Plain and the southeastern part of Transdanubia. In the coldest regions of the country this period is 3 days longer. In any other area of Hungary it is even longer.

4.6.4 Weather conditions during the vegetation period

The heat requirement of successful apple production is 18 –19 °C during the vegetation period (Tóth, 1997). Based on the data from the 1950's and 1960's the mean temperature for the vegetation period was lower the above mentioned values (Table 13.), but under these conditions apple production can also be efficient. Moderately strong negative correlation can be found with these average values.

The average value of growing degree days for the vegetation period was 2409 °C. From the bud break to the end of the season usually 404 mm rain fell. These values meet the requirements of apple production.

Table 13. Weather conditions during the vegetation period

	Mean temperature	Maximum temperature	Minimum temperature	Temperature amplitude
Average value	15.6 °C	21.6 °C	10.1 °C	11.6 °C
Pearson correlation coefficient	-0.560**	-0.532**	-0.422**	-0.166**

*: at $p<0.01$ significance level

5 New Scientific Results

Based on a 13-year-long phenological and weather dataset from 1952 to 1964 the following new scientific results were obtained:

1) With measuring the linear relationship between the timing of bud break and the growing degree days calculated for the preceding periods, 5.1 °C can be used as a start temperature for apples.

2) The longstanding statement that the end of the flowering occurs once a specific amount of heat accumulated was disproved based on correlation calculation for the 13-year-long dataset of seven apple varieties. During a longer flowering period higher amount of heat accumulated. The later the beginning of flowering is the later the end of petal fall.

3) Correlation calculations showed that the larger heat amount accumulated after the full bloom has a negative effect on harvest maturity data, so the optimal harvest date is shifted earlier.

4) Based on the 5.1 °C start temperature growing degree days were determined for the flowering period and the vegetation period too. During the flowering period 136 °C heat accumulated in average, during the whole vegetation period the average accumulated heat amount was 2409 °C.

5) For the specific phenological phases significant differences can be seen between the main climate regions of Hungary, but these differences can't always be explained by the meteorological factors.

6 Conclusion

In my research an analysis of phenological observations from 1952 to 1964 was performed in case of seven old apple varieties: 'Asztraháni piros', 'Batul', 'Húsvéti rozmaring', 'Jonathan', 'Nyári fontos', 'Starking' and 'Téli aranyparmen'.

The average timing of phenological phases was determined. Differences between varieties, seasons and climatic regions were examined by variation analysis.

When comparing different varieties, it can be clearly seen that in case of summer varieties ('Asztraháni piros', 'Nyári fontos') most of the phenological phases occur significantly earlier than in case of the remaining varieties. In contrast, non-Carpathian varieties can be described by later phenological dates.

In most cases, 1961 can be described as an extreme year with its early phenological dates. 1954 and 1958 were the opposite with their late phenological phases. The annual variety is conspicuous.

Although no spatial characteristics can be observed by analyzing the phenological maps, statistical analysis showed significant differences between Hungary's main climatic regions.

Weather conditions may have a varying impact on phenological dates. The role of growing degree days is outstanding. Based on the calculation of growing degree days for different periods before the bud break, 5.1 °C seems to be the optimal choice as the start temperature of apples. The higher amount of precipitation usually lengthens the phenological phases.

The above mentioned results hold true for traditional orchard management, they describe the characteristics of apples grown in seedling rootstocks.

Although these methods are not considered to be a modern fruit cultivation technique today, re-spreading of the examined species are justified by several reasons like people's nostalgic feelings for them and their key role in preserving biodiversity. The results of this study can be useful in achieving these mentioned purposes.

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8 Publications Related to the Subject of the PhD Thesis

Scientific article in reviewed journal

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