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TEMPERATURE CHARACTERISTICS AND SPRING FROST RISK IN THE SOUR CHERRY (*Prunus cerasus* L.) BLOOMING PERIOD IN 1985–2010

Abstract: The aim of the paper is an attempt to present the relationships between sour cherry (*Prunus cerasus* L.) blooming time, climatic conditions and spring frost risk in western Poland (Great Poland Lowland). Air temperature indices from meteorological stations in Przybroda and Poznań for the period 1985-2010 representing contemporary climate warming were used. 'English Morello' sour cherry phenological records for the period 1985–2010 were collected at the Research Station of Poznań University of Life Sciences located in Przybroda. The earliest end of blooming was observed on 2nd of May 1999, and the latest one on 26th of May 1987. The average period of sour cherry blooming was between 30th April and 12th May. During 50% of the years the blooming period lasted from 11 to 15 days. Mean monthly temperature in Przybroda varied from -1.1ºC in January to 19.6ºC in July. A significant relationship between the beginning date of cherry blooming and the beginning of the thermal vegetation period was found. Variability of the index explained more than 50% of variability in the first dates of cherries blooming (coefficient of determination $R^2 = 0.505$ is significant on the level $p < 0.05$). The beginning of blooming was also significantly ($p < 0.05$) correlated with mean April temperature, which could explain about 43% of variability in the dates of the first bloom. An increase in April temperature by 1.0ºC caused earlier blooming by about 2.8 days. During the period of 1985–2010 a significant increase in April temperature was observed (in Poznań 0.79ºC per decade). It had an effect on advanced dates of the beginning of sour cherry blooming of about 3 days per decade. In 26 of the years the last frost occurred 4 times (15% of seasons) during the blooming phenological phase or later in Przybroda. Frost occurred 10 days before blooming started and during blooming in 54% of the years.

Key words: frost hazard, phenology, western Poland, *Prunus cerasus*, vegetation period

Introduction

The global character of commercial agriculture provides macroeconomic factors affecting production growth in some regions and its decline in others. Regional development of agriculture is, however, primarily related to environmental factors which determine yield levels and costs associated with adaptations to local habitat conditions. Weather-related uncertainty of production concerns in particular horticulture and the fruit industry, for which strategies of crop protection from unfavourable conditions require capital intensive investments. Winter and spring frosts, drought, excessive precipitation, hail and strong winds can not only reduce but also eliminate seasonal yield and in extreme cases result in permanent destruction of perennial horticultural plantations. Among all climate risk factors low temperature is the most limiting one for fruit production in temperate climate areas (Eccel et al. 2009; Ladányi et al. 2010). The most harmful effect of low temperatures on fruit crops is related to flower bud injuries by frost during dormancy or spring development. Any long-term frame alterations of thermal conditions associated, for example, with global climate change effects can potentially modify cold damage risk in agricultural production.

Sour cherry (*Prunus cerasus* L., *Rosaceae*) originating from the Black and Caspian Seas areas (Perez-Sanchez et al. 2013) is one of the major commercially grown horticultural crops in central Europe. It is cultivated for its sour and succulent fruits used processed as frozen, canned fruits, juice concentrate, etc., as well as a fresh market commodity (Dirlewanger et al. 2009; Kirakosyan et al. 2009). Its high nutraceutical value, emphasized in recent studies is related to its antioxidant activity assured by the rich content of polyphenolic compounds (Perez-Sanchez et al. 2013; Toydemir et al. 2013). In Poland sour cherry fruit production amounting in the last decade to 160–200 thousand mt (metric tons) annually provides sour cherry with a leading position among all fruit species with a production scale on a comparable level to strawberry (*Fragaria* sp.) and currant (*Ribes* sp.) fruits, lower only when compared to apples (*Malus* sp.) (Ziółkowska 2013). The present production quantity has been achieved as a result of its dynamic growth since the early 1980s from the level of 36.5 thousand mt in 1981. In the period 1981-2004 year to year fluctuations of annual production were relatively low with a long-term growing tendency with the exception of the essential yield decline in 1987 (FAOSTAT 2013). The minimum air temperatures reaching from -34.2°C to -29.1°C in important fruit production regions on 14th of January 1987 resulted in lethal damage to 10–85% of fruit trees depending on species cultivar and area but sour cherry trees were affected the least in comparison to other commercially grown fruit species (Gruca et al. 1989; Mika and Czynczyk 1989; Zawadzka 1989; Grzyb and Rozpara 1998). Flower bud damage caused, however, a sour cherry yield decrease of 78% vs. the previous year on the nationwide level (FAOSTAT 2013). The example of 1987 illustrates the high winter hardiness of sour cherry wood and the moderate sensitivity of its flower buds to spring frosts. This characteristic of *Prunus cerasus* L. determined genetically may be considered as one of the considerations of the relatively low fluctuations of sour cherry yields in Poland in the 20th century. The other reason is associated with the properties of the major cultivar ‘English Morello’ (syn. ‘Lutowka’, ‘Schattenmorelle’) dominating over ¾ of commercial sour cherry production in Poland in recent decades (Jadczuk-Tobjasz and Bednarski 2007). The cultivar is regarded not only as winter hardy (Gruca et al. 1989), but due to its late bloom time compared to other cherry cultivars (Iezzoni 2005) also as less sensitive to spring frosts (Szpadzik et al. 2009). Moreover ‘English Morello’ is a cultivar setting over 20% of fruits after self-pollination, which improves productivity in seasons with unfavourable pollination conditions (Szpadzik et al. 2008).

After a relative stable growth of sour cherry fruit production in Poland in 1981-2004, the statistics of the last decade present several cases of year to year production deviations reaching values not observed before. In 2004 production decreased by 61.9 thousand tons *vs.* 2003, in 2007 by 87.2 thousand tons and in 2010 by 42 thousand tons *vs*. previous years (FAOSTAT 2013). It should be emphasized that in 2002 and 2012 a dramatic decline in sour cherry fruit production also took place in the United States. As a result of spring frost, US sour cherry production decreased by 111.3 thousand tons in 2002 and by 66.6 thousand tons in 2012 *vs*. previous years, leading to the lowest supply levels noted in half a century, which had a great impact on the international trade in processed cherry fruits (Winkler at al. 2010; Lee et al. 2013; USDA 2013). The situation raises the question about tendencies of low temperature pressure on regional and global sour cherry markets especially in terms of spring frost danger in relation to the changing climate. Among several factors determining the risk of flower bud frost damage during their spring development, the phenological advance of a bud during a freeze event is considered the most critical (Chmielewski et al. 2004; Dai et al. 2013). The aim of this study is an attempt to present the relationships between the sour cherry blooming period and the climatic conditions of western Poland in 1985-2010.

Materials and methods

The phenological data were obtained from the Agriculture and Pomology Research Farm of Poznań University of Life Sciences located in Przybroda. The data collected for the period 1985–2010 (26 years) referred to the dates of the beginning of, full and the end of flowering of 'English Morello' sour cherry trees grown on 'Prunus mahaleb' rootstock. For the same period climatological data were used including maximum, minimum and average daily air temperatures and daily total precipitation. For the comparison data from the synoptic station in Poznań airport Ławica (World Meteorological Organization, No. 12330) of the Institute of Meteorology and Water Management located about 15 km south east from Przybroda were used. The climatological data were obtained partly from the archive of the Institute of Meteorology and Water Management and from the SYNOP messages accessed on the OGIMET data base (http://www.ogimet.com) and the US National Climatic Data Center (http://www.ncdc.noaa.gov). The location of both stations representative for the Great Poland Lowland is presented in Table 1.

Table 1. Location of the stations

TEMPERATURE CHARACTERISTICS AND SPRING FROST RISK	Longitude (°E)	Latitude (°N)	Altitude (m a. s. l.)
Przybroda	16.6560	52.5244	87
Poznań	16.8540	52.4160	86

The stations are located on a similar altitude and are fairly representative of the sour cherry growing area of western Poland. Data from Przybroda were compared with data from Poznań synoptic station and checked for completeness and discontinuities. The temperature data between both stations were very well correlated (Table 2). It was possible to update some gaps in Przybroda as well as to correct some erroneous data. Most corrections were done by using the linear regression equation of air temperature in Przybroda (y) with temperature in Poznań (x). All regression equations are presented in Table 2. All values which differed more than 4°C from the regression model were corrected.

Table 2. Correlation of daily averages of temperature in Przybroda (y) with temperature in Poznań (x)

Month	Regression equation	Coefficient of determination R^2	Correlation coefficient R	Standard error of y estimation (±)°C
Jan	$y = 0.9881x - 0.1352$	0.977	0.988	0.9
Feb	$y = 0.9768x - 0.0471$	0.971	0.985	0.9
Mar	$y = 0.9628x + 0.1492$	0.953	0.976	0.9
Apr	$y = 0.9907x + 0.3636$	0.938	0.969	1.1
May	$y = 0.9941x + 0.4856$	0.919	0.959	1.1
Jun	$y = 0.9936x + 0.6674$	0.898	0.948	1.2
Jul	$y = 0.9533x + 1.4939$	0.885	0.941	1.2
Aug	$y = 1.0354x - 0.0232$	0.891	0.944	1.2
Sep	$y = 0.9870x + 0.4846$	0.918	0.958	0.9
Oct	$y = 0.9584x + 0.4713$	0.951	0.975	0.9
Nov	$y = 0.9377x + 0.0844$	0.963	0.981	0.7
Dec	$y = 0.9674x - 0.1073$	0.970	0.985	0.8

Note. All correlation coefficients are significant at the level 0.01

The standard error of estimation of daily average temperature in Przybroda on the strength of Poznań temperature varied from ±0.7°C in November to ±1.2°C in summer months (June-August). Errors of daily maximum temperature were smaller (from ±0.8°C to ±1.1°C) than the daily minimum (from ±1.0°C to ±1.2°C). Standard statistical calculations of averages, standard deviation and extremes were used for further analysis of phenological and daily temperature data. More detailed distribution of data was presented for selected percentiles (p = 1, 10, 25, 50, 75, 90 and 99 %). Linear regression and correlation analysis was used for comparison of phenological data with air temperature indices (average April temperature, dates of the beginning of the thermal growing season and dates of the last spring frost). Temporal changes were analysed by using linear trends. The results were taken into account if they were significant at least at the level $p < 0.05$.

Results and discussion

The average duration of 'English Morello' sour cherry blooming in the analysed period lasted two weeks. It varied from 8 days in 1993 and 2002 to 22 days in 1991. In 50% of years the blooming period lasted between 11 and 15 days. The earliest blooming was observed on 20 April 1989 and 1990, after very warm winters. The latest start of blooming was noticed on 10 May 1985. The earliest end of blooming was observed on 2 May 1999 and the latest one on 26 May 1987. The average period of sour cherry blooming was between 30 of April and 12 May. Generally full blooming was observed 1–3 days after the beginning. Only in 1991 did sour cherry blooming start on 2 May after days with an average temperature above 10°C, and full blooming was recorded 6 days later on 8 May due to a temperature decrease down to 4–8°C. The blooming finished on 23 May. Such conditions caused the longest blooming duration period (22 days) (Table 3).

Table 3. Statistics of sour cherry blooming in Przybroda (1985–2010)

Statistics	Dates of blooming			Number of day a year			Blooming duration in days
	Start of blooming	Full blooming	End of blooming	Start of blooming	Full blooming	End of blooming	
Average	30 Apr	2 May	12 May	120	122	132	14
SD	6	6	7	6	6	7	4
Percentiles (p)							
Max	10 May	11 May	26 May	130	131	146	22
P = 90%	7 May	9 May	24 May	127	129	144	18
P = 75%	4 May	7 May	18 May	124	127	138	15
P = 50%	30 Apr	1 May	13 May	120	121	133	14
P = 25%	26 Apr	28 Apr	5 May	116	118	125	11
P = 10%	22 Apr	24 Apr	5 May	112	114	125	9
Min	20 Apr	22 Apr	2 May	110	112	122	8

SD – standard deviation

The dates of sour cherry blooming depend on the cultivars (Ansari and Davarynejad 2008). In Central Poland dates of full bloom of 10 cultivars differed by 5 days (from 29 April to 4 May) and the end of blooming by 8 days (between 16 and 24 May) in 2005 (Jadczuk-Tobiasz and Bednarski 2007). Greater differences were noticed in the dates of harvest maturity (between 2 and 24 July). Mean monthly temperature in Przybroda varied from -1.1ºC in January to 19.6ºC in July (Table 4). During extremely cold days, average daily temperature dropped below -20ºC in January and February. The highest value 31.6ºC was reached in August. In April, the important month for cherry blooming, daily average temperature varied between -2.4ºC and 23.4ºC. During 10% of days in this month it can be lower than 4.1ºC and higher than 14.9ºC (see percentiles 10% and 90%).

Table 4. Monthly statistics of average temperature in Przybroda (1985–2010)

Statistics	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	−1.1	0.1	3.5	9.2	14.4	17.2	19.6	19.0	14.0	8.9	3.6	0.3
SD	5.7	5.0	4.0	4.4	4.0	3.7	3.5	3.6	3.2	3.9	3.7	4.5
Max	10.5	12.1	14.3	23.4	25.9	28.6	30.0	31.6	23.7	18.2	13.1	11.8
Min	−22.3	−21.4	−11.1	−2.4	1.6	8.4	11.4	11.4	6.0	−1.6	−9.9	−15.4
Percentiles												
p = 99%	8.8	9.7	11.8	21.0	23.7	26.6	27.8	27.4	21.7	17.2	11.2	9.5
p = 90%	5.3	6.3	8.5	14.9	19.7	22.0	24.5	23.8	18.2	14.0	8.0	5.6
p = 75%	2.7	3.3	6.2	12.1	17.2	19.8	21.9	21.5	16.2	11.9	6.2	3.2
p = 50%	0.1	0.6	3.6	9.0	14.4	16.9	19.4	18.7	13.7	8.9	4.0	0.7
p = 25%	−4.2	−2.4	0.8	6.2	11.3	14.6	17.1	16.3	11.7	6.0	1.0	−1.9
p = 10%	−9.0	−6.8	−1.3	4.1	9.4	12.5	15.2	14.2	10.0	3.8	−1.3	−5.5
p = 1%	−18.6	−12.9	−7.3	−0.1	6.4	9.9	12.9	12.0	7.7	0.5	−6.6	−13.1

The highest daily maximum temperature reached 37.4ºC in July. Hot days with a maximum temperature above 30.0ºC were observed from May to August. Ice days with a maximum temperature below 0.0ºC were recorded between November and April. In January, the coldest month, the extremes of daily maximum temperature varied from -19.8ºC to 14.0ºC (Table 5).

The lowest daily minimum temperature dropped to -29.0ºC in January (Table 6). Frosty days with a minimum daily temperature below 0.0ºC occurred from October to May. The lowest minimum temperature in May equalled -2.9ºC and in April -7.5ºC. In April during 10% of days the minimum temperature dropped below -1.2ºC, but with the same probability was higher than 8.3ºC.

Table 5. Monthly statistics of maximum temperature in Przybroda (1985–2010)

Statistics	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	1.2	2.9	7.3	14.3	19.5	22.0	24.7	24.2	18.6	12.9	6.1	2.3
SD	5.50	4.97	4.84	5.21	4.67	4.32	4.34	4.32	3.97	4.40	4.08	4.48
Max	14.0	16.6	21.2	27.9	32.0	35.7	37.4	36.6	29.7	25.8	17.0	14.9
Min	−19.8	−16.7	−7.7	−0.3	2.8	10.0	14.5	12.9	9.2	2.3	−6.5	−12.5
Percentiles												
p = 99%	12.0	13.9	18.7	26.6	29.1	32.3	35.0	33.5	28.0	22.5	14.6	12.4
p = 90%	7.9	9.4	13.7	21.2	25.7	27.9	30.6	29.7	24.4	19.0	11.3	7.9
p = 75%	4.9	6.5	10.6	17.7	23.0	25.0	27.7	27.3	21.3	16.0	8.9	5.2
p = 50%	1.6	2.6	7.2	14.1	19.5	21.8	24.5	24.3	18.2	12.9	6.5	2.1
p = 25%	−1.8	−0.1	3.6	10.3	16.2	19.0	21.5	21.1	15.6	9.8	3.5	−0.3
p = 10%	−6.0	−3.3	1.2	7.6	13.4	16.5	19.0	18.6	13.6	7.2	0.4	−3.2
p = 1%	−13.8	−8.5	−2.2	2.9	9.0	13.0	16.3	14.5	11.3	3.4	−3.7	−10.4

Table 6. Monthly statistics of minimum temperature in Przybroda (1985–2010)

Statistics	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	−3.7	−2.9	−0.2	3.5	7.9	10.8	13.1	13.0	9.4	5.0	1.0	−2.1
SD	6.3	5.5	3.9	3.7	3.5	3.2	2.8	3.0	3.1	4.2	3.9	5.0
Max	8.7	10.2	10.4	15.1	18.1	21.4	21.1	22.8	18.4	14.0	12.2	10.8
Min	−29.0	−23.9	−18.5	−7.5	−2.9	1.6	5.0	3.8	0.2	−7.5	−13.5	−21.5
Percentiles												
p = 99%	6.0	6.3	7.9	13.0	15.3	17.9	19.9	19.1	16.5	13.2	8.5	6.9
p = 90%	2.9	2.7	4.5	8.3	12.6	15.1	17.0	16.6	13.2	10.5	5.7	3.3
p = 75%	0.8	0.7	2.4	6.0	10.3	13.0	15.0	15.3	11.5	8.0	4.0	1.0
p = 50%	−2.0	−1.5	0.0	3.4	8.1	10.6	13.1	13.1	9.4	5.5	1.1	−1.2
p = 25%	−7.2	−5.7	−2.1	1.0	5.4	8.5	10.9	10.7	7.4	2.0	−1.4	−4.5
p = 10%	−12.2	−11.4	−5.0	−1.2	3.3	6.7	9.5	9.0	5.1	−0.7	−4.1	−9.1
p = 1%	−23.1	−18.4	−11.8	−4.9	0.3	3.5	6.8	6.5	2.1	−4.9	−10.5	−16.5

The time of cherry blooming is highly sensitive to changes in temperature in spring months. A significant relationship between the beginning date of cherry blooming and the beginning of the thermal vegetation period was found ($r = 0.711$). In agroclimatology the thermal growing season is defined as the period with a stable daily average air temperature above 5ºC. In Poznań such thermal conditions started on 27 March and one day earlier in Przybroda. Variability of the index explained more than 50% of variability in the first dates of cherry blooming (coefficient of determination $R^2 = 0.505$ is significant at the level $p < 0.05$). The change in the beginning of the thermal growing season by 10 days was associated with the advance of the first bloom date by 3.8 days. If the vegetation period starts early, for example on 11 March (70th day of the year) the beginning of cherry blooming can be expected 45 days later on 25 April (115th day of the year). But in the case of a late date of the beginning of the growing season (10 April), the cherry blooming will be approximately 27 days later (7 May). Chmielewski et al. (2004) also found a good correlation ($r = 0.95$ significant at $p < 0.001$) between the beginning of the growing season and sweet cherry blossom time in Germany. Cherry blooming was also significantly ($p < 0.05$) correlated with mean April temperature ($r = 0.656$), which could explain about 43% of variability in the dates of the first bloom. An increase in April temperature by 1.0ºC caused earlier blooming by about 2.8 days. After cool Aprils (below 7.0ºC) the first blooming of the cherry can be expected after 5 May. In the case of warm Aprils (above 10.0ºC) the blooming of cherry trees started between 22 and 27 April.

During the period of 1985–2010 a significant increase in April temperature was observed in western Poland (Fig. 1). In Poznań the increasing trend amounted to 0.79ºC per decade. It also had a great effect on advances in the dates of the beginning of cherry blooming of about 3 days per decade. The warming of the spring season resulted also in a shorter sour cherry blooming period by 1.6 days per decade (Fig. 2). Since 1992 blooming has lasted from 8 to 15 days. An earlier beginning of spring development was also observed in the case of several plant species in Europe (Ahas et al. 2002; Chmielewski and Rötzer 2002; Chmielewski et al. 2004; Bissolli et al. 2005; Jatczak and Walawender, 2009; Ladányi et al. 2010). Smaller scale changes were observed in North American spring phenophases (Schwartz and Reiter 2000). Investigations of the cherry blooming phenophase have also been used for modelling studies of climate change (eg Andresen et al. 2006; Chung et al. 2011; Ohashi et al. 2011).

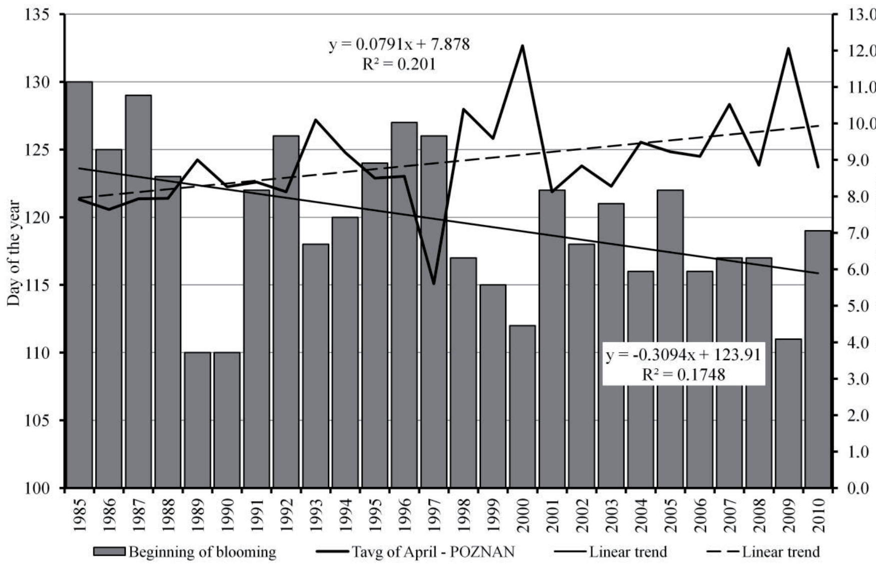

Fig. 1. Variability and linear trends of sour cherry blooming dates in Przybroda and the average April temperature in Poznań (1985–2010)

In the investigated area of western Poland spring frosts ended in the last decade of April on average (23 April in Przybroda and 25 April in Poznań). The latest frost was observed on 27 May 1991 in Poznań and on 14 May 2004 in Przybroda (Fig. 3). The earliest period without frosts started on 28 March 1998 in Przybroda and on 10 April 2008 in Poznań. In April the mean number of days with a minimum temperature below 0ºC amounted to 5 days, with a maximum of 15 days in 1997 and 10 days in April 1996 and 2003. Only April 1998 was a frost free month. Frost during or after the period of cherry flowering can damage blossoms and the set of fruitlets (Chmielewski at al. 2004; Dai et al. 2013). Characteristics of the 'English Morello' sour cherry blooming period according to frost hazard are presented in Fig. 4. In 26 of the years in Przybroda the last frost occurred during the blooming phenological phase or later only 4 times (15%) in 1989, 2004, 2007 and 2009. The frost during 10 days before blooming and during the blooming occurred in 54% of the years. In Hungary (Ladányi et al. 2010) during 1984–2006 such conditions were indicated during 45% of spring seasons.

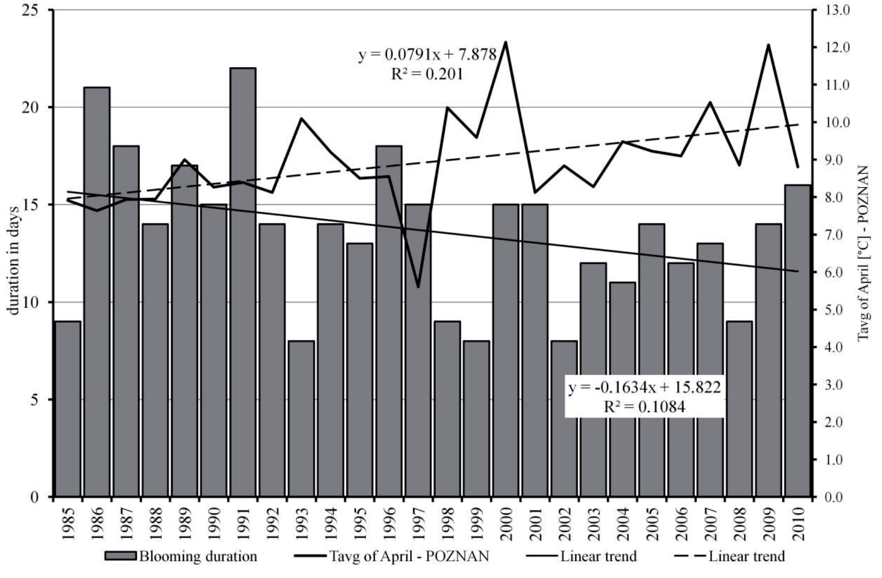

Fig. 2. Variability and linear trends of sour cherry blooming duration in Przybroda and the average April temperature in Poznań (1985–2010)

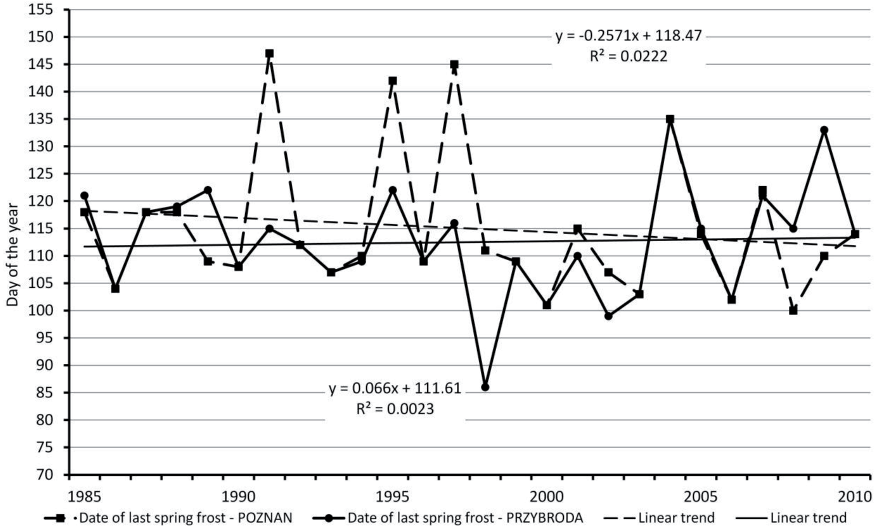

Fig. 3. Variability and linear trends of the dates of the last spring frost in Przybroda and in Poznań (1985–2010)

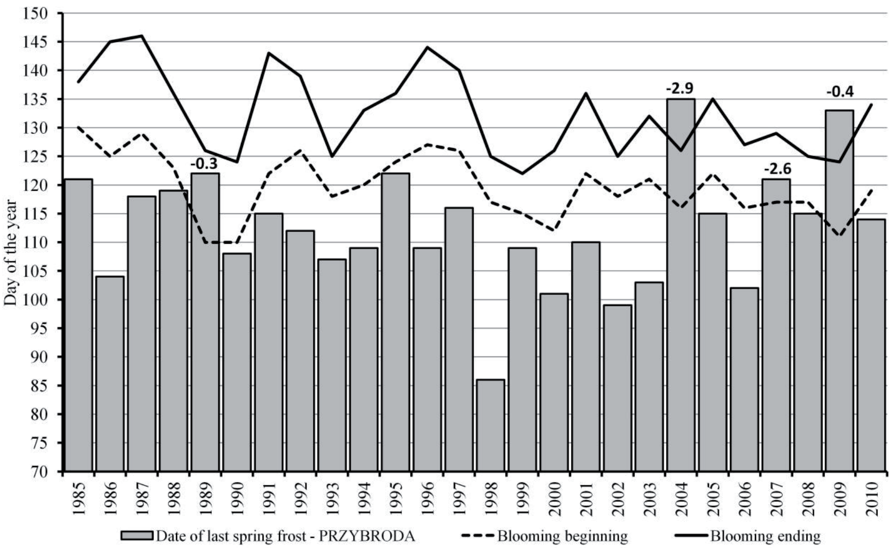

Fig. 4. Frost hazard during the sour cherry blooming period in Przybroda in 1985–2010. Note: numbers above the bars indicate the negative minimum temperature in ºC during or after the blooming period

Conclusions

1. The average period of 'English Morello' sour cherry blooming in the Agriculture and Pomology Research Farm in Przybroda, representative for western Poland, was between 30 April and 12 May. During 50% of years the blooming period lasted between 11 and 15 days.
2. A significant relationship between the beginning date of sour cherry blooming and the start date of the thermal vegetation period was observed. Variability of the index explained more than 50% of variability in the first dates of cherry blooming.
3. Sour cherry blooming was also significantly ($p < 0.05$) correlated with mean April temperature, which could explain about 43% of variability in the dates of the first bloom.
4. An increase in April temperature by 1.0ºC caused earlier blooming by about 2.8 days.
5. During the period of 1985-2010 a significant increase in April temperature was observed (in Poznań 0.79ºC per decade). It also had

a great influence on advances in the dates of the beginning of sour cherry blooming of about 3 days per decade.

6. In 26 of the years the last frost occurred 4 times (15% of seasons) during the blooming phenological phase or later. Frost occurrence 10 days before blooming started and during the blooming was recorded in 54% of years.

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References

AHAS R., AASA A., MENZEL A., FEDOTOVA V.G. and SCHEIFINGER H., 2002, Changes in European spring phenology, Int. J.Climatol., 22, 1727–1738.

ANDRESEN J.A., ZAVALLONI C., BLACK J.R., WINKLER J.A., BISANZ J.M. and FLORE J.A., 2006, The Pileus Project: Impact of Climate Variability and Climate Change on Sour Cherry Production in the Great Lakes Region, <http://pileus.msu.edu/agriculture/> [accessed 19 07 2013].

ANSARI M. and DAVARYNEJAD G., 2008, The flower phenology of sour cherry cultivars, American-Eurasian J. Agriculture Env. Sci., 4 (1), 117–124.

BISSOLLI P., MÜLLER-WESTERMEIER G., DITTMANN E., REMISOVÁ V., BRASLAVSKÁ O. and STASTNÝ P., 2005, 50-year time series of phenological phases in Germany and Slovakia: a statistical comparison, Meteorol. Zeit., 14 (2), 173–182.

CHMIELEWSKI F.-M., MÜLLER A. and BRUNS E., 2004, Climate changes and trends in phenology of fruit trees and field crops in Germany, 1961–2000, Agricultural Forest Meteorol., 121 (1–2), 69–78.

CHMIELEWSKI F.-M. and RÖTZER T., 2002, Annual and spatial variability of the beginning of growing season in Europe in relation to air temperature changes, Clim. Res., 19, 257–264.

CHUNG U., MACK L., YUN J.I. and KIM S.-H., 2011, Predicting the timing of cherry blossoms in Washington, DC and Mid-Atlantic States in response to climate change, PLoS ONE, 6 (11), e27439. DOI: 10.1371/journal.pone.0027439.

DAI J., WANG H. and GE Q., 2013, The decreasing spring frost risks during the flowering period for woody plants in temperate area of eastern China over past 50 years, J. Geograph. Sci., 23 (4), 641–652. DOI: 10.1007/s11442-013-1034-6.

DIRLEWANGER E., CLAVERIE J., IEZZONI A.F. and WUNSCH A., 2009, Sweet and sour cherries: linkage maps, QTL detection and marker assisted selection, Genetics and Genomics of Rosaceae / Folta K.M. and Gardiner S.E. (eds), 291–313.

ECCEL E., REA R., CAFFARRA A. and CRISCI A., 2009, Risk of spring frost to apple production under future climate scenarios: the role of phenological acclimation, Int. J. Biomet., 53 (3), 273–86.

FAOSTAT, 2013, Agriculture data. <http://apps. fao.org> [accessed 26 07 2013].

GRUCA Z., BOJAR K. and HOLUBOWICZ T., 1989, Uszkodzenia mrozowe drzew owocowych w rejonie Poznania po zimie 1986/87 roku (The frost injury of fruit trees after winter 1986/87 in the Poznań region), PTPN, Prace Komisji Nauk Rolniczych i Komisji Nauk Leśnych, 67, 47–57 (in Polish).

GRZYB Z.S. and ROZPARA E., 1998, Plum production in Poland, Acta Horticulturae, 478, 19–24.

IEZZONI A.F., SEBOLT A.M. and WANG D., 2005, Sour cherry breeding program at Michigan State University, Acta Horticulturae, 667, 131–134.

JADCZUK-TOBIASZ E. and BEDNARSKI R., 2007, Wstępna ocena wzrostu i owocowania dziesięciu odmian wiśni (Preliminary evaluation of the growth and yielding of 10 sour cherry cultivars), Zesz. Nauk. Inst. Sadownictwa i Kwiaciarstwa, 15, 17–27 (in Polish).

JATCZAK K. and WALAWENDER J., 2009, Average rate of phenological changes in Poland according to climatic changes – evaluation and mapping, Advan. Sci. Res., 3, 127–131.

KIRAKOSYAN A., SEYMOUR E.M., LLANES D.E.U., KAUFMAN P.B. and BOLLING S.F., 2009, Chemical profile and antioxidant capacities of tart cherry products, Food Chemistry, 115 (1), 20–25. DOI:10.1016/j.foodchem.2008.11.042.

LADÁNYI M., PERSELY Sz., SZABÓ T., SZABÓ Z., SOLTÉSZ, M. and NYÉKI J., 2010, Climatic indicator analysis of blooming time for sour cherries, Int. J. Horticultural Science, 16 (1), 11–16.

LEE S., ZHAO J. and THORNSBURY S., 2013, Extreme events and land use decisions under climate change in tart cherry industry in Michigan, AAEA and CAES Joint Annual Meeting, Washington, DC, 2013. <http://purl.umn.edu/150568> [accessed 26 07 2013].

MIKA A. and CZYNCZYK A., 1989, Report on the international planting system trial in Poland, Acta Horticulturae, 243, 243–248.

OHASHI Y., KAWAKAMI H., SHIGETA Y., IKEDA H. and YAMAMOTO N., 2011, The phenology of cherry blossom (*Prunus yedoensis* "Somei-Yoshino") and the geographic features contributing to its flowering, International Journal of Biometeorology, 56 (5), 903–914. DOI: 10.1007/s00484-011-0496-4.

PÉREZ-SÁNCHEZ R., MORALES-CORTS M.R. and GÓMEZ-SÁNCHEZ M.Á., 2013, Quality evaluation of sour and duke cherries cultivated in south-west Europe, Journal of the Science of Food and Agriculture, 93 (10), 2523–2530. DOI:10.1002/jsfa.6069.

SCHWARTZ M.D. and REITER B.E., 2000, Changes in North American spring, Int. J. Biometeo., 20 (8), 929–932.

SZPADZIK E., JADCZUK-TOBJASZ E. and ŁOTOCKA B., 2008, Preliminary evaluation of pollen quality, fertility relations and fruit set of selected sour cherry cultivars in Polish conditions, Acta Agrobotanica, 61 (1), 71–77.

SZPADZIK E., MATULKA M. and JADCZUK-TOBJASZ E., 2009, The growth, yielding and resistance to spring frost of nine sour cherry cultivars in central Poland, J. Fruit Ornamental Plant Res., 17 (2), 139–148.

TOYDEMIR G., CAPANOGLU E., GOMEZ ROLDAN M.V., de VOS R.C.H., BOYACIOGLU D., HALL R.D. and BEEKWILDER J., 2013, Industrial processing effects on phenolic compounds in sour cherry (*Prunus cerasus* L.) fruit, Food Res. Int., 53 (1), 218–225. DOI:10.1016/j.foodres.2013.04.009.

WINKLER J.A., THORNSBURY S., ARTAVIO M., CHMIELEWSKI F., KIRSCHKE D., LEE S., LISZEWSKA M., LOVERIDGE S., TAN P-N., HONG Sh., ANDRESEN J.A., BlACK J.R., KURLUS R., NIZALOV D., OLYNK N., USTRNUL Z., ZALALLONI C., BISANZ J.M., BUJDOSÓ G., FUSINA L., HENNIGES Y., HILSENDEGEN P., LAR K., MALARZEWSKI L., MELLER T., MURMYLO R., NIEDZWIEDZ T., NIZALOVA O., PRAWIRANATA H., ROTHWELL N., van RAVENSAY J., von WITZKE H. and WOODS M., 2010, A conceptual framework for multi-regional climate change assessments for international market systems with long-term investments, Clim. Change, 103 (3), 445–470.

ZAWADZKA B., 1989, The influence of virus and mycoplasma diseases on frost damage of apple trees, Acta Horticulturae, 235, 59–68.

ZIÓŁKOWSKA E., 2013, Rolnictwo w 2012 (Agriculture in 2012), Główny Urząd Statystyczny, Departament Rolnictwa (CSO Agriculture Depertment) (in Polish).