Europ.J.Hort.Sci., **76** (1). S. 1–5, 2011, ISSN 1611-4426. © Verlag Eugen Ulmer KG, Stuttgart

The Effect of Environmental Temperature on Sweet Cherry Phenology

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Summary

Phenological data of sweet cherry (*Prunus avium* L.) cultivars 'Burlat' and 'Germersdorfer' were analysed to ascertained the effect of air temperature on the onset of phenophases (first bloom, full bloom, end of flowering, maturity and calculated period of fruit development) during two 5-years-periods: before (P1) and during climate change (P2) in Slovenia. Although non-significantly higher mean temperatures from January to March during P1 influenced earlier date of flowering. The onset of 'Burlat' flowering phenophases were statistically similar during P1 and P2, being later first bloom and full bloom in P2, but the onset of 'Germersdorfer' flowering phenophases were significantly later during P2. Significantly higher mean temperatures of April and May during P2 shortened period of fruit development for 7 d in 'Burlat' and 11 d in 'Germersdorfer'. The speed of sweet cherry phenological progress was influenced by temperature of the preceding months. Shortened period of fruit development will most probably reduce sweet cherry fruit quality and yield, but advanced flowering after warmer winter months will increase risk of spring frosts.

Key words. *Prunus avium* – phenological phase – fruit development – air temperature – Slovenia

Introduction

Crop production is inherently sensitive to variability in climate (Craufurd and Wheeler 2009). Thermometer records show that, over the past 30 years, global average surface temperature increased by 0.2 °C per decade (Hansen et al. 2006). Data from phenological observations are considered to be the most sensitive for identifying how plant species respond to regional climatic conditions and to climatic changes (Chuine et al. 1999; Schwartz 1999; Rötzer and Chmielewski 2001). Shifts in the timing of plant activity (i.e. phenology) provide some of the most compelling evidence that species and ecosystems are being influenced by global environmental change (Cleland et al. 2007). Mean advance of spring/summer species' phenology in 21 European countries is by 2.5 d $°C^{-1}$ (Menzel et al. 2006). Fifty years of weather records and pome phenology data showed a distinct separation between the first phase (1958–1987) and a second phase (1988–2007), indicating the start of the climate change in 1988 (Blanke and Kunz 2009).

Most research on the agricultural impacts of climate change has focused on the major annual crops (Craufurd and Wheeler 2009) yet perennial cropping systems are less adaptable and thus potentially more susceptible to damage (Lobell et al. 2006). Perennial crops exhibited a significantly higher temperature response to mean spring temperature than the annual crops (Estrella et al. 2007). Growing season of 29 perennial species in Spain lengthened by 18 d, achieved mainly though the advance of leaf unfolding dates in spring (Gordo and Sanz 2009). Species and hybrids of *Cerasus* sp. or *Prunus* sp. grown in Japan flowered earlier over time, by an average of 5.5 d over the 25-yr study (Miller-Rushing et al. 2007). On average, apple and pear flowering was 10 d earlier after warm winters (Blanke and Kunz 2009).

There are only some studies of climate change on perennial fruit crops. In the future more efforts are necessary to estimate the impacts of temperature rise on fruit trees (Chmielewski et al. 2004). Various plant species react differently to various climatic factors (Wielgolaski 2003). Galan et al. (2001) and Orlandi et al. (2009) studied the role of the temperature on the olive (*Olea europaea* L.) flowering. Lobell et al. (2006) evaluated the impact of climate change on grapes, almonds, oranges, walnuts and avocados. Over 3 years the time of leaf budding, flowering and partly also ripening was studied along a Norwegian fjord in plum, pear, apple, raspberry and red currant (Wielgolaski 2003). Strong trends were found towards an earlier onset of bud breaking date in two walnut cultivars over the last two decades (1984–2006) (Solar et al. 2008; Črepinšek et al. 2009).

As far as we know, there are no data about the response of sweet cherry cultivar's phenology on climate change. In order to interpret correctly the climatic trend it is necessary to have a long series of data (Orlandi et al. 2009), however, series of data, especially data of phenological observations of the same cultivar grown at the same place, are infrequent. Fortunately, at our Institute phenological studies of sweet cherry cultivars have been carried out since 1965 (Smole 1965–1995; Usenik 1996–2007). The objective of our study is to determine the

influence of air temperature on the onset of major phenophases of two sweet cherry cultivars over two time-periods (before and during climate change) in Slovenia. The aim of this study is also to find correlations between air temperatures and the biological response of cultivars 'Burlat' and 'Germersdorfer' (*Prunus avium* L.)

Materials and Methods

Plant material

'Burlat' and 'Germersdorfer' sweet cherry trees (*Prunus avium* L.) on Mazzard rootstock, spaced 6 × 6 m, and trained as modified central leader were observed for phenological data. 'Burlat' is sweet cherry cultivar known to its early ripening season and 'Germersdorfer' is late ripening cultivar (Bargioni 1996). A database of phenological observations (flowering dates: first bloom, full bloom, end of flowering and date of maturity), collected from the experimental orchard of Agricultural and Forestry Institute Nova Gorica (45° 90' N, 13° 63' E, 70 m above sea level) by Biotechnical faculty staff as a part of a long-term testing of foreign varieties, was used for this study (Smole 1965–1995; Usenik 1996–2007).

Temperature data

Decade and monthly values of mean, minimum and maximum air temperatures from January to 1st decade (ten day period) of June for both observed time periods (without year 1971) were obtained from meteorological station of the Environmental Agency of Slovenia installed in Bilje by Nova Gorica.

Phenological observations

Two groups of trees of each cultivar which were planted in 1966 and 1995, respectively were observed. Phenological observations were made on 5 trees of each cultivar within each planting for 5 years. The 1966 planting was observed between 1970 and 1975 (P1) (without year 1971) – before climate change, and the 1995 planting from 1999–2003 (P2) – during climate change (Blanke and Kunz 2009). The phenological data were determined in the orchard following the Meier's scale (Meier et al. 1994) and were shown as a day of the year (DOY). According to BBCH-identification keys of stone fruit phenological growth stages first bloom was determined at BBCH 61, full bloom at BBCH 65, end of flowering at BBCH 67 and maturity at BBCH 87. On the base of the DOY of full bloom and DOY of maturity, the number of days from full bloom to maturity (period of fruit development) was calculated.

Statistics

Phenological data were used to calculate the average dates of flowering and maturity for selected time periods and to calculate mean number of days from full bloom to maturity. Statistical analysis was conducted with the program Statgraphics Plus 4.0 (Statgraphic, Herndon, VA). One-way ANOVA was used for analysis the effect of time period on the date of each observed phenological stages. Means between time periods were separated by the test for least significant difference (LSD) at a significance level of 0.05. Correlation between the onset of phenophases and the mean temperatures of the preceding months was determined at $P \leq 0.05$.

Results

Temperature

The comparison of mean monthly air temperatures during P1 and P2 in the present study showed higher temperatures from March to June for time-period 1999–2003 (P2) (5 years period during climate change), being significantly higher in April and May. T_{max} reached the highest values for January, February and March during P1 and during P2 for April, May and June (data not shown). From March to 1st decade of June significantly higher mean values of T_{min} were also measured during P2. Mean T_{max} of May was significantly higher in P2 compared to P1.

During P1, the mean monthly temperatures from January to March was 5.8 compared to 5.2 °C in P2 (Table 1). Comparison of mean monthly temperatures from February to March of P1 and P2 showed statistically similar values, 7.1 and 6.4 °C, respectively. There are no significant differences between P1 and P2 in the mean air temperatures from January to April and from March to April. Significantly higher mean temperatures were during P2 from March to April, from April to May, from April to 1st decade of June and from May to 1st decade of June compared to P1. During P2, mean air temperatures for the period from March to May was 1.8 °C higher, from April to May 2.2 °C higher, from May to 1st decade of June 3.1 °C higher and from April to 1st decade of June 2.5 °C higher, compared to P1.

The onset of phenophases

During P1 the mean date of phenological phase first bloom was for 'Burlat' 28 March [= 87 DOY (day of the year)] and not significantly different from 4 April (94 DOY) during P2 (Table 2). In P1, mean temperatures from February to March and from February to 1st decade of April had a statistically significant influence on the

Table 1. Average air temperatures with SE during two time-periods: P1 (1970–1975) and P2 (1999–2003) (n=5), Bilje, Slovenia.

	P1 (1970–1975)		P2 (1999–2003)	
	Average	SE	Average	SE
January, February, March	5.8	0.26	5.2	0.40
January, February, March, April	10.1	0.25	10.7	0.20
February, March	7.1	0.47	6.4	0.42
March, April	9.2	0.43	10.4	0.17
March, April, May	11.1	0.22	12.9	0.09
April, May	12.8	0.06	15.0	0.08
May, 1. decade June	16.1	0.39	19.2	0.41
April, May, 1. decade June	14.3	0.19	16.8	0.29

Table 2. Average onset of phenophases (day of the year – DOY) and the number of days from full bloom to fruit maturity with SE for 'Burlat' and 'Germersdorfer' during two time-periods: P1 (1970–1975) and P2 (1999–2003) (n=5).

	The onset of phenophases (DOY)				Number days from full bloom to maturity
	Flowering			Maturity	
	First bloom	Full bloom	End of flowering		
P1 'Burlat'	87 ± 2.67 b	94 ± 2.85 b	111 ± 5.46 a	142 ± 2.91 b	47 ± 0.88 a
P2 'Burlat'	94 ± 2.58 ab	101 ± 2.48 ab	109 ± 2.26 a	140 ± 0.81 b	40 ± 2.44 a
P1 'Germersdorfer'	89 ± 5.21 b	93 ± 4.93 b	104 ± 7.81 a	162 ± 1.00 a	69 ± 5.13 a
P2 'Germersdorfer'	98 ± 2.24 a	105 ± 2.60 a	113 ± 2.13 a	162 ± 2.01 a	58 ± 2.42 b

Different letters indicate significantly different values at $P < 0.05$.

onset of first bloom for 'Burlat' (r=−0.991 and −0.999, respectively). In P2, DOY of the first bloom of 'Burlat' was the most affected by the mean temperature in March (r=−0.896). The mean date of 'Burlat' full bloom was for 7 d later during P2 and not statistically different from P1. DOY of full bloom of 'Burlat' was significantly correlated with the mean temperatures from February to 1st decade of April in P1 and P2. End of flowering and maturity of 'Burlat' was for two days earlier during P2 and not significantly earlier from P1. For the early ripening cultivar 'Burlat' DOY of maturity was during P1 the most influenced by mean temperatures from March to maturity date (22.5.) (r=−0.976) and during P2 by mean temperatures from April to DOY of maturity (r=−0.766).

The mean DOY of the phenological phases first bloom, full bloom and the end of flowering of 'Germersdorfer' were statistically later during P2, for 9, 12 and 9 d, respectively. In P1, 'Germersdorfer' DOY of first bloom was significantly affected by the mean temperature in March and in P2 by the mean temperature in February, March and 1st decade of April (r=−0.762). The onset of full bloom of 'Germersorfer' in P1 was significantly correlated with mean temperatures in March and in P2 with the mean temperatures from February to 1st decade of April. The mean date of 'Germersdorfer' maturity was the same, 11 June (162 DOY) for both time-periods. For the late sweet cherry cultivar 'Germersdorfer' DOY of maturity was during P1 significantly influenced by mean temperatures from May to maturity date (11.6.) (r=−0.999) and during P2 by mean temperatures in May (r=0.514).

Time between bloom and maturity

The time between bloom and maturity was in present study from 40 to 47 d for 'Burlat' and from 58 to 69 d for 'Germersdorfer' (Table 2). Comparison of number of days from full bloom to maturity between P1 and P2 for 'Burlat' showed no significant differences, being lower for 7 d during P2.

Period from full bloom to maturity was for 'Germersdorfer' significantly shortened for 11 d during P2, compared to P1. Number of days from full bloom to maturity was for 'Burlat' in P1 the most influenced by mean temperatures in April and first two decades of May (r=0.996) and in P2 by temperatures in April and May (r=−0.925). The period of 'Germersdorfer' fruit development was in P1 the most influenced by temperatures in May (r=−0.790) and in P2 by temperatures in May and in June until fruit maturity (r =−0.829).

Discussion

Phenological observations applied to agriculture are used to determine significant relationships between meteorological variables and plant behaviour (Orlandi et al. 2009). As far as we know, there are no data about the response of sweet cherry cultivar's phenology on climate change. The effect of air temperatures on the onset of phenological phases was performed in the present study. Temperature is a major determinant of the rate of plant development (Wielgolaski 2003). Ambient air temperature is the usual 'temperature' used to quantify responses to temperature (Craufurd and Wheeler 2009).

According to the data derived from Environmental Agency of the Republic of Slovenia, the mean annual air temperature for 1971–2000 in Bilje is 12.0 °C with mean annual measured precipitation 1446 mm. The mean number of days with T_{min}<0 °C for 1971–2000 is 96 and the mean number of days with T_{max}>30 °C is 79. Across most of the territory of Slovenia there is a strong interaction of three major climate systems: Continental, Alpine and sub-Mediterranean which influence big daily and annual temperature spans. Phenology data analysed from 156 year records for Ljubljana (the capital of Slovenia) show that the average temperature of the year was increased for 1.3 °C (Kajfež-Bogataj 2008).

Onset of phenophases for different sweet cherry cultivars grown in Slovenia has demonstrated substantial year-to-year variation (Smole 1965–1995; Usenik 1996–2007). Phenological changes were a clear reaction to temperature (Menzel et al. 2006), what can be assumed also with the results of the present study. Climate change after 1988 has been documented elsewhere but there exist also year to year variation. Our results show that sweet cherry flowering phenophases were earlier after warm months prior to the onset of phenophase (in our study in P1) and the delay in onset of spring flowering phenophases of both sweet cherry cultivars in P2, being statistically significant for 'Germersdorfer'. Although non-significantly higher mean temperatures from January to March influenced earlier date of flowering during P1 (period before climate change). Apple and pear flowering was 10 d earlier after warm winters (Blanke and Kunz

2009). Different groups have documented a correlation between earlier spring phenology and rising temperatures in recent years (Williams and Abberton 2004; Menzel et al. 2006; Estrella et al. 2007; Sadras and Monzon 2006; Črepinšek et al. 2009). Menzel et al. (2006) report that 78% of all observations in 21 European countries showed earlier flowering due to warming. Shifts in earlier onset of sweet cherry phenology are expected in the future considering future climate scenarios for Slovenia (Bergant and Kajfež-Bogataj 2005) which can lead to the highest risk of spring frosts.

In spite of the fact, that mean temperatures of April and May have been significant higher during P2 (during climate change), the same reported Kajfež-Bogataj (2008) for the long time period for Slovenia, date of maturity of both cultivars was not affected. Blanke and Kunz (2009) reported the more pronounced temperature rise in January and February for Klein-Altendorf (West Germany) during climate change. Responses to supra-optimal temperatures are poorly understood – though clearly these will become more important as the frequency of high temperature events increases under projected climate change (Craufurd and Wheeler 2009).

The time between full bloom and maturity in present study was from 40 to 47 d for 'Burlat' and from 58 to 69 d for 'Germersdorfer'. Roper and Kennedy (1986) reported 65 to 75 d for 'Bing'. Generally, our results show that higher temperatures during fruit growth shortened period of fruit development, which is the most commonly documented impacts of climate change on crops (Craufurd and Wheeler 2009). The fruit development was shortened for 7 d in 'Burlat' and 11 d in 'Germersdorfer', achieved mainly though the advance of fruit development. Cherries are unique among deciduous tree fruits because of the short time among bloom and harvest (Roper and Kennedy 1986). Already short period from bloom to maturity, shortened for some days, means that sweet cherry fruits have less time for cell division, pit hardening and mesocarp growth. If we speculate, shortened sweet cherry fruit development process can have impact on lower fruit quality because of quickened progress of events. Delayed process of maturity due to the GA_3 application influenced better sweet cherry fruit quality (Usenik et al. 2005). Under climate change, warmer temperatures that shorten development stages of determinate crops will most probably reduce the yield of a given variety (Craufurd and Wheeler 2009).

For most phenological phases, the correlation coefficients were negative. Thus, higher temperatures were related to earlier onset dates (Menzel et al. 2006). Strong correlations between the timing of spring events and mean temperatures in the preceding months have been shown for different species (Chmielewski et al. 2004; Menzel et al. 2006; Črepinšek et al. 2009; Orlandi et al. 2009), but our results show also the cultivar specific response to temperature. Menzel et al. (2006) found that the phenophases were most highly correlated with the mean monthly temperature of the preceding month and less with mean temperature 2 months prior to the phenophase. The present study suggests that the onset of phenophases in sweet cherry was significantly influenced by mean temperatures two or three months prior to phenophase, particularly for flowering phenophases. This statement shows that the onset of flowering is influenced by every day with appropriate temperature after chill accumulation. It is well known that chill accumulation and temperature forcing are related to breaking dormancy (Cesaraccio et al. 2004). Usually 4.5 °C is the base above which the growth degree days (GDDs) are calculating (Faust 1989).

Phenophases of sweet cherry are related to environmental temperature. The onset of flowering phenophases was mainly influenced by mean temperatures two or three months prior to the phenophase. The very few years of observation showed that winter months in the period before climate change (P1) were warmer compared to years during P2 but spring months April, May and June were significantly warmer in P2 (during climate change). Advanced phenological stages as a response to higher temperatures prior to the onset of phenophase are expected in the future and will probably increase risk of spring frosts and decrease both fruit quality and yield of sweet cherry.

Acknowledgement

This work is part of program Horticulture No. P4-0013-0481 granted by the Slovenian Ministry of Higher Education, Science and Technology.

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Received March 25, 2010 / Accepted December 16, 2010

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