



Forty-year investigations on apricot blooming: Evidences of climate change effects

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ABSTRACT

Current climate change negatively impacts on key seasonal biological processes of perennial plants causing erratic productions and, consequently, significant yield reductions. Being flowering time of fruit crops one of the most widely used indicators for climate change studies, the present research aimed to assess, over a long-term period (1973–2016), the climatic trend and its influence on blooming date and intensity of 40 apricot cultivars (*Prunus armeniaca* L.) grown in central Italy. Over the autumn-spring seasons, the main climatic parameters (temperature, rainfall) were acquired, and calculation of chill accumulation according to the Chilling Units model (CU) was performed. Results showed significant trends in warming of autumn-winter monthly minimum and average temperatures, particularly since the 1990s. During the critical period for overcoming of flower bud endodormancy, a dramatic loss of CUs was recorded. Most of the examined cultivars, belonging to Italian and foreign germplasm and opportunely selected for different flowering time, showed important blooming delays and blooming intensity decreases. In particular, the early-blooming cultivars showed the highest average shift of around 12 days and a loss in blooming intensity score which fell to levels of around 50% with respect to previous periods. The CUs, negatively correlated with blooming time and positively correlated with blooming intensity, seem to be crucial for apricot floral biology. The irregular autumn-winter cold rate of recent years may mean that substantial impacts can be expected in the future with possible geographic shifts of the apricot cultivation areas towards more potentially suitable areas located in the northern Italian and European regions, with considerable socioeconomic inference.

1. Introduction

Current climate change, represented by a substantial global warming, is impacting on the biological dynamics of plants showing phenological variations as a function of vulnerable environmental conditions (Walther et al., 2002; White et al., 2009). The biological processes leading to flowering are affected by ongoing climate alteration due to seasonal extreme events. In pome and stone fruit trees of temperate regions, these events may negatively influence key phases, such as bud dormancy, causing erratic budbreak and, consequently, significant plant yield reductions and financial losses (Byrne et al., 2000; Legave et al., 2013). Bud dormancy is defined as a strategy of plants for survival under unfavorable growing conditions by the insensitiveness of meristems to growth-promoting signals (Rohde and Bhalerao, 2007). In particular, endodormancy, in which growth is regulated by physiological factors inside the bud (Lang et al., 1987), is under the combined control of decreasing day-length (Caffarra et al.,

2011) and chilling accumulation (Erez et al., 1971; Chuine and Cour, 1999). The genotype-specific chilling requirement has to be satisfied by cold temperatures during the autumn-winter season to ensure endodormancy release. When the chilling requirement is fulfilled, buds go into ecodormancy, an apparently quiescent state up to the exposure to warm temperatures inducing which induce the flower bud burst (Horvath et al., 2003).

A number of recent studies focusing on dormancy related traits and adaptation of genotypes to specific cultivation areas showed that, in recent years, the frequent occurrence of warmer winters in Mediterranean regions has significantly affected endodormancy release due to an unfulfilled chilling requirement. As a consequence, several fruit species may show physiological and biological disturbances producing detrimental effects on productivity (Luedeling et al., 2011; Gannouni et al., 2017; Prudencio et al., 2018). This is what has been happening for apricot (*Prunus armeniaca* L.), a fruit species strongly influenced by weather-environmental factors which impact on its floral

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biology patterns through the appearance of flower bud anomalies, drops and alterations of phenological processes (Rodrigo and Herrero, 2002; Bassi et al. 2006; Legave et al., 2006; Oukabli and Mahhou, 2007). In particular, several studies have shown that, as a consequence of short or warm winter seasons, an incomplete resumption of flower bud dormancy occurs resulting in scanty apricot blooming (Viti and Monteleone, 1995; Erez, 2000). Among apricot cultivars, substantial differences in chilling requirements have been reported (Viti et al., 2006). However, most of them need a medium chilling requirement in Mediterranean areas (Ruiz et al., 2007; Viti et al., 2013), namely 800–1200 chilling units (CUs) according to the Utah model proposed by Richardson et al. (1974). In particular, in Tuscany crop-lands of central Italy, the threshold of 1000 CUs has been considered a determinant amount for the fulfilment of chilling requirement in the majority of apricot cultivars (Viti et al., 2006; Guerriero et al., 2010). Nevertheless, the tendency of the winter climate to become progressively milder may determine substantial impacts on apricot, a species sensitive to physiological disorders such as appearance of floral anomalies and flower bud drop (Legave et al., 1982; Viti et al., 2008). Thus, studies concerning the effect of climate factors on the floral biology processes are important in planning the apricot culture for the future, focusing on resilient genotypes able to remain economically productive over the years.

Accordingly, as the flowering time of fruit crops is one of the most widely used indicators of climate change, the present research aimed to assess, over a long-term period, the climatic trend and its influence on the blooming date and intensity of a number of apricot cultivars grown in central Italy.

2. Materials and methods

2.1. Study site and plant material

From 1973 to 2016, 40 apricot cultivars characterized by different blooming and ripening time were studied. In Table 1 cultivars are shown in three groups according to the blooming time recorded under our Tuscan environmental area: i) early (before March 5th), ii) mid (between March 6th and 15th), iii) late (after March 15th). For each cultivar, the ripening time as - early (E, before June 15th), - mid (M, up to June 30th), - late (L, after July 1st), and the type of fruiting habit (long shoot, L and/or spur, S) are indicated. Most of them, belonging to

Italian germplasm, are still cultivated in the main apricot crop areas. Several worldwide foreign cultivars, such as, 'Bulida', 'Canino', 'Currot', 'Goldrich', 'Harcot', 'Moniqui', 'Polonais', 'Rival' and 'Rouge de Roussillon' were considered too.

Trees, grafted onto Myrabolan 29C rootstock and trained to a free palmette system (4 m × 4.5 m), were grown at the experimental site of the Department of Agriculture, Food and Environment of Pisa University located along the Tyrrhenian coastal area of Tuscany (Italy, Venturina, altitude 6 m a.s.l., lat. 43°02' N, long. 10°36' E). Over the forty-four years period, the experimental orchards have been renewed to maintain the cultivar efficiency and thus, in this work, full-bearing apricot trees (6–10 years old) were considered. The site is characterized by Mediterranean climate with warm-winters and annual average rainfall of about 600 mm; the soil in orchard is loam, moderately deep, medium texture, slightly alkaline, non-calcareous. Trees were not irrigated and routine conventional horticultural managements (pruning, thinning, fertilization, pest and disease protection) were performed. The experimental design was established in a randomized design (five single-tree replications per cultivar).

2.2. Climatic parameters

Starting in 1973, the main climatic parameters were acquired over the autumn-spring seasons. Daily measurements of hourly air temperatures were taken by thermo-hydrometers and data-loggers (Tynitag Plus[®], West Sussex, UK, 2003) located inside the orchards; rainfall data were provided by the Hydrological Service of Tuscany (SIR). From 1976 onwards, minimum and maximum temperature data were converted to 'Chilling Units' (CUs), according to the Utah Model (Richardson et al., 1974). This model, the most suitable under our experimental areas (Viti et al., 2010a), assigns variable weights to differing temperature ranges, resulting in CU amount. Temperatures with a positive effect ranged between 1.5 and 12.4 °C, while temperature with a negative effect are higher than 15 °C. The start of CU accumulation is fixed when the largest value of CU is attained in autumn; in our environmental conditions the end of vegetative season (50% of leaf drop) usually occurred within the first fifteen days of November. In this work the CU accumulation is shown up to January 31st, which was considered a significant date for reaching 1000 CUs. This threshold-amount reflects the fulfilment of chilling requirement of most apricot cultivars recorded over the years in the same geographical area of this study (Viti et al., 2006; Guerriero

Table 1

Forty apricot cultivars studied over 44 year-long period (1973–2016). Cultivars have been clustered according to the blooming time: i) early (before March 5th), ii) mid (between March 6th and 15th), iii) late (after March 15th). Geographical origin, ripening time (RT) as - early (E, < before June 15th), - mid (M, up to June 30th), - late (L, after July 1st), and fruit bearing habits (FH) on long-intermediate shoot (L) and/or spur (S), are shown. Blooming and ripening times are referred to the Tuscan province of Livorno (Italy).

Early-blooming					Mid-blooming				Late-blooming			
Cultivar	Origin	RT	FH		Cultivar	Origin	RT	FH	Cultivar	Origin	RT	FH
1 Antonio Errani	Italy	E	LS		Alessandrino	Italy	L	LS	Alessandria	Italy	L	LS
2 AmabileVecchioni	Italy	E	L		Bella d'Imola	Italy	L	LS	Canino Tardivo	Spain	L	LS
3 Boccuccia Liscia	Italy	E	LS		BoccucciaSpinosa	Italy	M	LS	Castelbrite	USA	L	LS
4 Bulida	Spain	E	S		Cafona	Italy	E	LS	Cibo del Paradiso	Italy	L	LS
5 Caldesi	Italy	E	LS		Comune	Italy	M	LS	Costasciaccia	Italy	L	S
6 Canino	Spain	E	LS		Moniqui	France	E	LS	Damasquina	Spain	L	S
7 Currot	Spain	E	S		Portici	Italy	M	LS	Dasycarpa	Asia	L	LS
8 Goldrich	USA	E	LS		Rival	Canada	E	LS	Harcot	Canada	L	LS
9 New Jersey	USA	M	LS		Rouge De Roussillon	France	E	LS	Manini	Italy	L	LS
10 O'Pazzo	Italy	E	S						Molodoi	Moldova R.	M	S
11 Precoce Imola	Italy	E	LS						Nonno	Italy	L	LS
12 San Castrese	Italy	M	LS						Nugget	USA	L	LS
13 Venturina	Italy	E	LS						Orange Red	USA	M	LS
14 Vitillo	Italy	E	S						Perla	Italy	M	LS
15									Polonais	France	L	LS
16									Precoce di Monplaisir	France	L	LS
17									Reale d'Imola	Italy	M	LS

et al., 2010).

2.3. Blooming time and intensity

The blooming of apricots was measured on four branches per tree. Fruiting shoots, homogeneous for similar length (60–80 cm), were tagged at different canopy positions (Bartolini et al., 2004) during the early autumn. The following parameters were recorded: a) phenological evolution of buds according to (Bartolini et al., 2004); b) blooming time expressed as Julian Days (JD 1 = January 1st); c) rate of bloom determined as initial (10% of opened flowers, F2 phenological stage), full (50% F2) and end (90% F2); d) blooming intensity visually estimated by rate on a scale of 1–5: 1 (scarce), 2 (medium-scarce), 3 (medium), 4 (abundant), 5 (very abundant).

2.4. Data analysis

Data are reported by means \pm standard error (SE). Statistical analysis (ANOVA, Student *t*-test) and regression analysis, in order to determine relationships between blooming and climatic parameters, were performed using the package GraphPad Prism 5 (GraphPad Software, Inc.).

3. Results and discussion

3.1. Climatic parameters

3.1.1. Temperatures and rainfall

The monthly average temperatures from November to March, over the years 1973–2016, are shown in Fig. 1. During this long-term period, a general and continuous increase in temperatures was recorded. This trend was particularly noticeable in November and January when average temperatures rose by 1.9 °C and 3 °C, respectively. Furthermore, from 2003 onward marked increases were recognizable in all considered months, with the strongest values in correspondence with the last four years (2013–16). In this latter period, the highest average temperature increase by 2 °C was recorded in January. To better outline the observed increasing temperature trend, in Table 2 shows the angular coefficients obtained from linear relationships between monthly minimum, maximum and mean temperatures (°C) and time series from 1973 to 2016. Positive coefficients were generally obtained for the minimum temperatures, in agreement with Meehl et al. (2007), who revealed that daily minimum temperatures increase more rapidly than maximum ones. The highest coefficient value was recorded in November, identifying this month as the most significant in determining increasingly warmer autumn seasons. On the other hand, the maximum temperatures showed a general negative coefficient, denoting a

Table 2

Angular coefficients ($P \leq 0.05$) obtained from linear relationships between monthly minimum, maximum and average temperatures (°C) and time series, from 1973 to 2016.

Temperature	November	December	January	February	March
Min.	0.0638	0.0297	0.0282	0.0059	−0.004
Max.	0.0013	−0.0154	−0.0304	−0.0348	−0.0104
Average	0.0326	0.0134	0.0433	0.0302	−0.0082

tendency to lower values during the last four decades. This situation, in agreement with research showing dramatic global climate warming since the 1980s (Moriondo and Bindi, 2007; Yong et al., 2016), confirms a climate change also within our restricted geographical area. The noticeable increases in average temperature, close to or above 2 °C, which is a widely used metric for assessing risks associated with global warming between 2030 and 2060 (Giannakopoulos et al., 2009), are in agreement with Yong et al. (2016) who explain the phenomenon by a lower buffering ability of the local climate.

The observed increasing trend of minimum temperatures and decreasing of maximum temperatures influenced the day-night range, which has been found to be unfavorable for the accumulation of assimilates in crop storage organs (Lesk et al., 2016) and of great importance for a regular synchronism between dormancy release and certain biological processes related to floral biology (Bartolini et al., 2006; Andreini et al., 2012). Table 3 gives the average daily range (difference between maximum and minimum temperatures, $\Delta^\circ\text{C}$) calculated from November to March over the last four decades. A reduction in the average monthly $\Delta^\circ\text{C}$ was observed and, examining differences between the last and the first observation period (2016–1973), the highest value (−2.4 °C) was recorded November, which significantly influenced the total sum of the five months (−6.6 $\Delta^\circ\text{C}$). This data analysis confirms November as the month mainly subjected to an increase in minimum temperatures, which determined a weakening of the temperature range. In particular, the reduction in $\Delta^\circ\text{C}$ was ascertained from the 1990s, while in the previous twenty-year period no substantial changes had been found.

Exploring the effect of warming on frost events, it has been observed that the warming tends to reduce the amount of frost days per year (Liu et al., 2018). Our results are in accordance with this finding considering that, in the final years of the observation period (2013–2016), a decreasing trend in winter and spring frosts was observed (Table 4). The lately observed frost reduction was different in comparison to the previous decades (1983–2012) which were characterized by more frequent frost episodes, mainly during the spring season. Although the final study period is represented by only 4 years, the frost reductions could prompt a forecast towards a lower risk in future, particularly for late spring frosts (Eccel et al., 2009; Martínez-Lüscher et al., 2017). This prediction could be advantageous for early blooming fruit species, such as apricot, which are susceptible to frosts at key phenological stages like bud break, blooming and fruit-set (Julian et al., 2007; Viti et al., 2010b).

As regards rainfall data (Table 4), over a forty-year period (1973–2012) the yearly amounts ranged from 533 to 722 mm, in agreement with the average data usually recorded in Tuscany over the years (Bartolini et al., 2014). On the contrary, a great rainfall increase occurred during the final 4 years (about 1000 mm/year) in comparison to the previous decades, almost twofold increase compared to 2003–12. This result is corroborated by the increase in the frequency of extreme rainfall events verified in recent years, confirming the link between increased precipitation and climate change due to global warming (Held and Soden, 2006). Unfortunately, recent climate models predict for the twenty-first century remarkable changes in the climate of the Mediterranean region (Gualdi et al., 2013).

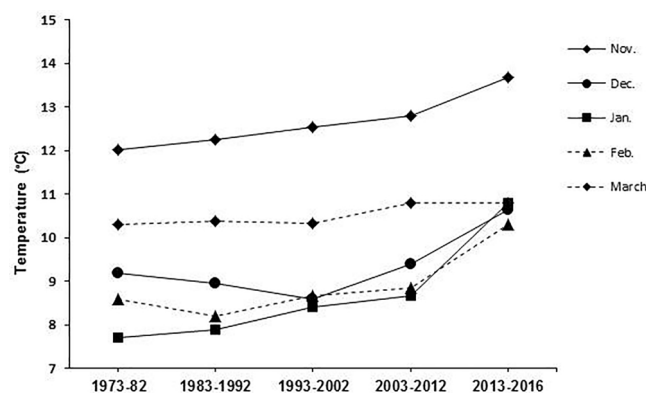


Fig. 1. Monthly average temperatures (°C) from November to March, over the period 1973–2016. Data are shown per decade; the last period is represented by 4 years.

Table 3

Differences between monthly average maximum and minimum temperatures ($\Delta^{\circ}\text{C}$) over the period 1973–2016 by decades. Total $\Delta^{\circ}\text{C}$ per decade, and $\Delta^{\circ}\text{C}$ between final (2013–16) and first (1973–82) period are also shown. The comparison between final and first time series was performed by the Student's *t*-test ($P \leq 0.05$).

Month	$\Delta^{\circ}\text{C}$						<i>t</i> -test
	1973–82	1983–92	1993–02	2003–12	2013–16	2016–1973	
November	10.2	10.4	8.8	8.8	7.8	−2.4	*
December	9.9	11.2	8.9	7.5	8.9	−1.0	ns
January	9.7	11.1	8.7	8.4	8.4	−1.3	ns
February	10.4	11.6	11.3	9.6	8.8	−1.6	ns
March	10.2	10.9	11.3	9.9	9.9	−0.3	ns
Total	50.4	55.2	49.0	44.2	43.8	−6.6	

3.1.2. Chilling units

Starting in 1976, from November to the end of January, the number of CUs gradually decreased up to 2016 when just over 800 CUs were recorded (Fig. 2). At this time, a strong CU decrease (around 40% of 1300 CUs recorded in the 1970s) occurred with an average loss of about 60 CUs/five-year period. However, the most dramatic losses were found in the 2000s, when the 1000 CU threshold, crucial for overcoming the endodormancy of most apricot cultivars needing a low-medium chilling requirement (Viti et al., 2006; Guerriero et al., 2010), was no longer attained. A similar trend, towards a reduction in chilling accumulation, has also been verified in several other perennial fruit crop areas using various models for the chilling requirement estimation (Baldocchi and Wong, 2008; Campoy et al., 2011; Luedeling et al., 2011; Atkinson et al., 2013; Andreini et al., 2014; Measham et al., 2017).

In the final fifteen years, the lower effectiveness of temperatures able to determine a good CU accumulation was mainly due to an increase in warmer autumn-winter seasons (Fig. 1, Table 2). This climatic trend frequently caused a very late attainment of 1000 CUs, often after March 10th, causing a shift of the blooming date (Andreini et al., 2012).

In order to clarify temperature efficacy on CU accumulation, several regression analyses were carried out using minimum, maximum and average temperatures of single or joint autumn-winter months. Fig. 3 shows the most significant inverse relationships obtained from three temperature (*T*) sets: i) average daily *T* of November ($R^2 = 0.7976$); ii) average of minimum *T* of November ($R^2 = 0.6803$); iii) average daily *T* from November to January ($R^2 = 0.5437$). The highest coefficient obtained by the daily average *T* of November confirmed that, over the autumn season, maximum and minimum daily temperature range during this month can play a key role for chilling accumulation.

3.2. Blooming time and intensity

During the last four decades, the blooming time of the apricot cultivars studied, belonging to different blooming classes (early, mid and late), have occurred over about one month. The average blooming date (F_{50}) was from February 24th (55 JD) to March 25th (84 JD). Between the final considered period (2012–16) and the first decade (1973–82), an overall blooming shift (BS) was recorded (Fig. 4). Cultivars

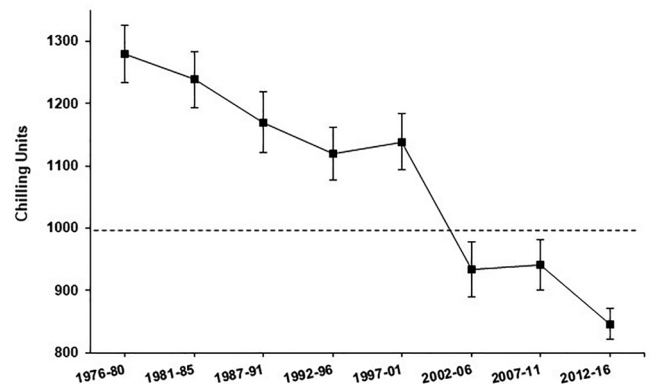


Fig. 2. Cumulated chilling units (CUs) up to January 31st, from 1976 to 2016. Data are shown as 5-year averages (\pm SE). Dotted line indicates the 1000 CU threshold-amount.

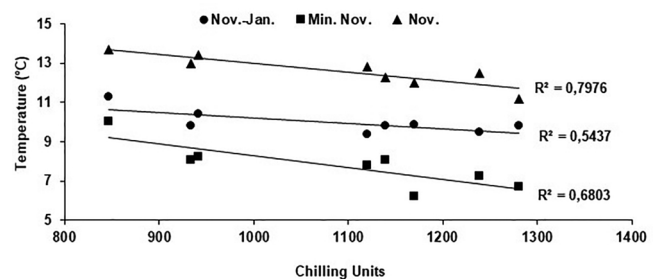


Fig. 3. Linear regression ($P \leq 0.05$) between cumulated chilling units and three sets of temperatures (*T*, $^{\circ}\text{C}$): i) average *T* from November to January; ii) average *T* of November; iii) average minimum *T* of November. Data, from 1976 to 2016, are referred to 5-year periods.

belonging to the early-blooming class showed the highest average BS of around 12 days, while in the other classes a lower but reliable BS change of about 8 (mid-blooming) and 5 days (late-blooming) was recorded. Within each cultivar-class, the BS varied greatly with changes:

Table 4

Frost and rainfall events over the period 1973–2016. A) Frosts: number of winter (December–February) and spring (March–April) day events. B) Rainfall: average (mm, \pm SE) per semester (November–March; April–October) and yearly total. Data are shown per decade, except for the final shorter period.

	1973–82	1983–92	1993–02	2003–12	2013–16
Frost					
Winter	69	167	145	108	9
Spring	2	7	24	19	3
Total	71	174	169	127	12
Rainfall					
Nov.–March	338.1 \pm 23.2	294.8 \pm 38.4	270.1 \pm 36.8	245.8 \pm 32.7	495.6 \pm 80.9
Apr.–Oct.	384.6 \pm 29.5	363.1 \pm 55.9	380.6 \pm 56.7	287.4 \pm 59.1	478.2 \pm 154.9
Total	722.7	657.9	650.7	533.2	973.8

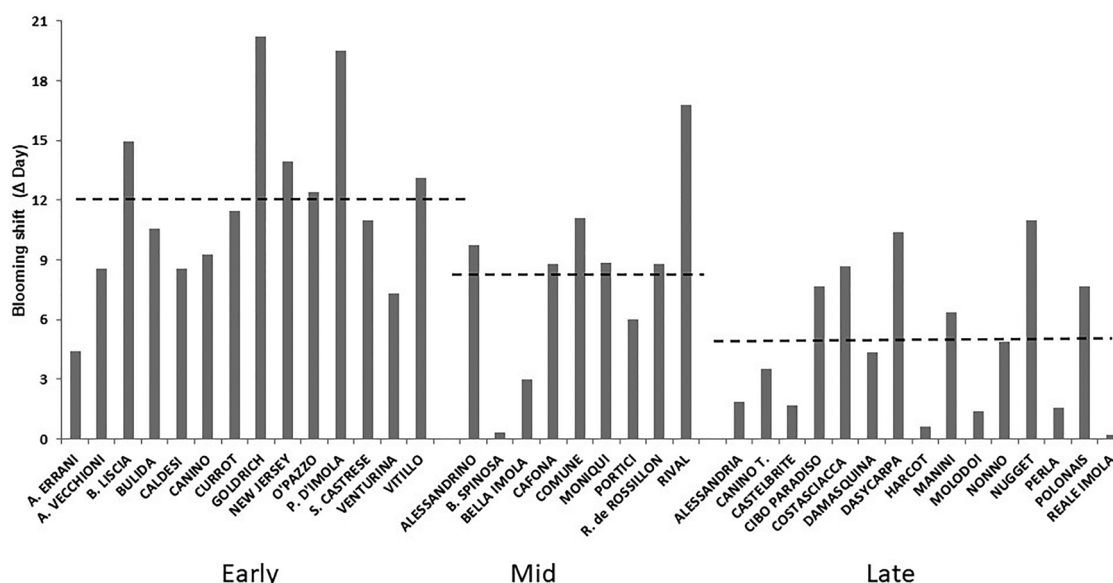


Fig. 4. Blooming time shift (BS, Δ-day) between final (2012–16) and first (1973–82) observation period of apricot cultivars ordered according to blooming classes (early, mid, late). For each cultivar group, dotted lines represent the BS average.

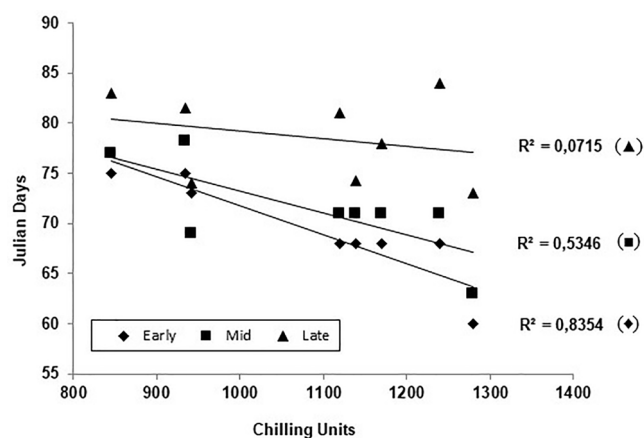


Fig. 5. Linear regression ($P \leq 0.05$) between blooming time (Julian Days) and chilling units accumulated at January 31st, over forty years (1976–2016). Apricot cultivars are grouped according to early, mid and late blooming class. Each point represents average data per 5-year periods.

from 4 to 20 days for the early cvs ‘Antonio Errani’ and ‘Goldrich’, respectively, from 1 to 17 days for the mid cvs ‘Boccuccia Spinosa’ and ‘Rival’, respectively; and from 1 to 11 days for the late cvs ‘Harcot’ and ‘Nugget’, respectively. Analyzing a possible effect of the fruiting habits of cultivars, i.e. bearing fruits on long, intermediate shoots (L) and/or spurs (S), on the blooming time change, no relationship was found. Indeed, cultivars showing the lowest and highest blooming shift exhibited an equilibrium between the different type of shoots, fruiting both on long-intermediate shoots and spurs (Table 1). Although the blooming time is a complex phenomenon related to environmental and endogenous cues such as development and physiological status of plants (Amasino, 2010), chill temperatures seems to be the factor mainly involved in regulating the blooming time. This has been documented in other temperate woody species that with inadequate chilling by warm autumn temperatures showed delayed and erratic budburst in the following spring (Cannell and Smith, 1986; Atkinson and Lucas, 1996; Heide, 2003; Darbyshire et al., 2017). Recently, a considerable flowering delay for peach and apricot cultivars has been observed in years characterized by low chilling accumulations (Ghrab et al., 2014; Martínez-Lüscher et al., 2017). Also under our environmental

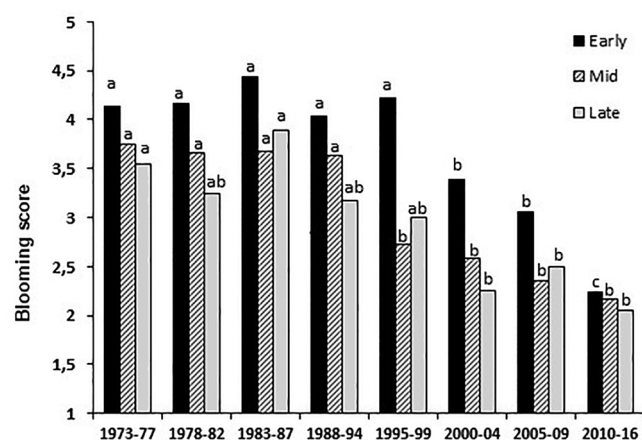


Fig. 6. Blooming scores (rate on a scale of 1–5, scanty-abundant) assigned to 40 apricot cultivars grouped according to different blooming time classes: early, mid and late. Data are shown by average of 5-year periods, from 1973 to 2016. Within each blooming class, different letters are significantly different ($P \leq 0.05$) according to Kruskal–Wallis's test.

conditions, the constant reduction in CUs accumulated up to January 31st could have affected the blooming time, producing the above-mentioned shifts. This statement was corroborated by the inverse relationships found between blooming time and CUs (Fig. 5). As previously observed for BS, correlation analysis gave evidence of the highest coefficient for the early-blooming cultivars ($R^2 = 0.8354$) which showed a clearer tendency to postpone the flowering date once CUs diminished.

As regards blooming intensity, a general decrease was observed over the years, particularly from the end of the 1990s (Fig. 6). However, the early- and mid-blooming cultivars were able to maintain a valuable flowering intensity (≥ 3) up to 2009, showing good performances under our environmental conditions. The warmer autumn-winter seasons occurring in the following years could have been responsible for the loss of blooming intensity, which reached values of below 2.5. Indeed, particularly for the early-cultivars, blooming scores fell to levels of around 50% with respect to previous periods.

The regression analysis between blooming score and CU amount at January 31st showed a positive and significant relationship with high

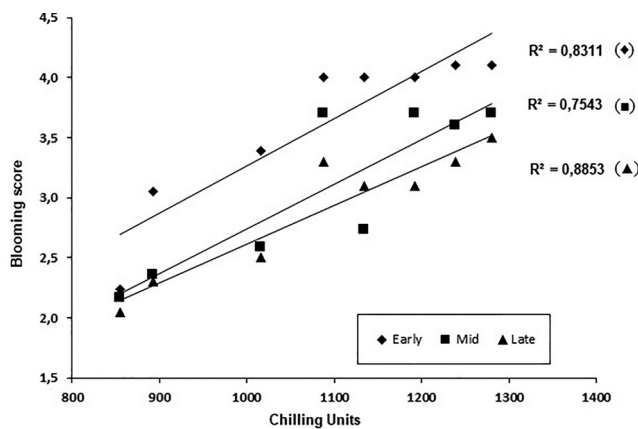


Fig. 7. Linear regression ($P \leq 0.05$) between blooming score and chilling units accumulated at January 31st, over forty years (1976–2016), for 40 apricot cultivars grouped according to different blooming time classes: early, mid and late.

coefficient values ($R^2 = 0.7543$ – 0.8853) for all cultivar-classes (Fig. 7). This result indicated the strong decline in CU accumulation, during the deepest dormancy period of apricot flower buds (November–January), negatively affecting the quality of buds leading to a decrease in flowering intensity, irrespective of the habitus habits of the cultivars (Table 1). This confirmed the chilling accumulation as a key factor that contributes to ensuring a regular overcoming of flower bud endodormancy, a complex phenomenon due to genotype-environment interaction (Andreini et al., 2014). This confirmed the chilling accumulation as a key factor that contributes to ensuring a regular overcoming of flower bud endodormancy, a complex phenomenon due to genotype-environment interaction.

It has been observed that an irregular CU accumulation can delay the chilling requirement fulfillment, so extending the endodormancy phase. The trend towards a later start of chilling accumulation recorded in recent decades determined negative impacts on yields of apricot orchards in Mediterranean areas (Viti et al., 2010a). In particular, the cold accumulation delay, producing a fewer CUs, may cause physiological disorders that alter the dormancy process. Indeed, a delay in overcoming endodormancy may be negatively related to the succeeding ecodormancy phase, which ends with the heat requirement fulfillment, leading to bud-break and flowering. Studies carried out on several fruit species suggest that a contrasting chill accumulation can cause anomalies in phenology and fruit-set (Egea et al., 2003; Elloumi et al., 2013; Legave et al., 2013). In particular, changes in flowering phenology manifested as flowering advancement, flowering delay or no change, have been observed as a result of different impacts of warmer autumn-winter and spring temperatures on flowering phenology (Guo et al., 2015; Legave et al., 2015). In addition to these events, mild climate conditions may cause a high rate of floral anomalies and unbroken flower buds as recorded in the main apricot production districts, with serious repercussions on fruit-set and, consequently, economic losses for producers (Bassi et al., 2006; Legave et al., 2009).

4. Conclusions

Results from a temperature time series analysis carried out during the last four decades in the Tuscan coastal area show a dramatic decline in the number of CUs during the critical period of overcoming flower bud endodormancy, as a consequence of warmer autumn-winter temperatures, mainly since the 1990s. The CUs, negatively correlated with blooming time and positively correlated with blooming intensity, seem to be crucial for apricot floral biology. Most of the examined cultivars showed significant blooming changes in terms of date and intensity. In particular, the early-cultivars showed a significant flowering delay, an

occurrence that could enable them to face a minor risk of frost damage during anthesis in environments characterized by frequent spring cold returns.

The irregular autumn-winter cold rate of recent years may mean that substantial impacts can be expected in the future with possible geographic shifts of the apricot cultivation areas towards more potentially suitable areas located in the northern Italian and European regions, with considerable socioeconomic inferences.

To face the challenge of the coming years, is essential to find resilient genotypes as a main requisite to achieving good yields. Intensive investigations on the impact of changing climate on apricot biological processes should be carried out in order to assess the performance of genotypes in specific environmental areas. The implication of future reductions in winter cold prompt an estimation of the cultivar-specific chilling requirement which plays a key role for the selection of genetic material (Bassi et al., 2006). Thus, special effort should be addressed to supporting specific breeding programs stressing the selection of cultivars with a low chilling requirement and late blooming time which would be more suitable for Mediterranean regions.

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