



Chilling and heat requirements for woody taxa in Tétouan (NW Morocco)

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Abstract Impact of climate change affects chilling and heat accumulation that phenological development of plant needs, air temperature being determinant for flowering, pollination and fruit production, but few knowledges are available in the winter and spring climate of Tétouan. The physiological mechanisms of the reproductive cycle that controls pollen emission are related with temperature, and different environmental factors regulate strongly the reproductive phases of the plant's life cycle. However, from an empirical point of view, the alternance between endodormancy and ecodormancy is not well detectable. Our work focuses on determining the heat accumulation periods associated with the thermal balance needed to fulfill the chilling and heat required for bud-break and bloom timing. To evaluate *Morus*, *Pistacia*, *Quercus* and *Olea* response to changes in chill and heat accumulation rates, the Dynamic Model and the Growing Degree-Days Method were used. Regression analyses identified the chilling and forcing periods for these taxa. Over the past 12 years, chill accumulation

during tree dormancy increased significantly for most of woody taxa studied, while heat accumulation decreased not significantly for all taxa. Heat accumulation was the main driver of bloom timing, with effects of variation in chill accumulation.

Keywords Heat requirement · Dynamic model · Chilling requirement · Dormancy · Flowering · Woody taxa · Tétouan

1 Introduction

The physiological behavior of woody plants with winter–spring flowering is subject to constant variations due to the action of different bioclimatic parameters (Fuertes-Rodríguez et al., 2007). The impact of meteorological parameters on flowering depends on the bioclimatic conditions in different areas (Hoxha, 2007; Jato et al., 2004; Ščevková et al., 2021). Adaptation of phenology to temperature is a topic that is receiving increasing attention (Menzel et al., 2006, 2020; Parmesan et al., 2007).

Before flowering, temperature is considered as the primary factor influencing the growth and development of plants, the maturation of reproductive organs and pollen production (Dahl et al., 2013). Secondary factors, such as photoperiod, temperature and relative humidity, affect the opening of anthers and anthesis. Airborne pollen from anemophilous plants is greatly influenced by meteorological conditions and

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is dispersed by a tertiary factor, the wind, which acts by its speed and direction (Fuertes-Rodríguez et al., 2007; Rojo et al., 2016; Cianni et al., 2020).

The Mediterranean region is characterized by a changeable climate, especially in spring when temperature varies quickly from one day to another. Moreover, interannual variations affect the onset of flowering, its intensity and then, pollen production. The air temperature is a good meteorological indicator for the pollen season timing forecast (Achmakh et al., 2015). Forcing models based essentially on heat requirements measured as degree hours or degree-days above a threshold are suitable to quantify phenological development (Galán et al., 2005). The works involved in estimating the best threshold temperature for plant development in a range of climates have been analyzed for several years both in agronomy and botany and more recently in reproductive phenology of airborne pollen (Aguilera et al., 2014, 2015; Garcia-Mozo et al., 2002). Depending on several factors in both, the plant and the environment, threshold temperatures vary (Galán et al., 2004; Aguilera et al., 2014; Achmakh et al., 2015).

In addition, several studies have indicated that warm temperatures during the heat period can advance spring phenology (Guo et al., 2015; Horvath et al., 2003; Vitra et al., 2017), but is also likely to be influenced by increased CO₂ emissions and frost free days (Ziska et al., 2019). The exposure to chilling temperatures in winter and early spring is needed to break plant endodormancy (Coville, 1920; Schwartz & Hanes, 2010). In this period, which is known as the chilling period, high temperatures may have a negative impact on plant phenology (Xu et al., 2020). Warmer temperatures in early spring affect flushing by shortening the ecodormancy phase (Dantec et al., 2014). Contrariwise, in temperate regions, warmer temperatures during winter can conduct to later endodormancy release or to insufficient chilling for the full release of endodormancy, increasing the heat accumulated for budburst (Cannell & Smith, 1986; Murray et al., 1989; Sarvas, 1972; Wareing, 1953). For example, modeling results in North Atlantic Oceanic (NAO) and Mediterranean regions suggest that a later release of dormancy in plants caused by warmer temperatures would lead to a further delay in the flowering date or insufficient chilling (Galán et al., 2016; Legave et al., 2013). Thus, the role of chilling may become more important with increasing

air temperature, warmer temperatures therefore leading to a nonlinear advance in tree reproductive phenology in the future (Chuine et al., 2010; Fu et al., 2012; Laube et al., 2013). Moreover, a recent study in aerobiology shows that over the last 50 years the pollen season of some tree species have advanced in response to the temperature increase (Gehrig & Clot, 2021).

The relation between heat and chilling requirements differs markedly between species (Cannell, 1997; Murray et al., 1989; Vitasse & Basler, 2013). In the next few decades, the leaf unfolding will apparently occur earlier under conditions of recurrent climate change in woody species with a low chilling requirement, while species that require a highly fulfillment of chilling may show constant or even later leaf unfolding date due to an unsatisfied chilling requirements or a later endodormancy release (Fu et al., 2012; Harrington et al., 2010; Morin et al., 2010; Murray et al., 1989; Polgar & Primack, 2011; Vitasse et al., 2010). The rate of chilling and forcing temperatures needed to trigger spring plant phenology varies among species and among different places (Campoy et al., 2012; Chuine et al., 2016; Dantec et al., 2014; Vitasse & Basler, 2013). In general, species tending to develop their leaves and bloom earlier might have a lower chilling requirement for spring phenology (Fu et al., 2012; Murray et al., 1989).

For the quantification of chill, many approaches were used, and the Dynamic Model being mainly as the most robust chilling model (Campoy et al., 2011; Luedeling & Gassner, 2012; Luedeling et al., 2009a, 2009b; Ruiz et al., 2007; Zhang & Taylor, 2011), while for determining the heat requirement, the method proposed by Ring et al. (1983) is also a robust model.

In the present study, based on long-term airborne pollen observations in Tétouan, the aim was to determine the timing of chilling and forcing periods, the optimal temperature threshold within the region and to quantify the chilling and heat requirements of *Morus*, *Pistacia*, *Quercus* and *Olea* in the warm climate of this region.

2 Materials and methods

Tétouan (35°34'N; 5°22'W) is located at 65 ma.s.l. in the northwest of Morocco in the

Thermomediterranean belt. It is characterized by a Mediterranean warm subhumid climate (Benabid, 1982) with rainy autumns and winters and dry summers. The annual average temperature is 18.7 °C, and mean annual rainfall is 594.7 mm. Depending on the year, December–February are the coldest months and July or August the warmest months (Aboulaich et al., 2013). The prevailing wind directions are those blowing from NE and SW (Aboulaich et al., 2011).

A 7-day volumetric spore trap of Hirst type sampler was used for aerobiological sampling (Hirst, 1952) over a 12-year period (2008–2019). It was installed, 15 m above ground level, on the roof of the Department of Biology of the Faculty of Science (Abdelmalek Essaâdi University; 35°34'N; 5°22'W). Sampling and data analysis were carried out according to the protocol drawn up by the Spanish Aerobiology Network (REA) (Galán et al., 2007) and the minimum requirements of the European Aerobiology Society (EAS) (Galán et al., 2014). The average daily pollen concentrations were expressed as the number of pollen/m³ of air.

The meteorological data were registered by an automatic meteorological station located in our Biology Department of the Faculty of Sciences, where the pollen trap was installed.

The study focused on *Morus*, *Pistacia*, *Quercus* and *Olea* pollen types in Tétouan during 2008–2019. The main pollen season (MPS) was calculated as described by Velasco et al. (2013), but it was modified given the low pollen concentrations recorded in the Tétouan region, compared to Córdoba, Spain. The threshold daily pollen concentration (pollen/m³) chosen as the start and end of the MPS was as follows:

- *Olea*: 10 pollen/m³ + 5 days with 10 or more pollen/m³; End = 10 pollen/m³ + 5 days with concentrations below this level.
- *Morus*, *Pistacia*, *Quercus*: 3 pollen/m³ + 5 days with 3 or more pollen/m³; End = 3 pollen/m³ + 5 days with concentrations below this level.

In order to calculate the chilling requirement, we used the dynamic model proposed by Fishman (1987); Chilling portions (CP) were calculated from 1st December to the end of chilling considered as 15 February for every taxa. Threshold temperatures from 9 to 12 °C were tested increasing by 0.5 °C.

For determining the heat requirement, we used the method proposed by Ring et al. (1983). In this method, growing degree-days (GDD°) were calculated using the sum of the difference between daily mean temperatures and threshold temperatures: °D = $\sum (T_{\text{mean}} - T_{\text{th}})$; then, °D is set equal to 0 when threshold was higher than T_{mean}. Accumulated Heat Units, starting from the day after the chilling accumulation until seven days before blooming. Seven threshold temperatures from 13 to 16 °C were tested increasing by 0.5 °C. The most accurate threshold temperature was chosen for each taxa, taking into account the lowest root mean square error (RMSE) of the predicted (d^1) minus the observed (d^2) date daily calculating the sum of GDD for each study year (n) (Galán et al., 2005):

$$\text{RMSE} = \sqrt{(d^1 - d^2)^2 / n}$$

Three variables in relation to the heat accumulation period were calculated: (1) the length (in days) of the heat accumulation period (length heat period), which was considered as the time difference between the heat accumulation start date and the end date of the heat accumulation (i.e., as the first day of seven days before the start of flowering); (2) the timing difference between the peak of chilling date and the heat period start date (peak_ch/start_ht); and (3) the duration of the period between the peak of chilling date and the peak of flowering date (peak_ch/peak_fl). The number of days was calculated from the 1st December of the previous year, taking into account that the chilling portions were calculated from the autumn of the year preceding flowering, and to avoid biasing the calculation in the period between the end of chilling and the end of heat accumulation (seven days before the date of flowering), the DOY of this later was from the 1st December.

To evaluate the effect of heat accumulation period characteristics on the pollen season start in the different studied taxa, Pearson's parametric correlation analysis was performed.

Variance analysis (one-way ANOVA) was performed to determine the differences in the heat accumulation periods of the different studied taxa. When there were significant differences, a post hoc Tukey test was performed. The analyses have been executed by the IBMSPSS 20.0 Statistics Software package.

Linear regression was made to analyze temporal trends of chilling and heat accumulation during respective periods for *Morus*, *Pistacia*, *Quercus* and *Olea* during 2008–2019. The Mann–Kendall test, a tool commonly used for time series analysis, was undertaken for trends statistical significance (Tao et al., 2006). Linear regression was used to study the interrelation between chilling and heat accumulation and mean temperature variations during the corresponding chilling and forcing periods. Results were evaluated for significance using analysis of variance.

3 Results

The dates corresponding to the pollen season start (PSS) are shown in Table 1. The most common PSS of *Morus* and *Pistacia* is late March, the mean date being 15 March, 25 March, respectively. For *Quercus* and *Olea*, the mean PSS occurred in the first fortnight of April (5 April, 17 April), respectively (Table 1).

Similar average peak chilling and end dates were recorded for the studied taxa. The average of the peak chilling dates for all studied taxa was 22 January and the average of the end of chilling dates occurred as 17 February. The chilling accumulation was calculated from the first December to the end of chilling over 12 years differed between years and registered an average of 18.70 CP for all taxa (Fig. 1). As the chilling amounts were similar, the average heat

accumulation start dates was also similar for all taxa and recorded on 18 February (81 DOY). When the growing degree-days (GDD) were calculated, GDD values showed an interannual fluctuations, with highest annual values in 2010 for *Morus*, *Pistacia* and *Quercus*, and in 2016 for *Olea*. As regards, cumulated heat between taxa, *Olea* recorded the highest values, whereas *Morus* showed the lowest values (Fig. 1). Averages GDD ranged between 4 and 30 GDD for *Morus* and *Olea*, respectively (Table 2).

For the average flowering peak dates, significant differences between these taxa were found ($F=27.882$; $P<0.001$). Here, three groups were observed (Fig. 2). The averages peak of flowering dates in Tétouan was on 29 March (119 DOY) for *Morus*, on 03 April for *Pistacia* (124DOY), on 22 April (143 DOY) for *Quercus* and on 9 May (160 DOY) for *Olea* (Table 2). A Significant difference was reported also for the length of the heat accumulation period ($F=3.756$; $P<0.01$) (Fig. 2), which *Olea* revealed the highest mean value (49 days), followed by *Quercus* (37 days), *Pistacia* (28 days) and *Morus* (17 days). Here, two groups were noticed (Table 2, Fig. 2).

A clear difference was recorded for the time period between the peak of chilling date and the peak of flowering date with three groups listed ($F=12.823$; $P<0.001$); while the time period from the peak of chilling to the heat period start date, recorded the same value for the taxa studied (Fig. 2). For the first

Table 1 Beginning of the main pollination season of *Morus*, *Pistacia*, *Quercus* and *Olea* (day–month), number of days from 1 December of the previous year

Study period	<i>Morus</i>		<i>Pistacia</i>		<i>Quercus</i>		<i>Olea</i>	
	Date	DOY	Date	DOY	Date	DOY	Date	DOY
2007–2008	2 March	93	14 March	105	15 March	106	1 April	123
2008–2009	8 March	99	13 March	104	28 March	119	5 April	127
2009–2010	26 March	117	27 March	118	31 March	122	20 April	142
2010–2011	11 March	102	20 March	111	26 March	117	19 April	141
2011–2012	16 March	107	18 March	109	15 April	136	23 April	145
2012–2013	13 March	104	26 March	117	16 April	138	22 April	144
2013–2014	20 March	111	20 March	111	23 March	114	5 April	127
2014–2015	11 March	102	26 March	117	25 March	116	22 April	144
2015–2016	15 March	106	30 March	121	6 April	128	6 May	158
2016–2017*	20 March	111			13 April	135	1 April	123
2017–2018	12 March	103	3 April	125	23 April	145	4 May	156
2018–2019	17 March	108	4 April	126	10 April	132	31 March	122
Mean value	15 March	105	25 March	115	5 April	126	17 April	138
SD		6		8		12		13

*The values were low to calculate the pollen season for *Pistacia*

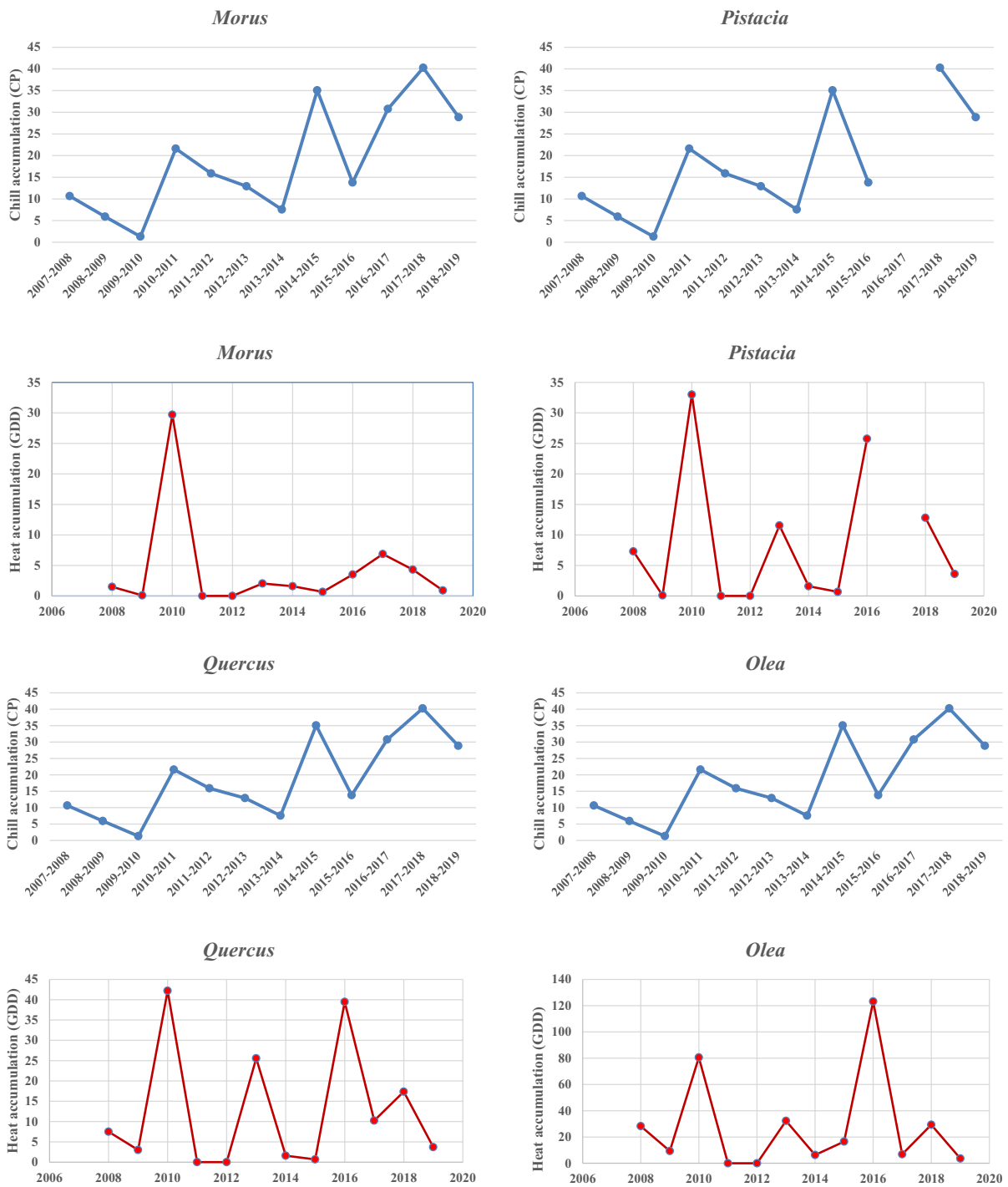


Fig. 1 Chilling and Heat accumulation for *Morus*, *Pistacia*, *Quercus* and *Olea* during chilling and forcing periods from 2008 to 2019. *The values were low in 2017 to calculate the pollen season for *Pistacia*

Table 2 Average values of the main characteristics of the heat accumulation period of each taxa studied. End-ch End of chilling date, Peak-ch Peak of chilling date, Start-ht heat accumula-

tion start date, Peak-fl peak of flowering date, *GDD* growing degree-days amounts

Taxa	End-ch (DOY)	Peak-ch (DOY)	Start-ht (DOY)	Peak-fl (DOY)	Threshold (°C)	GDD	Peak-ch/Start-ht (Days)	Length heat period (Days)	Peak-ch/Peak-fl (Days)
<i>Morus</i>	80 ± 12	53 ± 10	81 ± 11	119 ± 5	16	4 ± 5	29 ± 11	17 ± 9	66 ± 10
<i>Pistacia</i>	80 ± 12	53 ± 10	81 ± 11	124 ± 5	16	9 ± 6	29 ± 11	28 ± 9	71 ± 9
<i>Quercus</i>	80 ± 12	53 ± 10	81 ± 11	143 ± 9	16	12 ± 8	29 ± 11	37 ± 9	90 ± 12
<i>Olea</i>	80 ± 12	53 ± 10	81 ± 11	160 ± 10	16	30 ± 20	29 ± 11	49 ± 11	108 ± 11

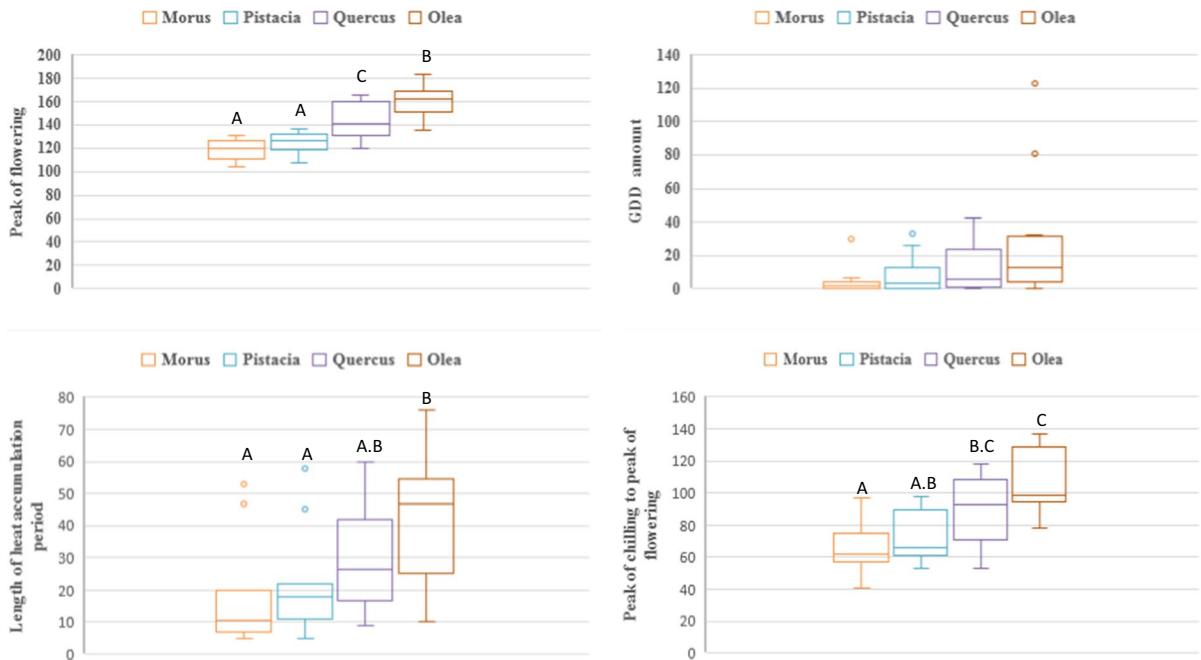


Fig. 2 Boxplots of the different parameters studied. Different letters indicate statistically different values ($P < 0.05$)

parameter, *Olea* showed the highest mean value, followed by *Quercus* and *Pistacia* (108, 90, 71 days, respectively). The time period from the peak of chilling to the peak of flowering showed the lowest value for *Morus*, which was 66 days. For the second parameter, the time period from the peak of chilling to the heat period was identical for all species (29 days) (Table 2).

Correlation analysis was fulfilled for the relationships between the heat accumulation period characteristics for all taxa studied. Only the start date of the heat accumulation period correlated significantly and positively with the peak chilling date, showing a similar coefficient of correlation

($r = 0.694$; $P < 0.05$). Non-significant coefficients were obtained for the other parameters considered in this analysis.

Chilling accumulation for *Olea* in Tétouan showed a significant trend, increasing by 2.54 CP per year ($P < 0.01$) during 2008–2019 (Fig. 3). However, Chilling accumulation decreased as mean temperatures increased during the chilling period of *Olea*, but the trend was not significant during the past 12 years (Fig. 4). Heat accumulation during the forcing period showed a slight and non-significant negative trend (Fig. 3), whereas rising mean temperatures during the forcing period increased heat accumulation by 7.66 GDD/°C (Fig. 4).

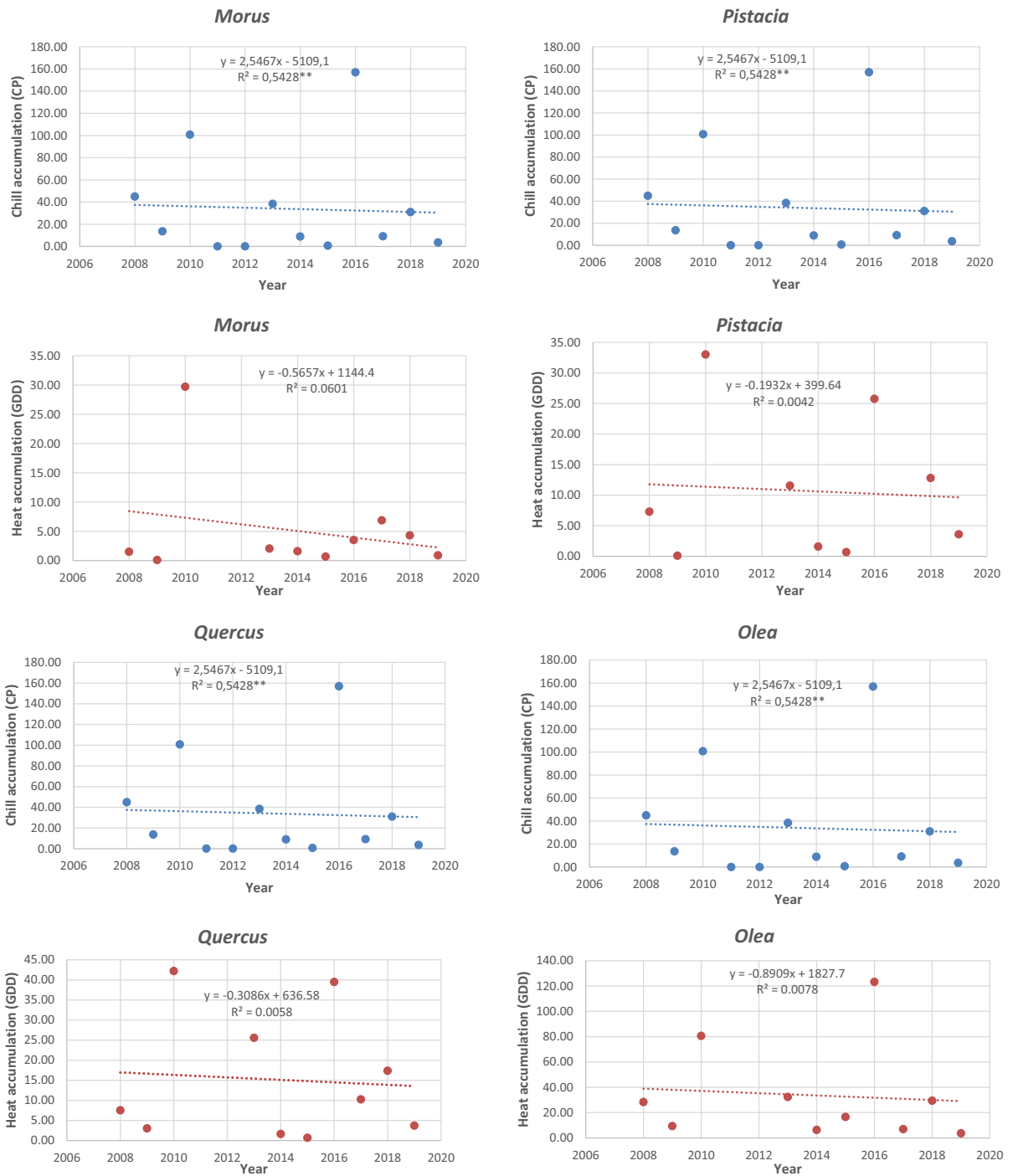


Fig. 3 Trends of chilling and heat accumulation for *Morus*, *Pistacia*, *Quercus* and *Olea* during chilling and forcing periods from 2008 to 2019. Blue dots Chill accumulation, red dots heat

accumulation. Trends are significant with * $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$

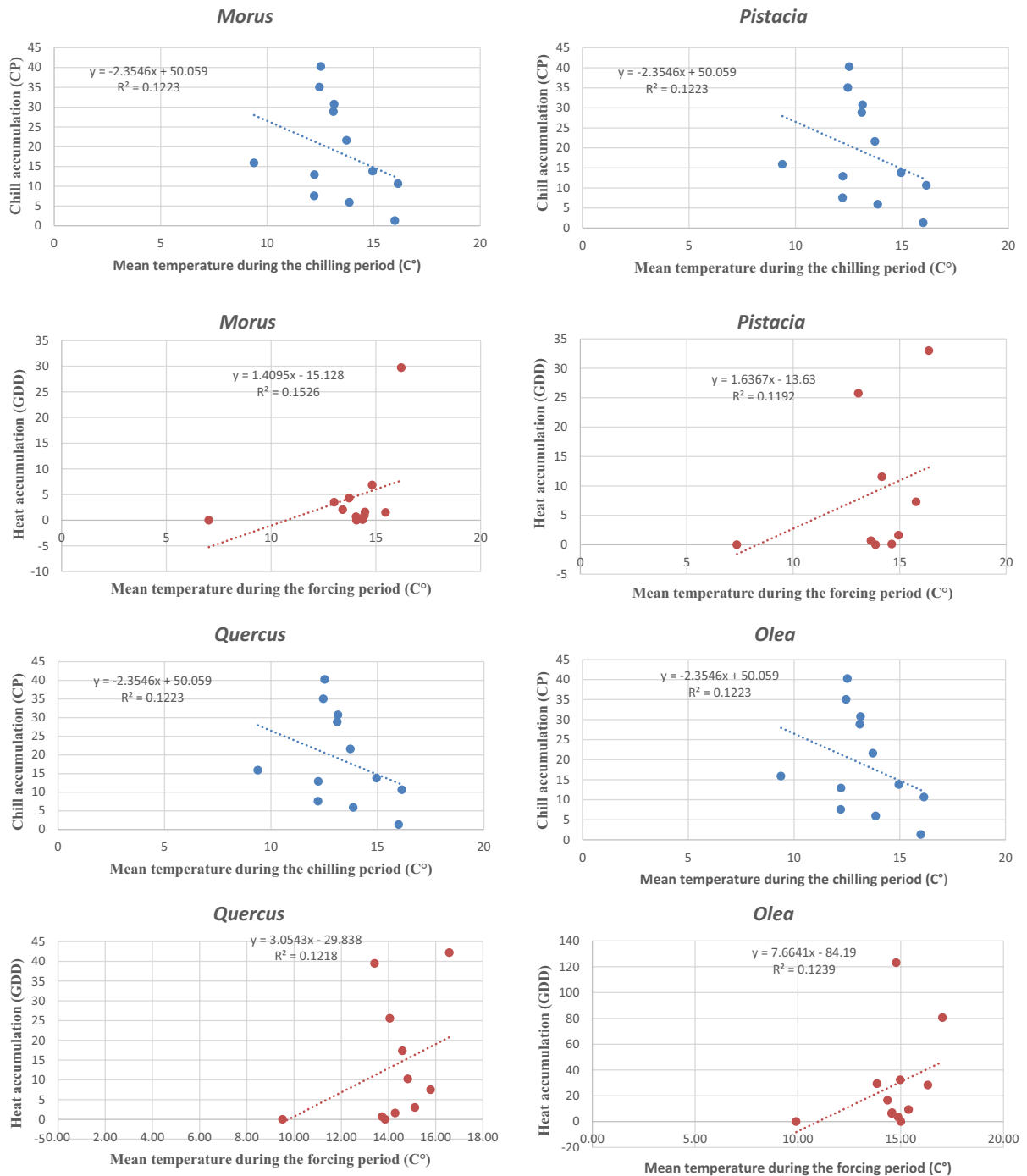


Fig. 4 Trends of relationships between chilling and heat accumulation and mean temperature during relevant periods for all taxa studied. Blue dots Chill accumulation, red dots heat accumulation. Trends are significant with $*P < 0.1$, $**P < 0.05$

A similar response of chilling and heat accumulation occurred for *Morus*, *Quercus* and *Pistacia* showing a significant increasing of chilling accumulation

over time by 2.54 CP per year ($P < 0.01$) was observed (Fig. 3). Chilling accumulation decreased during chilling period when the mean temperatures increased

but not significantly. Rising mean temperatures during the forcing period increased heat accumulation of *Morus*, *Pistacia* and *Quercus* by 1.40, 1.63, 3.05 GDD/°C, respectively (Fig. 4). However, the trend decreased not significantly for heat accumulation (Fig. 3).

4 Discussion

The phenological response of spring-flowering woody species to temperature has been widely approved and correlates very well with the air temperature (Menzel, 2002; Spano et al., 1999). After flower bud break, morphological development requires a certain thermal contribution to continue to develop after their latent phase (Anderson et al., 2005; Foley et al., 2009; Orlandi et al., 2002). In general, our results confirm a clear relationship between the beginning of pollination and air temperature.

It is commonly accepted that heat is only effective after sufficient chill has been met (Cannell & Smith, 1983; Cesaraccio et al., 2004; Fuchigami & Nee, 1987; Rea & Eccel, 2006). The models to estimate chill accumulation are under disagreement due to their variability among climates and the lack of physiological knowledge involved in their development (Luedeling, 2012). The choice of which type of model to use is often made a priori in phenology modeling studies, and models are then fitted to available data (Guo et al., 2013).

The chilling requirement based on “chill portions” has been considered as one of the best models for temperate nuts and fruits (Guo et al., 2013; Luedeling et al., 2009a, 2009b; Zhang & Taylor, 2011). This Dynamic Model has been found to be effective for other woody species (Xu et al., 2020), naming apricot (Benmoussa et al., 2017; Zhuang et al., 2016), olive (Aguilera et al., 2013), apple (Parkes et al., 2020), pistachio (Benmoussa et al., 2017; Zhang & Taylor, 2011), walnut (Luedeling et al., 2009a, 2009b), almond (Benmoussa et al., 2017) and cherry (Luedeling et al., 2013a). As a result, we kept the same parameter values proposed by Fishman et al. (1987) to calculate the chill portions of four taxa in this study. The Dynamic Model has often been found to be the most suitable among common chill models, especially in warm regions (Benmoussa et al., 2017).

The biothermic requirements that govern the different phenological development of the woody species in Mediterranean areas and estimated by different methodologies and threshold temperatures were the objective of numerous studies (Alba and de la Guardia, 1998; Galán et al., 2005; Bonofiglio et al., 2008; Aguilera et al., 2014, 2015; Achmakh et al., 2015). Although numerous methods for calculating GDD have been reported, agreement in estimating the best threshold temperatures has not received widespread acceptance (Achmakh et al., 2015; Ruml et al., 2010). The threshold temperature resulting effective in this research differs from those recorded for woody species in previous studies. The base temperatures reported ranged between 5 and 12.5 °C for *Olea* in Andalusia region and Italy (Galán et al., 2005; Orlandi et al., 2006), between 0 and 25 °C in Tunis (Aguilera et al., 2014) and between 4 and 12 °C for *Quercus* in different climatic zones in Spain (Garcia-Mozo et al., 2000). Previously in the area of Tétouan, threshold temperatures of 10 and 7 °C performed well at forecasting the initiation of pollen season and full anthesis of *O. europaea*, respectively (Achmakh et al., 2015). This fact can be considered to depend mainly on methodology used both to begin the heat accumulation and to statistically evaluate the best GDD threshold temperatures. Indeed, in the previous study undertaken in Tétouan, Achmakh et al. (2015) tested a range of base temperatures from 0 to 10 °C. Aguilera et al. (2014) reported that the thresholds values decrease proportionally; as the latitude increases, different threshold was obtained and ranged from 16 °C in Perugia to 23 °C in Zarzis. These results showed that the lower threshold or base temperature may vary between geographical areas. A relationship may exist between specific climatic conditions and taxa (Benmoussa et al., 2017). However, we have observed that the threshold temperatures are the same for the four taxa studied.

The peak of chilling, i.e., the day of the year with the maximum accumulation of positive chilling portions, has not been considered as the day to begin the heat accumulation in any taxa studied. This later fitted as the day after the end of chilling. This result suggests that, despite arriving at the peak chilling day, the chilling requirements have not been met and the endodormancy phase release would need more days of chilling (Lang, 1987).

According to several studies, chilling and heat accumulation appeared discontinuous (Benmoussa et al., 2017; Guo et al., 2013) due to different physiological processes inside the bud that happen during different stages within the chilling and forcing periods. Dormancy initiation and release and plants sensitivity to chill are governed by genetical, genomic and physiological mechanisms (Ríos et al., 2014). Other factors such as endogenous signals, temperature, photoperiod and water availability regulate the flowering transition (Benmoussa et al., 2017).

Moreover, when buds chilling is met and conditions are favorable for budbreak, the active phenological development starts (De la Rosa et al., 2000). In this regard, the results of the present study demonstrate a good approximation. Here, for all studied taxa, the cumulative chilling decline after the peak of chilling provided the best start date to begin the heat accumulation period.

On these terms, a period of approximately one month between the peak of chilling and the heat accumulation start date was detected for all taxa, accumulating the same amount of chilling. However, different GDD was required for their flowering onset. This finding might indicate that in woody species flowering in early spring, such as *Morus*, *Pistacia* and *Quercus* species, endodormancy release occurs earlier which is consequently related to their adaptive capacity to the environment concerned. However, for *Olea*, the endodormancy release seems to occur later. Indeed, Aguilera et al. (2014) suggested that a delay in the peak flowering date of olive observed in the Italian and Spanish areas might be provoked by a long transition between the end of endodormancy and the initiation of ecodormancy. Several studies have reported that, for the olive, low temperatures are needed only to break dormancy in previously initiated buds, as occurs in other fruit-tree species (Fernández-Escobar et al., 1992; Pinney & Polito, 1990; Rallo & Martin, 1991).

Summer temperature, winter chilling units and heat accumulation in woody species have been studied by numerous authors (Arnold, 1959; Chuine et al., 1999; Frenguelli & Bricchi, 1998; Galán et al., 2001; Garcia-Mozo et al., 2000) in order to clarify their involvement in the settlement and intensity of dormancy as well as cold acclimatization. In the Tingitana peninsula, the coldest temperature is recorded during December–February (Aboulaich et al., 2013).

Chilling requirements were not completely met under present climate conditions and insufficient in 2009 and 2010 for all populations, due to a warm winter. This result suggests that woody species in the southern of the Mediterranean sea need more heat than chilling showing their natural plasticity. However, the physiological effects of suboptimal chilling/forcing combinations should be investigated by horticultural researchers, which may have implications on crop yield or quality (Luedeling et al., 2013b).

The different results observed in chilling and heat requirements between flower and vegetative buds may be due to different environmental factors during the growing plant ‘life cycle’ (Rahemi & Pakkish, 2009). Thus, chilling and heat requirement amounts vary from year to year depending on photoperiod, plant nutrition (Powell, 1987), temperature (Jacobs et al., 2002) and other environmental factors (Rahemi & Pakkish, 2009).

In our analysis, chill accumulation trend showed a significant increase for most of taxa studied over the past 12 years. This could be due to the significant decreasing trend of annual and monthly minimum temperatures observed in Tétouan in our previous study (Boullayali et al., 2021). Heat accumulation increased significantly with rising mean temperatures during the forcing period. However, during 2008–2019, heat accumulation trend of *Morus*, *Olea*, *Pistacia* and *Quercus* decreased by -0.89 – -0.19 GDD per year. These tendencies in heat requirements have been related to abundant chill accumulated, and this conclusion was also confirmed by Alburquerque et al. (2008).

Corresponding with many other studies, heat accumulation is the main driver for flowering dates of woody taxa. Similarly, to this study, Guo et al. (2013) demonstrated in the cold winter climate of Beijing that forcing effects were much stronger than those of chilling on chestnut and jujube. Alonso et al. (2005) showed a similar result on almond in the cool climate of Zaragoza in northeast Spain. Sparks (1993) indicated that bud break of pecan could occur even when no chill is accumulated, and heat requirements are satisfied. In contrast, Egea et al. (2003) showed that in Spain, the initiation of flowering of almond cultivars was influenced mostly by chilling requirements, with a little heat requirements contributing. This result was corroborated by other studies concerning namely apricot, almond, pistachio and sweet cherry cultivars

(Albuquerque et al., 2008; Campoy et al., 2012; Rahemi & Pakkish, 2009; Ruiz et al., 2007).

Regarding our results, it seems that warming due to increasing mean temperature during some parts of the dormancy season decreased chill accumulation rates, whereas the chill trend increased during the whole period studied. Since chilling requirements of woody taxa are met in all winters under present climate conditions of Tétouan, changes in winter chill may cause delays in spring phases in the near future. In contrast, impacts due to climate change are thus likely to arise from increased rates of heat accumulation rather than from changes in chill (Guo et al., 2013). These two figures may translate into delayed bud break and partial flowering compromising fruit production and resulting in low yield production.

5 Conclusion

Adaptation of phenology to temperature is the subject of numerous studies. Thermal balance of chilling and heat requirements is necessary for metabolic activation and budbreak time in woody taxa. Based on long-term aerobiological observations in Tétouan, our results determine the timing of chilling and forcing periods, the optimal temperature threshold within the region and quantify the chilling and heat requirements of taxa studied in the warm climate of this region. During the past 12 years, heat accumulation of *Morus*, *Olea*, *Pistacia* and *Quercus* decreased by -0.56 ; -0.89 ; -0.19 ; -0.30 GDD per year, respectively. Flowering dates of all taxa were determined by heat accumulation, when ecodormancy is met, with chill accumulation contributing a small effect on bloom timing. In woody species flowering in early spring, endodormancy release occurs earlier. However, for late spring specie, it was observed later suggesting a long transition between the end of endodormancy and the onset of ecodormancy. Since chilling requirements of woody taxa were achieved under present climate conditions, changes in winter chill may cause delays in spring phases in the near future.

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Declarations

Conflict of interest The authors declare no commercial or associative interest that represents a conflict of interest with the results submitted.

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