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FLOWERING PHENOLOGICAL TRENDS UNDER THE EFFECT OF CLIMATIC PARAMETERS OF THE ARID MEDITERRANEAN REGION: THE MODEL OF DATE PALM

AFIFA HACHEF[1], HEDIA BOURGUIBA[1], WEJDENE SAFFAR[1], MOHAMED BEN SALAH[2], EMIRA CHERIF[1,3] AND SALWA ZEHDI-AZOUZI[1]

[1]*University of Tunis El Manar, Faculté des Sciences de Tunis, Laboratoire de Génétique Moléculaire, Immunologie et Biotechnologie, Campus Universitaire, 2092 El Manar, Tunis, Tunisia*
[2]*Centre Régional de Recherches en Agriculture Oasienne, Degache 2260, Tunisia*
[3]*DIADE IRD, University of Montpellier, 911 Avenue Agropolis, 34934 Montpellier Cedex 5, France*
[*]*Corresponding author's email: salwa.zehdi@fst.utm.tn*

Abstract

Flowering is a key event in the life cycle of plants. However, in the last Century, the timing of this major reproductive episode has been disturbed by climate change especially in the arid Mediterranean regions. Monitoring these phenological processes is interesting because it allows to quantify the extend of the ecological perturbation caused by global climate change in this area. We, therefore, investigated the flowering response of male date palms (*Phœnix dactylifera* L.) to climatic variation for a period of three years in order to establish a flowering calendar that allows us to address its asynchronism. The flowering phenological data were collected for the emergence and the opening of the first spathe events of 180 male genotypes from January to April of each study year. Meteorological data were analyzed at the temporal scale of observations. In this study, a great yearly variability of the reproductive phase within this collection was observed between years. The recorded flowering events revealed a striking trend of precocity for the first spathe emergence and a high stability in the spathe opening stage. Moreover, our findings demonstrated a advancement of the flowering onset and an extended emergence-opening duration. At correlation level, minimum, maximum and mean temperatures, minimum relative humidity and sunshine duration were, involved in the flowering phenological response of the Tunisian male accessions. Our results proved that the date palm flowering is not immune to the climate change effects. This investigation represents an essential phenotypic basis for upcoming flowering-linked genetic research in date palm.

Key words: Flowering asynchronism, Climate change, Great variability, *Phœnix dactylifera* L., Striking trend.

Introduction

Climate change is one of the major threats of the planet's biodiversity. In fact, the Intergovernmental Panel on Climate Change (IPCC) predicted that 20-30% of the current species might go extinct due to increasing global warming (IPCC 2014). Climate-impact on animal and plant kingdoms has been subject to many scientific studies, aimed at provide management and conservation programs for our natural resources (Parmesan & Hanley, 2015; Cadieux *et al*., 2020; Campana *et al*., 2020, Doody *et al*., 2020; Tang *et al*., 2020).

Numerous studies have shown that the climate changes have triggered shifts at population, community and ecosystem levels by modifying the population size, population dynamics and structure as well as the ecosystem functioning (Root *et al*., 2003; Parmesan, 2006; Rosenzweig, 2008). At the species level, organisms have developed diverse strategies to cope with climate fluctuations such as phenotypic plasticity, evolutionary adaptation and changes in seasonal timing being the main strategies (Parmesan, 2006).

Seasonal timing, or phenology, is the science that studies the chronology of cyclical phases and seasonal events in flora (Rathcke & Lacey, 1985) or fauna (Denny *et al*., 2014) as well as species and their relationship with the climatic conditions (IPCC, 2007). Plant phenology is one of the strongest and most effective biological indicators of climate change (Schwartz, 2013). Therefore, tracking phenology is an interesting topic for scientists as it allows to understand and survey the global climate changes. In the last decade, studies examining plant phenology have given the most accurate clues of the climate impact in the timing of its phenophases (Cleland *et al*., 2007).

Data on the timing of plant activity are effective observation tools to detect phenology shifts at species and ecosystem levels. Hence, many approaches have used plant phenology monitoring such as species-level observations. This experimental protocol is largely carried out in several plants such as annual, hemicryptophyte, herbaceous perennial and small-stature woody perennial plants (Segrestin *et al*., 2019) including grass (Cebrino *et al*., 2017) and tree species (Paltineanu & Chitu, 2019; Zhijun *et al*., 2019; Bruno *et al*., 2019; Medina-Alonso *et al*., 2020).

The Mediterranean region has been identified as one of the 25 "hot spots" in the world in terms of climate change (IPCC, 2014). This region is exposed to rising temperature, declining rainfall, longer dry periods and intense rainfall events (Cleland *et al*., 2007). All these meteorological variations apply a pressure on ecosystems and species in the area, especially in the North Africa semi-arid and arid zones where date palm (*Phœnix dactylifera* L.) is one of the most valuable crops. We count at least 250 varieties in Tunisia (Rhouma, 2005) and more than 400, 800 and 200 cultivars in Libya, Algeria and Morocco respectively (Toutain & Chari, 1971; Benkhalifa, 1996; Racchi *et al*., 2014). This species ensures the oases' ecosystem biodiversity and provides food and economic resources for the local populations (Rhouma, 1994). Date palm tolerates very severe ecological conditions like high temperatures and water scarcity. Moreover, it can grow in saline and infertile soils and takes advantage of its root system to use the groundwater in case of drought (Barrow, 1978).

Despite its adaptive ability, date palm is facing climate change effects like the other species of the Mediterranean regions notably Almond (*Prunus dulcis* Mill.) (Lorite *et al*., 2020), Apple *(Malus domestica*) (El yaacoubi *et al*., 2019), Black pine (*Pinus nigra* Arn.) (Sangüesa-Barreda *et al*., 2019) and Olive (*Olea europaea*) (Elloumi *et al*., 2020). In date palm, these weather fluctuations are serious threats because they alter the flowering phenophase which is a crucial process for pollination and the utimate date yield. Flowering phenological shifts can result in either an advance or a delay for both male and female date palms and consequently lead to flowering asynchronism and non-pollen availability for pollination. As climate change progresses, it is possible to forecast more severe changes which may intensify the disturbances of the oases agro-system. Thus, the extent of these shifts can induce an expansion of double flowering, which was initially spotted within the marginal cultivation areas such as the South-East of Niger (Jahiel & Fortin, 1990).

It is thus important to assess the potential effect of climate change on the reproductive process of date palm and provide a baseline data that shell help to prioritize appropriate conservation strategies of those genetic resources overtime development.

Studying the flowering of the male date palm provides an excellent tool to design a flowering calendar that can address these ecological shifts in the oasis eco-system and ensure the future date production in an increasing climate change. In this research, we investigate the trends of flowering phenological shifts of a collection of Tunisian male date palms in order to analyze their phenological responses, identify the climatic triggers of these flowering shifts and select the date palm males whose flowers are in synchrony with female accessions.

Materials and Methods

Site Study and plant material: The study site is located in Tozeur (33° 55' N, 8° 7' E) in the arid South West of Tunisia (Fig. 1). One hundred and eighty male palm genotypes conserved in a collection at the experimental plot of the Research Regional Centre Oases Agriculture of Degache. These male palms numbered from M1 to M180 and the geographical coordinates are marked by a Geographical Positioning System (Garmin eTrex Venture HC, 2007) when the elevation ranged from 37 to 53 m.

Monitoring of floral phenology: The phenological stages selected for this study are the emergence and the opening of the first spathe (Fig. 2). Weekly observations were checked over the entire flowering period from January to April for the three successive years 2014, 2015 and 2016. During each survey, each flowering event was recorded qualitatively (presence or absence) (Castellana *et al*., 2010; Pintaud, 2012).

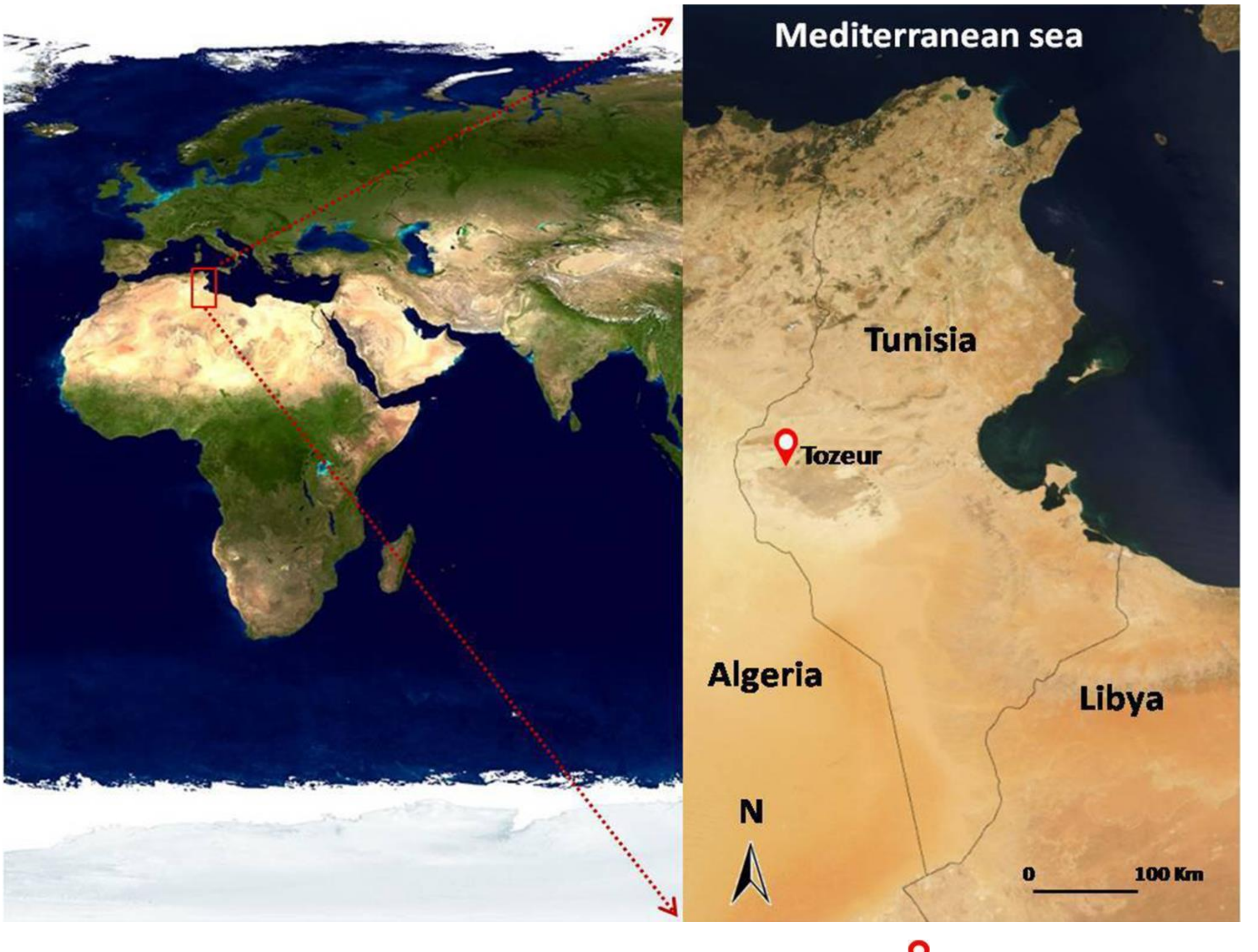


Fig. 1. Maps showing the geographic location of the study site (📍).

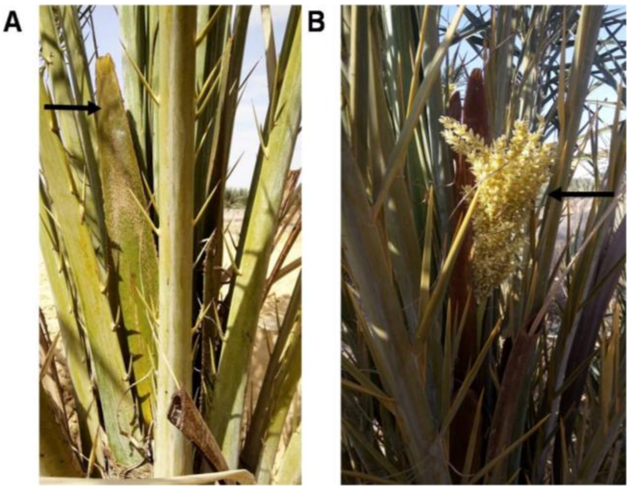
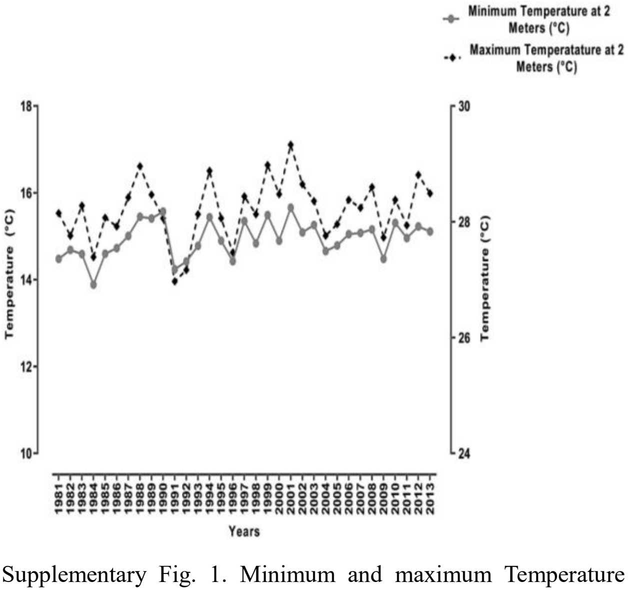


Fig. 2. Flowering phenological phases studied at the male date palm collection; Emergence of the first inflorescence **(A)**; Opening of the first spathe **(B)**.

Retrieved climatic data: The climatic data of the study site over the period 1981-2013 were collected from the National Aeronautics and Space Administration/ Prediction of World Wide Energy Resources (NASA/P OWER; http://power.larc.nasa.gov). Climatological characteristics retrieved are the minimum temperature (°C) at 2 meters and the maximum temperature (°C) at 2 meters (Supplementary Fig. 1).



Supplementary Fig. 1. Minimum and maximum Temperature (°C) recorded at the study site from 1981to 2013.

Over the three years of the flowering surveys (2014-2016), the daily meteorological data collected from Tozeur meteorological station were obtained from the Tunisian National Institute of Meteorology (INM). The studied parameters for the monitoring period of each year consist of the minimum and the maximum temperatures (°C), the minimum and the maximum of relative humidity (%), sunshine duration (h) and the maximum wind speed (km h^{-1}).

Phenological and climatic input data: The phenological data collected for each year was used to classify the male genotypes according to their flowering period, the emergence of their first spathe, the opening of their first inflorescence and the time from the emergence to the cracking of the first spathe. The phenological matrices and the climatic data sets form the input data for graphical representation and statistical analyses.

Statistical analyses

Histograms were made to illustrate the patterns and the two phases of the phenological flowering during the three study years. To estimate variation, standard deviation (*SD*) and coefficient of variation (%) were calculated at each observation date. The distributions of the examined male genotypes based on each flowering event were investigated using the PCA approach. The climatic data were subjected to ANOVA to detect significant differences among the years. Next, these data were combined in order to determine the relationship between the studied flowering stages and the weather variables. To do so, linear regression and Pearson's correlation test were used. Graphing and data analysis were carried out using GraphPad Prism 7.04 and R (R Core Team v3.5.1).

Results

Flowering phenological patterns

Trends of variability at the emergence event: The spathe emergence date marks the start of the flowering period in date palm. The number of date palm males characterizing each emergence period underscored an inter-annual variation during the three analyzed years where the mid-season emergence period presented the highest variation with a coefficient of variation up to 100% (Table 1). From one year to another, the examined male genotypes of this collection tended to have an earlier emergence of their inflorescence (Fig. 3A). During the three surveyed seasons, a two-week advancement was recorded at the beginning, at the end and at the peak time of emergence spathe (Table 1).

This reproductive episode of the studied collection is revealed by a principal component analysis (Fig. 4B). Based on their spathe emergence behaviors, the male accessions were categorized into four groups using the PCA where the first two axes explained 45.30 % and 38.89 % of the total variation, respectively. The first group contained 134 male genotypes, which flowered earlier. The second one included 25 male genotypes with a mid-season flowering period. The third group gathered 10 late flowering male genitors. The fourth group represents 10 male genotypes with flowering fluctuation during the three monitored seasons.

Evaluation of the opening of the first spathe event: The opening of the first spathe, which is the second flowering event, revealed another pattern of variation. During each study year, the floral stage recorded its highest level in the full season. This dominance was more pronounced in the season of 2016 with 94 % of the entire collection (Table 1). This result reflects the great stability of this flowering event (Fig. 3A). The opening of the first spathe of all individuals of the studied seasons at each observation date revealed the potential stability of the full opening activity at the fourth week of March (Table 1).

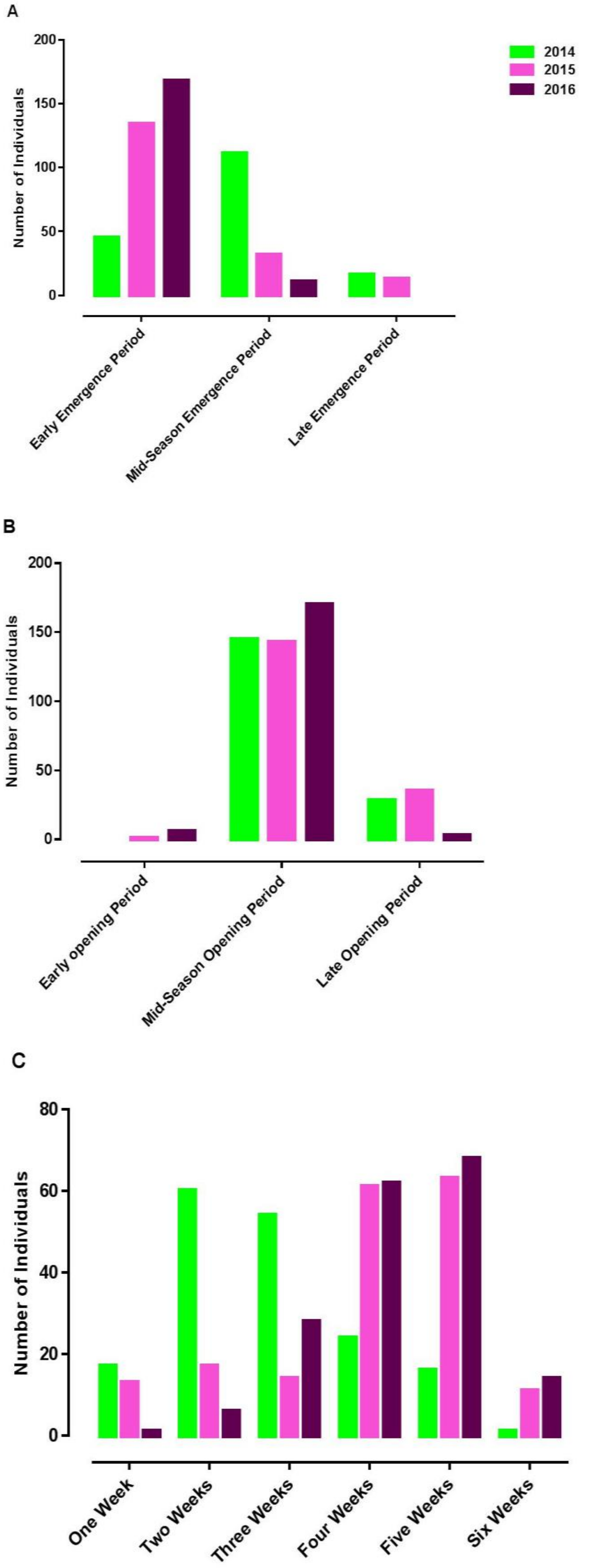


Fig. 3. Distribution of male genotypes for each studied flowering even throughout the years of the study; Distribution of male accessions according the three periods of the emergence of the first spathe **(A)**; Number of male genitors characterized each period of the opening of the first inflorescence **(B)**; Emergence-Opening duration of the first spathe for this collection across the three studied flowering seasons **(C)**.

The studied male accessions were subjected to PCA based on their opening spathe pattern (Fig. 4B). This projection represents 80.63 % of the total inertia. In this component, the distribution shows three groups. The first group includes 124 male genotypes that started the opening of their spathe throughout the month of March for the three seasons. During these periods, we recorded an opening spathe stability in the last week of March for 27 male palms and only one male genotype out of this group that conserved both its emergence and the opening spathe dates. The second group contains two individuals, which conserved their opening spathe in April throughout the three study years. The third group contained the individuals that exhibited a fluctuating opening date of their first spathe.

Period between the emergence and the opening of the first spathe: The number of weeks between the two stages of flowering phase was counted for each genotype in this collection over the three study seasons (Fig. 3C). In 2014, most date palm males recorded two and three weeks for the growth and development of their spathe. However, the longest duration was six weeks. During the seasons of 2015 and 2016, the individuals of this collection scored a longer duration with two important peaks at the fourth and the fifth weeks. At this level, we can conclude that a wide range of male genotypes showed a trend to decelerate the inflorescence development pace.

Selection of the interesting male genotypes from the studied collection: By observing the spathe emergence and opening date of this collection, we identified and selected 31 male palms. These male genotypes are considered very interesting because of their capacity to cover the flowering period of female varieties in the case of very early, early or late flowering. This list consists of the 27 male genotypes, which maintained their early flowering. One male genitor displayed mid-season flowering period stability is one among of the selected palms. The remaining members were the three male palms characterized by flowering alternation between early and late period.

The spathe opening of the selected male palms was graphically represented in order to identify their pollen availability for the pollination. This calendar mentions that the pollen availability of these male date palm ranged from the third week of February to the last week of April (Fig. 5). This result shows that these male genotypes are able to synchronize the headway or the delayed flowering period of the female accessions.

Fluctuations of climatic variables: From 1981 to 2013, the retrieved temperature data of the study site revealed a great interannual variability (Supplementary Fig. 1). The minimum Temperature at 2 meters ranged from 13.89°C for 1984 to 15.66°C for 2001. The maximum temperature at 2 meters oscillated from 26.97°C to 29.33 °C for 1991 and 2001, respectively. The climatic data for the phenological survey period 2014-2016 is summarized in Table 2. By examining the minimum and maximum values, a considerable climatic variation and fluctuation was recorded at the climatic parameters between years. Simultaneously, this climatic data was subject to ANOVA to quantify this variation. As detailed in Table 2, this test showed a significant difference in maximum temperature, temperature range and sunshine duration. Taken together, these results illustrate the meteorological disturbances, which hit the arid regions of Tunisia.

Table 1. Statistics on the flowering phenology data recorded in the studied site during the period in analysis.

Period	Early								Full-Season				Late			
Observation date: Month/Week	January				February				March				April			
	1st W	2nd W	3rd W	4th W	1st W	2nd W	3rd W	4th W	1st W	2nd W	3rd W	4th W	1st W	2nd W	3rd W	4th W
	Emergence event															
2014	0	0	0	0	0	13	28	4	52	51	4	4	10	2	4	0
2015	0	0	0	1	10	18	56	49	8	9	12	3	5	3	5	0
2016	0	0	0	2	38	55	62	11	6	4	1	0	0	0	0	0
Standard deviation	0.0	0.0	0.0	1.00	19.70	22.94	18.15	24.21	26.00	25.81	5.69	2.08	5.00	1.53	2.65	0.00
Coefficient of variation (%)	0.0	0.0	0.0	100.00	123.11	80.03	37.29	113.50	118.18	121.00	100.35	89.21	100.00	91.65	88.19	0.00
	Opening event															
2014	0	0	0	0	0	0	0	0	2	15	33	96	7	6	10	3
2015	0	0	0	0	0	0	0	1	3	19	9	111	20	8	3	5
2016	0	0	0	0	0	0	1	5	22	54	23	71	3	0	0	0
Standard deviation	0.0	0.0	0.0	0.0	0.0	0.0	0.58	2.83	11.27	21.46	12.06	20.21	8.89	4.16	5.13	2.52
Coefficient of variation (%)	0.0	0.0	0.0	0.0	0.0	0.0	173.21	132.29	125.22	73.14	55.64	21.81	88.88	89.21	118.42	94.37

*1st W: First week, 2nd W: Second week, 3rd W: Third week, 4th W: fourth week

Table 2. Climatic parameters for the studied years and ANOVA test.

	2014		2015		2016		*Pr* (>*F*)
	Min	Max	Min	Max	Min	Max	
Minimum temperature (°C)	5.39	16.98	3.74	18.31	6.18	18.85	0.2101
Maximum temperature (°C)	21.37	37.73	19.62	40.26	16.91	31.49	0.007661**
Mean temperature (°C)	13.60	27.35	11.69	29.14	11.55	25.09	0.3187
Temperature range (°C)	15.43	21.04	14.61	22.24	7.14	13.81	7.544e-11***
Minimum relative humidity (%)	18.16	41.71	16.16	48.00	11.14	33.57	0.305
Maximum relative humidity (%)	53.16	76.69	50.00	90.00	55.00	78.62	0.6968
Mean relative humidity (%)	35.66	55.68	35.94	69.00	33.42	55.37	0.4976
Sunshine duration (h)	40	72	40	96	47	88	0.03961*
Maximum wind speed (km h^{-1})	23.4	64.28	29.15	68.85	27.90	57.60	0.6081

'***' $p \leq 0$; '**' $p \leq 0.01$; '*' $p \leq 0.05$

Table 3. Linear Regression Analyses between the flowering phenology of the examined collection of the male palms and climatic variables.

	Emergence event			Opening event		
	R^2	F-statistic	p-value	R^2	F-statistic	p-value
Minimum temperature	0.515*	7.421	0.030	0.001	0.007	0.938
Maximum temperature	0.443*	5.556	0.051	0.001	0.008	0.930
Mean temperature	0.531*	7.939	0.026	0.001	0.008	0.932
Temperature range	0.079	0.601	0.464	0.001	0.007	0.937
Minimum relative humidity	0.553*	8.658	0.022	0.009	0.065	0.806
Maximum relative humidity	0.124	0.988	0.354	0.009	0.064	0.808
Mean relative humidity	0.373	4.164	0.081	0.013	0.090	0.773
Sunshine duration	0.510*	7.281	0.031	0.072	0.541	0.486
Maximum speed wind	0.151	1.249	0.301	0.284	2.778	0.140

Significant correlation: '*' at the 0.05 level

Table 4. Pearson's product-moment correlation between the flowering initiation and climatic variables.

	r	p-value
Minimum temperature	-0.717*	0.030
Maximum temperature	-0.665*	0.051
Mean temperature	-0.729*	0.026
Minimum relative humidity	0.744*	0.022
Sunshine duration	-0.714*	0.031

Significant correlation: '*' at the 0.05 level

Flowering phenology and climatic variables relationships: The linear regression model was drawn to test the existence of relationships between climatic conditions and the studied reproductive events (Table 3). A significant link appeared between the emergence process and temperature with their minimum, maximum and mean values. Besides, there was a significant relationship between flowering initiation and minimum relative humidity. Furthermore, a linear relation was observed between the sunshine duration and the flowering onset. These results may partly explain the recording of fluctuations and the advance shown in the timing of floral initiation from one year to another. No relationship was detected between the first spathe opening and the examined climatic variables. This finding indicates that this phenomenon is not affected by climatic changes.

The *Pearson's* correlation coefficient was used to confirm the contribution of climatic parameters to the variation of flowering phenology. This test with 95% confidence interval revealed a significant correlation between the emergence of the first spathe and the climatic variables (Table 4). The flowering onset was negatively correlated with minimum, maximum and mean temperatures as well as the sunshine duration. However, the minimum relative humidity gave a positive correlation. These results confirm the linear regression analysis and indicate that these climatic variables have a major role in first spathe emergence changes.

Discussion

As global temperatures rise, climate change alters worldwide ecosystems including the timing of seasonal activities of plants. Therefore, shifts in phenology have been considered as 'fingerprints' to climate change (Walther *et al*., 2002; Jentsch *et al*., 2009). Plant phenology is widely used to monitor these shifts and to evaluate the ecological responses under climate changes (Mo *et al*., 2017). Flowering phenology of date palm males collection in arid Mediterranean region is a study case.

Within this collection, several behaviors were reported during the floral phase of date palm males in response to climatic changes. A deeper analysis of this reproductive phase has shown a significant forward shifting in the flowering initiation of these male genotypes from one year to another. This result is in the line with previous observational studies (Guo *et al*., 2013; Cebrino *et al*., 2017; Wadgymar *et al*., 2018; Hájková *et al*., 2020). Nevertheless, the flowering precocity of date palm has a greater magnitude during a short study period in comparison with other species that require a long-term observation. An investigation into the phenological responses of peach trees to climatic change uncovered a blooming precocity of 11.1 days throughout a 30 year observation (Yong *et al*., 2016). Similarly, the flowering onset advanced for an average rate of 10.0 and 6.7 days for apple and pear tree orchards respectively, in the last 50 years in southern Romania (Chitu & Paltineanu, 2020). These findings suggest that date palm is very sensitive to climate change and the threshold of shifts is very high at the reproductive phase. The pattern of shifting underscored in the collection of the studied male genotypes is a valuable assessment of ecological perturbations at oases ecosystem and largely coincides with the effect reported by Gordo & Sanz (2010) in the Mediterranean ecosystems within a global climate change context.

The shift caused by climate change is not limited to floral events but also affects other plant phenophases. As outlined by Cola *et al*., (2016), earliness has been scored at the veraison phase of Grapevine in Georgia. Other authors have discussed precocity of leaf unfolding for four deciduous species (Juknys *et al*., 2016). Sangüesa-Barreda *et al*., (2019) found a shift of the growth patterns for Black pine across the Mediterranean basin. Moreover, Dengpan *et al*., (2019) reported maturity date advancement of maize in northern China. Other study set up a considerable reduction on wheat and barley yields in Kazakhstan (Schierhorn *et al*., 2020). According to Han *et al*., (2015), vegetation at desert steppe of Inner Mangolia showed senescence date advancement from 2004 to 2012.

Furthermore, these changes affected the date of the peak of flowering onset of the examined male genotypes. Similar findings have been reported in the majority of 136 studied Chinese species which scored earliness for the timing of all the floral events including the beginning, the peak and the ending of flowering (Mo *et al*., 2017).

According to the flowering onset behavior, the distribution of the studied collection by the PCA approach revealed an emergence period stability in a large number of individuals. Part of this group conserved even the date of their flowering initiation. These date palms are endowed with plasticity and potential adaptation to climatic changes. Conversely, other male genitors exhibited a fluctuated flowering period. Such flowering strategy reflects the sensitivity of these individuals to climatic changes. These observations suggest that each male date palm has its own reaction to climate change.

The pattern of the opening spathe event showed a strong dominance of the full season activity and the peak for this biological process concentrated in the last week of March during the three studied years. Hence, this phenomenon appears to be not disrupted by changing climatic conditions. On an individual scale, the date of this phase gave a new grouping of this collection. This finding may be due to the different pace of physiological activity for each male genotype in the elongation and maturity of inflorescences independently of their emergence.

Comparing the two stages of the flowering phase, the emergence was found to be more sensitive to climate change, which is reflected by a rapid speed of shifts and a remarkable earliness of flowering onset during the three studied years. Previously, a phenological monitoring of 29 Mediterranean perennial plant species has demonstrated that the fruiting and leaf falling events are more sensitive to climate change then the flowering, and leaf unfolding events (Gordo & Sanz, 2010).

By observing the flowering duration pattern, these male accessions showed a noteworthy trend to prolong the time interval between the emergence and the opening of their spathes. These variations indicate that the rate of spathes growth and development are affected by changes in climatic factors. Our findings corroborate previous research maintaining that global warming has caused the prolonging of the growing-season length for several species in southern Spain (García-Mozo *et al*., 2010). According to Wang *et al*., (2017), the duration between the studied cotton phenophases tends to either prolong or shorten during the observational period. El Yaacoubi *et al*., (2019) also revealed in their research on a Moroccan apple orchard an extended period from flowering to harvesting. On individual scale, this growing cycle length recorded a determinable stability for eight male genotypes. So, these results suggested that date palms are endowed with greater resilience face to climatic changes. Our results bring additional insights to the great ability of date palm to cope with arid environment.

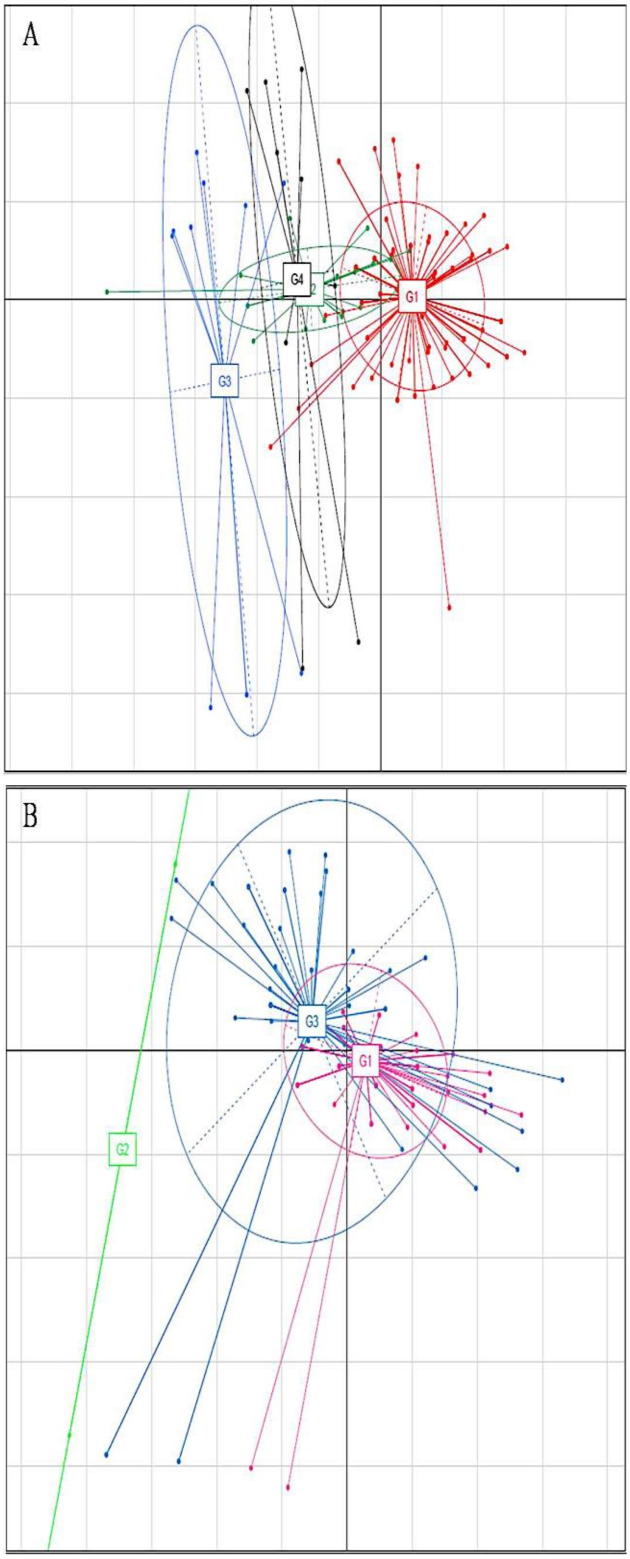


Fig. 4. Principal component analysis performed on the reproductive phenology of the examined male genotypes; Principal component analysis based on the emergence behavior of the studied male genitors **(A)**; Principal component analysis using the opening pattern of the study collection **(B)**.

Ultimately, the flowering phenological assessment uncovered two divergent responses of date palm to climate change i) pronounced shifts at the emergence event triggered by weather variations reflecting the sensitivity of date palm to climate fluctuations and ii) a strong stability at the spathe opening event highlighting the great resilience of date palm to a varying climate.

The thirty-one male date palms selected from this collection confirmed their ability to cover the flowering period of female accessions especially the early and the late one. This type of data needs a second selection in order to determine among this list the best performers in terms of pollination, quality and quantity of production.

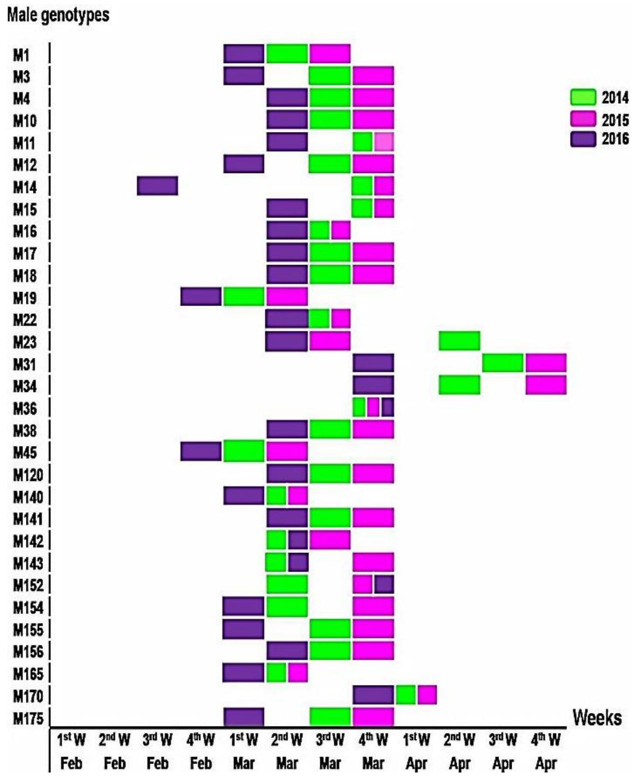


Fig. 5. Calendar of the opening spathe for the selected date palm male genotypes from the three study years (2014-2016); **1st W:** First week**, 2nd W:** Second week**, 3rd W:** Third week**, 4th W:** fourth week**, Feb:** February; **Mar:** March; **Apr**: April.

The significant variability in the climatic factors at the studied site is a great evidence for climatic variations in the oases ecosystem. This result provides a clear picture of climate changes in the arid Mediterranean areas. The connections between meteorological variations and flowering shifts show that fluctuations of temperature have the strongest effect on the flowering phenophase. This finding corroborates the studies of Munier (1963, 1980). This author pointed out that temperature is a primary climatic factor controlling the reproductive cycle of date palm. The contribution of relative humidity and sunshine duration in flowering phenophase shifts of the studied collection confirmed that the initiation of inflorescences is the fruit of the interactions between several factors. In the same way, Jahiel & Fortin (1990) demonstrated by a flowering examination of date palm in the South-East of Niger that the hygrometry and evaporation climatic factors are responsible for triggering a second reproductive cycle. In other palm species, inflorescence production has been influenced by temperature and relative humidity (Peñuela *et al*., 2019).

A central question is how species behave towards global climate change and whether these responses evolve at the same pace as the phenomenon progresses. The phenoclimatic measures and surveys are relevant methodologies to answer this core question. Our assessment of the flowering phenology pattern of a collection of male date palm showed considerable shifts of the flowering phase and a substantial effect of the relative humidity and sunshine duration on these responses. Our results emphasize the potential impact of climate change in the Mediterranean arid areas through one of its emblematic species and the critical situation facing the date palm under ongoing changes. This data set of floral phenology can be a tool to resolve the core issue of the oases agro-system through male genotypes collection allowing the genetic improvement.

References

Barrow, S. 1998. A monograph of *Phœnix* L. (*Palmae: Coryphoideae*). *Kew Bull*., 53: 513-575.

Benkhalifa, A. 1996. Diversity of date-palm (*Phœnix dactylifera* L.) in the Algerian oases. *Medit. Options. Gr. Sirot*., 28: 160-160.

Bruno, M.M.A., K.G. Massi, M.M. Vidal and J.D.V. Hay. 2019. Reproductive phenology of three *Syagrus* species (*Arecaceae*) in a tropical savanna in Brazil. *Flora*, 252: 18-25.

Cadieux, P., Y. Boulanger, D. Cyr, A.R. Taylor, D. Price, P. Sólymos, D. Stralberg, H.Y.H. Chen, A. Brecka and J.A. Tremblay. 2020. Projected effects of climate change on boreal bird community accentuated by anthropogenic disturbances in western boreal forest, Canada. *Divers. Distrib*., 1-15.

Campana, S.E., R.B. Stefánsdóttir, K. Jakobsdóttir and J. Sólmundsson. 2020. Shifting fish distributions in warming sub-Arctic oceans. *Sci. Rep*., 10(16448).

Castellana, R., J.C Pintaud and C. Littardi. 2010. Phénologie du palmier dattier: caractérisation du cycle reproducteur au niveau populationnel sur un échantillon italien de *Phoenix dactylifera*. Issued by The Phoenix Project 2010.

Cebrino, J.L.J. García-Castaño, E. Domínguez-Vilches and C. Galán. 2017. Spatio-temporal flowering patterns in Mediterranean *Poaceae*. A community study in SW Spain. *Int. J. Biometeorol*., https:// doi: 10.1007/s00484-017-1461-7.

Chitu, E. and C. Paltineanu. 2020. Timing of phenological stages for apple and pear trees under climate change in a temperate-continental climate. *Int. J. Biometeorol*., https://doi.org/10.1007/s00484-020-01903-2.

Cleland, E.E., I. Chuinev, A. Menzel, H. Mooney and M. Schwartz. 2007. Shifting plant phenology in response to global change. *Trends. Ecol. Evol*., 22(7): 357-365.

Cola, G., O. Failla, D. Maghradze and L. Mariani. 2016. Grapevine phenology and climate change in Georgia. *Int. J. Biometeorol*., doi 10.1007/s00484-016-1241-9.

Dengpan, X., Z. Yanxi, B. Huizi, H. Yukun and C. Jiansheng. 2019. Impacts of climate warming and crop management on maize phenology in northern China. *J. Arid. Land*., https://doi.org/10.1007/s40333-019-0028-3.

Denny, E.G., L.K.Gerst, A.J. Miller, Rushing, L. Geraldine, G.L. Tierney, T.M. Crimmins, C.A.F. Enquist, P. Guertin, A.H. Rosemartin, M.D. Schwartz, K.A. Thomas and J.F. Weltzin. 2014. Standardized phenology monitoring methods to track plant and animal activity for science and resource management applications. *Int. J. Biometeorol*., 58: 591-601.

Doody, J.S., J. Mc Glashan, H. Fryer, L. Coleman, H. James, K. Soennichsen, D. Rhind and S. Clulow. 2020. Plasticity in nest site choice behavior in response to hydric conditions in a reptile. *Sci. Rep*., 10(16048).

El-Yaacoubi, A., N. El Jaouhari, M. Bourioug, L. El Youssfi, S. Cherroud, R. Bouabid, M. Chaoui and A. Abouabdillah. 2019. Potential vulnerability of Moroccan apple orchard to climate change-induced phenological perturbations: effects on yields and fruit quality. *Int. J. Biometeorol*., https://doi.org/10.1007/s00484-019-01821-y.

García-Mozo, H., A. Mestre and C. Galán. 2010. Phenological trends in southern Spain: A response to climate change. *Agric. For. Meteorol*., 150(4): 575-580.

Elloumi, O., M. Ghraba, A. Chattia, A. Chaaria and M. Ben Mimoun. 2020. Phenological performance of olive tree in a warm production area of central Tunisia. *Sci. Hort*., 259(108759).

Gordo, O. and J.J. Sanz. 2010. Impact of climate change on plant phenology in Mediterranean ecosystems. *Glob. Chang. Biol*., 16:1082-1106. doi: 10.1111/j.1365 2486.2009.02084.x.

Guo, L., J. Dai, S. Ranjitkar, J. Xu and E. Luedeling. 2013. Response of chestnut phenology in China to climate variation and change. *Agric. For. Meteorol*., 180: 164-172.

Hájková, L., K. Věra, M. Možný and L. Bartošová. 2020. Influence of climate change on flowering season of birch in the Czech Republic. *Int. J. Biometeorol*., https://doi.org/10.1007/s00484-020-01869-1.

Han, F., Q. Zhang, A. Buyantuev, J.M. Niu, P.T. Liu, X.H. Li, S. Kang, J. Jing Zhang, C.M. Chang and Y.P. Li. 2015. Effects of climate change on phenology and primary productivity in the desert steppe of Inner Mongolia. *J. Arid. Land*, https://doi.org/10.1007/s40333-014-0042-4.

IPCC WGII. 2007. *Intergovernmental Panel on Climate Change (IPCC): Climate Change 2007-Impacts, Adaptation and Vulnerability*. Cambridge (UK).

IPCCI WGIII. 2014. *Intergovernmental Panel on Climate Change (IPCC): Climate Change 2014-Mitigation of climate chang*e. Copenhague, Danemark.

Jahiel, M. and L. Fortin, 1990. La double floraison du palmier dattier dans le Sud-Est du Niger. *Fruits*, 45(6): 615-621.

Jentsch, A., J. Kreyling, J. Boettcher-Treschkow and C. Beierkuhnlein. 2009. Beyond gradual warming: extreme weather events alter flower phenology of European grassland and heath species. *Glob. Chang. Biol*., 15: 837-849.

Juknys, R., A. Kanapickas, I. Šveikauskaitė and G. Sujetovienė. 2016. Response of deciduous trees spring phenology to recent and projected climate change in Central Lithuania. *Int. J. Biometeorol*., doi: 10.1007/s00484-016-1149-4.

Lorite, I.J., J.M. Cabezas-Luque, O. Arquero, C. Gabaldón-Leal, C. Santos, A. Rodríguez, M. Ruiz-Ramos and M. Lovera. 2020. The role of phenology in the climate change impacts and adaptation strategies for tree crops: a case study on almond orchards in Southern Europe. *Agric. For. Meteorol*., 294: 108142.

Medina-Alonso, M.G., J.F. Navas, J.M. Cabezas, C.M. Weiland, D. Ríos-Mesa, I.J. Lorite, L. León and R. de la Rosa. 2020. Differences on flowering phenology under Mediterranean and Subtropical environments for two representative olive cultivars. *J. Exp. Bot*., 180 (104239).

Mo, F., J. Zhang, J. Wang, Z.G. Cheng, G.J. Sun, H.X. Ren, X.Z. Zhao, W.K. Cheruiyot, L. Kavagi, J.Y. Wang and Y.C. Xiong. 2017. Phenological evidence from China to address rapid shifts in global flowering times with recent climate change. *Agric. For. Meteorol*., 246:22-30.

Munier, P. 1963. *Prospection phénicicole du territoire de la République du Niger*. IRFA, Paris:

Munier, P. 1980. *Mission palmeraies en République du Niger*. AFVP, Montlhéry.

Paltineanu, C. and E. Chitu. 2020. Climate change impact on phenological stages of sweet and sour cherry trees in a continental climate environment. *Sci. Hortic.*, 261. https://doi.org/10.1016/j.scienta.2019.109011.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. *Annu. Rev. Ecol. Evol. Syst.*, 37: 637-669.

Parmesan, C. and M.E. Hanley. 2015. Plants and climate change: complexities and surprises. *Ann. Bot.*, 116: 849-864.

Peñuela, M.C., M. Bustillos-Lema, S. Álvarez-Solas and L.A. Núñez-Avellaneda. 2019. Reproductive phenology variation of the multiple inflorescence-palm tree *Wettinia maynensis* in relation to climate, in a Piedmont forest in western Amazonia. *Trees*, https://doi.org/10.1007/s00468-019-01824-7.

Pintaud, J.C. 2012. Protocoles pour la caractérisation des cycles végétatif et reproducteur élaborés sur le site italien de Sanremo (2008-2011). Issued by The Phoenix Project 2012.

Racchi, M.L.A., Bove, A. Turchi, G. Bashir, M. Battaglia and A. Camussi. 2014. Genetic characterization of Libyan date palm resources by microsatellite markers. *3 Biotech*., 42: 1-32. doi 10.1007/s13205-013-0116-6.

Rathcke, B. and E.P. Lacey. 1985. Phenological patterns of terrestrial plants. *Ann. Rev. Ecol. Evol.* Syst., 16: 179-214.

Rhouma, A. 1994. *Le palmier dattier en Tunisie, Le patrimoine génétique*. Vol: I. Arabesque, Tunis, Tunisie

Rhouma, A. 2005. *Le palmier dattier en Tunisie, Le patrimoine génétique*. Vol: II. IPGRI Rome, Italy.

Root, T.L., J.T. Price, K.R. Hall, S. H. Schneider, C. Rosenzweig and J.A. Pounds. 2003. Fingerprints of global warming on wild animals and plants. *Nature*., 421: 57-60.

Rosenzweig, C. 2008. Attributing physical and biological impacts to anthropogenic climate change. *Nature*, 453: 353-357.

Sangüesa-Barreda, G., J.J. Camarero, R. Sánchez-Salguero, E. Gutiérrez, J.C. Linares, M. Génova, M. Ribas, P.A. Tíscar and J.A. López-Sáez. 2019. Droughts and climate warming desynchronize Black pine growth across the Mediterranean Basin. *Sci. Total. Environ*., 697(133989).

Schierhorn, F., M. Hofmann, I. Adriand, I. Bobojonov and D. Müller. 2020. Spatially varying impacts of climate change on wheat and barley yields in Kazakhstan. *J. Arid. Environ*., 178(104164).

Schwartz, M.D. 2013. Introduction. In: Schwartz, MD (ed) Phenology: An Integrative Environmental Science. Netherlands: Springer; p. 1-5

Segrestin, J., M.L. Navas and E. Garnier. 2019. Reproductive phenology as a dimension of the phenotypic space in 139 plant species from the Mediterranean. *New Phytol*., doi: 10.1111/nph.16165.

Tang, J., R.R. Swaisgood, M.A. Owen X. Zhao W. Wei, N.W. Pilfold, F. Wei, X. Yang, X. Gu, Z. Yang, Q. Dai, M. Hong, H. Zhou, J. Zhang, S. Yuan, H. Han and Z. Zhang. 2020. Climate change and landscape-use patterns influence recent past distribution of giant pandas. *Proc. Royal. Soc. B*., 287(20200358).

Toutain, G.A.B. and M. Chari. 1971. *Cartographie variétale de la palmeraie marocaine*. DRA, Rabat.

Wadgymar, S.M., J.E. Ogilvie, D.W. Inouye, A.E. Weis and J.T. Anderson. 2018. Phenological responses to multiple environmental drivers under climate change: insights from a long-term observational study and a manipulative field experiment. *New Phytol*., doi: 10.1111/nph.15029.

Walther, G.R., E. Post, P. Convey, A. Menzel, C. Parmesank, T.J.C. Beebee, Fromentin, J.M. O. Hoegh-GuldbergI and F. Bairlein. 2002. Ecological responses to recent climate change. *Nature*, 416: 389-395.

Wang, Z., J. Chen, F. Xing, Y. Han, F. Chen, L. Zhang, Y. Li and C. Li. 2017. Response of cotton phenology to climate change on the North China Plain from 1981 to 2012. *Sci. Rep*., 7(6628). doi: 10.1038/s41598-017-07056-4.

Yong, L., W. Lirong, Z. Gengrui, F. Weichao, C. Ke, C. Changwen, W. Xinwei and W. Xiaoli. 2016. Phenological response of peach to climate change exhibits a relatively dramatic trend in China, 1983-2012. *Sci. Hort*., 209: 192-200.

Zhijun, L., Z. Xiao, Z. Yaqiong, Q. Aijun and Z. Ling. 2019. Effects of temperature on flowering phenological traits of *Populus euphratica* Oliv. and *Populus pruinosa* Schrenk populations, Xinjiang, China. *J. Arid. Land*, https://doi.org/10.1007/s40333-019-0026-5.

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