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Climatic changes and fruit trees phenology in the region of Constantine (Algeria)

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Abstract

The current study was carried out in Constantine region of north-east Algeria, during four successive campaigns from 2012/2013 to 2015/2016 where climatic changes are recorded by warming or cooling months. The aim of our study is to observe the behavior of 15 fruit trees with climate respect, and to determine the effect of meteorological conditions on the phenological phase of flowering stage and on the yield. Our method was basedon selected field surveys of the flowering periods of the chosen populations and on the comparison of the phonological plant behavior against climatic changes. The obtained results showed that the species can be grouped according to the flowering period which is strongly related to photo-period and thermo-period.The results reveals a flowering precocity of 7.62 and 11.12 days on average marked respectively during the two agricultural years 2013/2014 and 2015/2016 and a double gametophytic phase produced toward the *Eriobotrya japonica* (Thunb.) Lindl. Early to bloom had adverse effects, especially the yield was completely wiped out as a result of reproductive exposure to spring frost. We concluded that the behavior or response of species to the same climatic changes is different from one year to the next, suggesting an acclimatization supported by a kind of plant memory and thus a genetic mechanism regulating the response to the climatic factors in order to ensure the survival of the species.

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Introduction

Phenology is the study of recurring events appearance such as: flowering, foliage, and fruiting, established by the weather seasonal variations, in which plants develop under climatic conditions that are the most favorable seasons, in order to provide their survival and the birth of a new generation.

Anthropogenic activity and mainly fossil fuels combustion have increased the atmospheric dioxide carbon (CO_2) concentration by infrared absorption; this gas contributes to a greenhouse effect and restricts the earth's surface cooling, which would lead to a few degrees increasing in temperature and a change in the precipitation's distribution (Meyer *et al.*, 2008).

These climatic changes have biological and phenological effects (Guédon and Legave, 2008; Pau *et al.*, 2011; Palgar and Primack, 2011), and agronomic impacts, where there are difficulties in adapting to certain cultivars and, in particular, there is a risk of further production irregularities and disruptions of regional specialties. (Legave, 2003; Domerge *et al.*, 2004).

The main objective of this study is to characterize the climatic changes influence on the flowering stage of fruit trees distributed in the region of Constantine which is a Mediterranean region of north-east Algeria and to see their yield consequences.

Materials and methods

Plant material

The studied fruit trees of 15 species: *Eriobotrya japonica* (Thunb.) Lindl.; *Prunus dulcis* (Mill) D. A. Webb.; *Prunus armeniaca* L.; *Prunus cerasus* L.; *Prunus persica* (L.) Batsch; *Prunus domestica* L.; *Pyrus malus* L.; *Pyrus communis* L.; *Cydonia vulgaris* Pers.; *Juglans regia* L.; *Citrus aurantifolia* (Christm.) Swingle; *Olea europaea* L.; *Punica granatum* L.; *Vitis vinifera* L. and *Opuntia ficus-indica* (L.) Mill. were observed for their flowering periods.

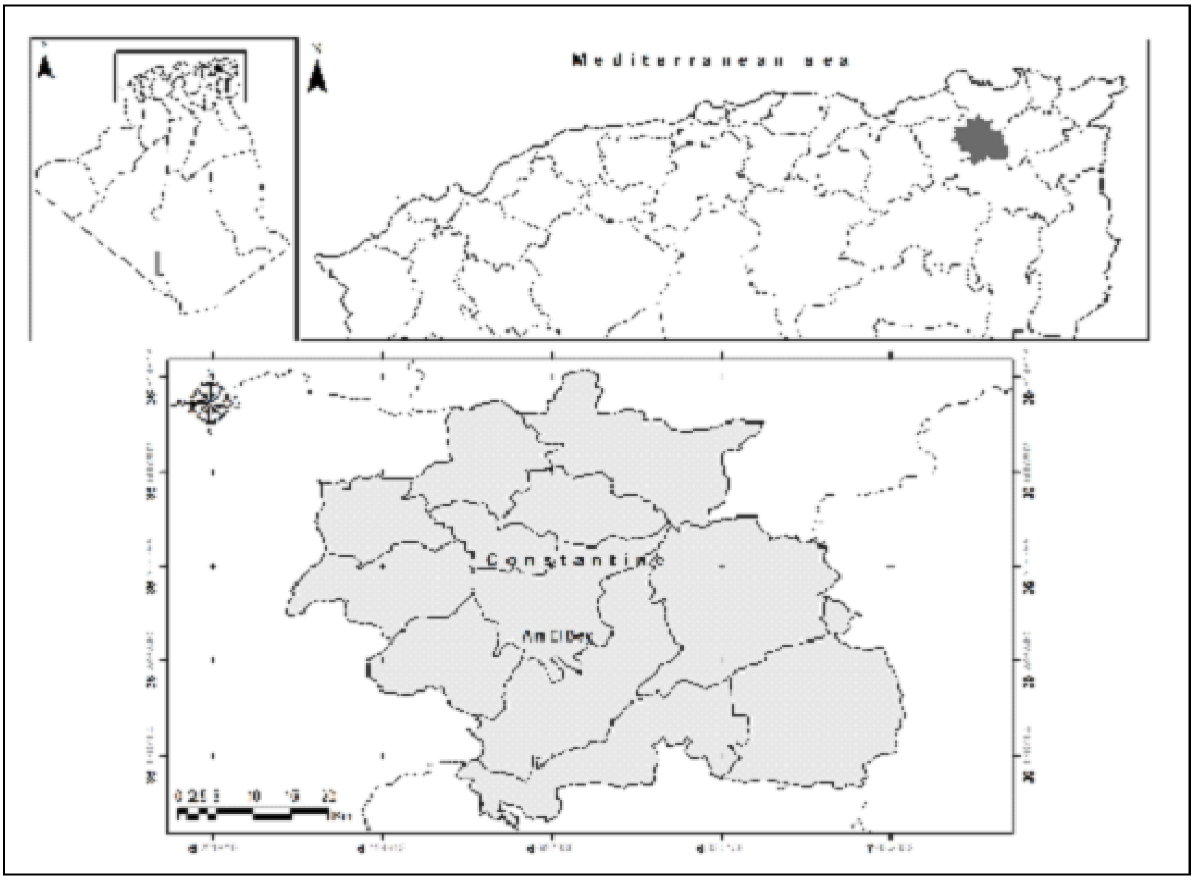


Fig.1. Presentation of the study area.

The trees were identified by Technical institute of fruit trees and vines (ITAFV) of hamma bouziane in Constantine; Algeria.

Study area

The study is carried out in the region of Constantine (Ain-El-Bey site), a Mediterranean region located in north-eastern Algeria at 36.23 ° latitude, 7.35 ° longitude and 694m altitude (Fig. 1).

Phenological survey

This study required field surveys during four successive agricultural campaigns (2012-2013, 2013-2014, 2014-2015 and 2015-2016) with more than 300 organized outings: to choose the work site (altitude homogeneity and sun exposure of studied species individuals) ; to put out the phenological monitoring of these species at the study site, especially during the flowering period (beginning and end of flowering) of the chosen populations and to establish the floral calendar for the studied species. Furthermore, the differences of the beginning of the flowering periods for each species between the four studied campaigns were calculated and compared. Hence, the effects of the climatic changes from one to another campaign on plant phenological responses were considered.

A needful climatological study for this type of investigation was carried out in order to interpret the biological aspect in its ecological environment.

Climatological study

The collected climatic data from the National Office of Meteorology-station services (Ain-El-Bey) allow us to describe the climate of the region.

Indeed, a visual examination of the ombro-thermal diagram established for the period of 1981-2010 (Fig. 2) reveals a dry period extending from the second fortnight of May to beginning of October.

This period is marked by high temperatures.

According to the Table 1, the study area had a seasonal HPAE system (H: winter, P: spring; A: Autumn; E: summer) for 30 years (period of 1981 to 2010). This regime is reflected in the monthly distribution irregularities of the precipitation, while the months of the wintry season (December, January and February) are receiving the greatest amount of rain, then the spring season (March, April and May), closely followed by the autumn season (September, October and November), and finally the summer season (June, July and August) that receives the least amount of rain.

To better define the exceptionally cold and warm periods of the study area, we calculated the pluviothermic quotient of Emberger (Q_2) and we estimated both of the hottest month maxima average (M) and the coldest month minima average (m). For the period extending from 1981/2010, it was found that the region is classified in the sub-humid bioclimatic stage in the mild winter (Table 2).

Fig. 3 shows the average monthly length of the days when it is noted that our region is typified by a stretching photoperiod extending from the month of February to the end of July, and a decreasing photoperiod extending from the end of July until January.

Therefore, the study area is characterized by a sub-humid climate; which is generally a seasonal climate representative of wet and cool winter with a relatively short photoperiod and a dry and hot summer with a relatively long photoperiod.

The study, carried out during the four agricultural campaigns 2012-2013, 2013-2014, 2014-2015 and 2015-2016, the climatic data of which are shown in Figs. 4 and 5, and Table 3 below, allows picking out the recorded climatic variations (temperature, rainfall and frozen days) over the four years.

The climatic data comparison of the four study periods reveals changes, especially for the temperature where a warming of 3 ° C is recorded for the month of February, and a cooling of -2.5 ° C is recorded for the month of March during the year

2013/2014, we also noticed a warming of 3.2 ° C during the month of February 2016 compared to the month of February 2013. Whereas for the precipitation, the year 2012/2013 recorded a cumulative rainfall amount lower than that recorded in the year 2013/2014 with a difference of - 47.8 mm and greater than that recorded in the year 2015/2016 with a difference of 102.5 mm.

According to Table 3, the study region encounters frost periods year after year, during the winter and early spring.

Statistical analysis

The statistical method used is the principal component analysis (PCA), first to examine the relationships between the appearance of the flowers in individuals and climatic factors, second to distribute the species according to their flowering responses. Statistical analysis was carried out using the XLSTAT Statistical software version 5.03.

Results and discussion

Climatic factor and flowering calendar

The results obtained from the phenological follow-up of the fifteen (15) studied fruit species during the four (04) biological cycles enabled us to establish the floral calendar represented hereafter (Table 4).

During the 2012/2013 season, the flowering of the studied species took place in the spring when climatic conditions were characterized by an elongation photoperiod (Fig. 3): a relatively high mean temperature (11.2 °C) in March and an low mean temperature of 1.97 °C during winter for vernalization, with a significant amount of water at ground level (194.9 mm) related to precipitation during this period.

Table 1. Rainfall regime of the study area.

Month	P (mm)	Seasons	Seasonal Rainfall (mm)	Seasonal pattern
September	35,91			
October	37,77	Autumn	126.89	A
November	53,21			
December	82,80			
January	69,90	Winter	204.92	H
February	52,22			
March	56,06			
April	53,10	Spring	149.76	P
May	40,60			
June	17,40			
July	12,31	Summer	41.75	E
August	12,04			
Total	-	-	523.32	-

These conditions favored the passage of the studied species from the vegetative state to the reproductive state (flowering) shown up by induction, floral evocation and initiation, and flowering, according to Côme (1992); Ducreux (2002); Morot-Gaudry *et al.* (2012); While Gordo and Sanz (2010); McKinney *et al.* (2012) and Mu *et al.* (2012), suggest that interactions between species also modify flowering.
However, it should be noted, that the species *Eriobotrya japonica* (Thunb.) Lindl. represents an exception. Indeed, this species begins flowering in autumn when climatic conditions are characterized by a decrease in photoperiod (Fig. 3), a relatively high mean temperature (21.7 ° C) and an average precipitation of 29.4 mm in November.

The floral buds of this species are protected against the cold in the end of autumn and the beginning of winter by cuticulated and hairy scales which join the ideas of Guédon and Legave (2008). In addition, the hypanthium can also protect flower because it has the same protective tissues as the scales.

Table 2. Emberger rainfall quotient of the study area.

P (mm)	T°				Q_2	Bioclimatic floor
	Warmest month	M (°C)	Coldest month	m (°C)		
523.32	July	24.92	January	6.44	97.13	Sub-humidmild winter

Table 3. Number of Jelly Days.

Months Campaigns	September	October	November	December	January	February	March	April	May	June	July	August
2012/2013	0	0	0	16	18	16	4	1	0	0	0	0
2013/2014	0	0	1	15	9	8	6	0	0	0	0	0
2014/2015	0	0	0	6	9	6	3	1	0	0	0	0
2015/2016	0	0	0	25	12	13	0	0	0	0	0	0

The species of long days (e.g.*Olea europaea* L.), which bloom in spring can be divided into four groups:

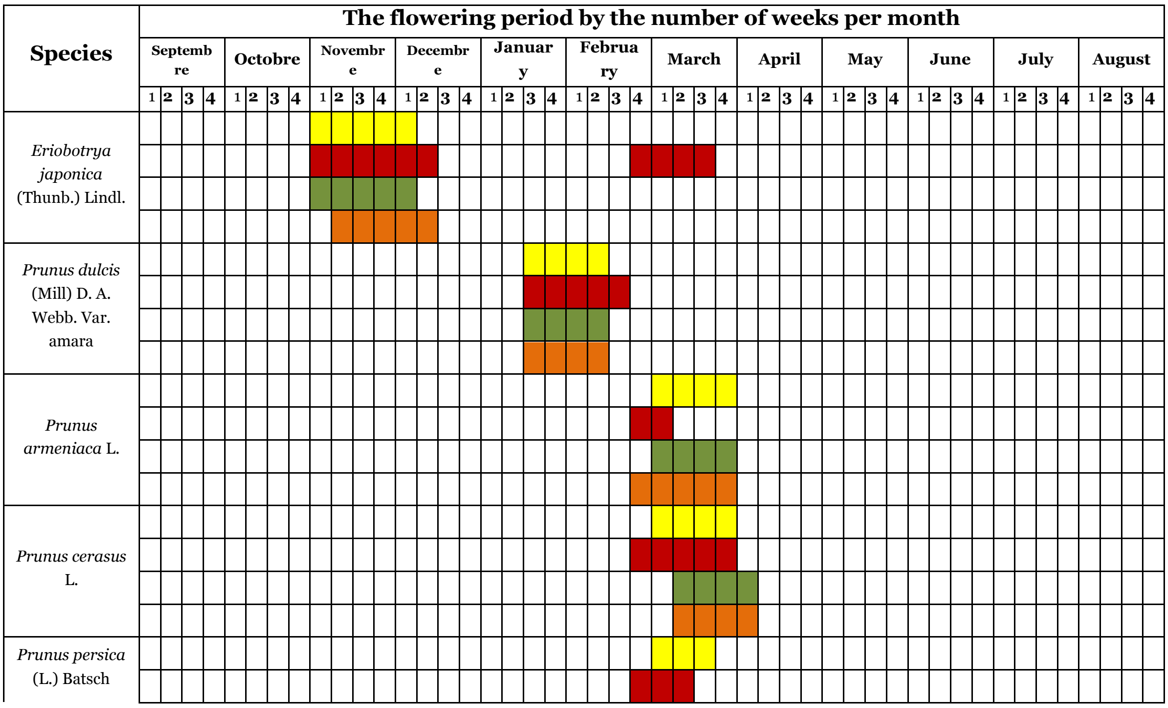
Group 1 represented by the species *Prunus amygdalus* L. which blooms from the end of February, it is considered as a sensitive species to the elongation of the day;

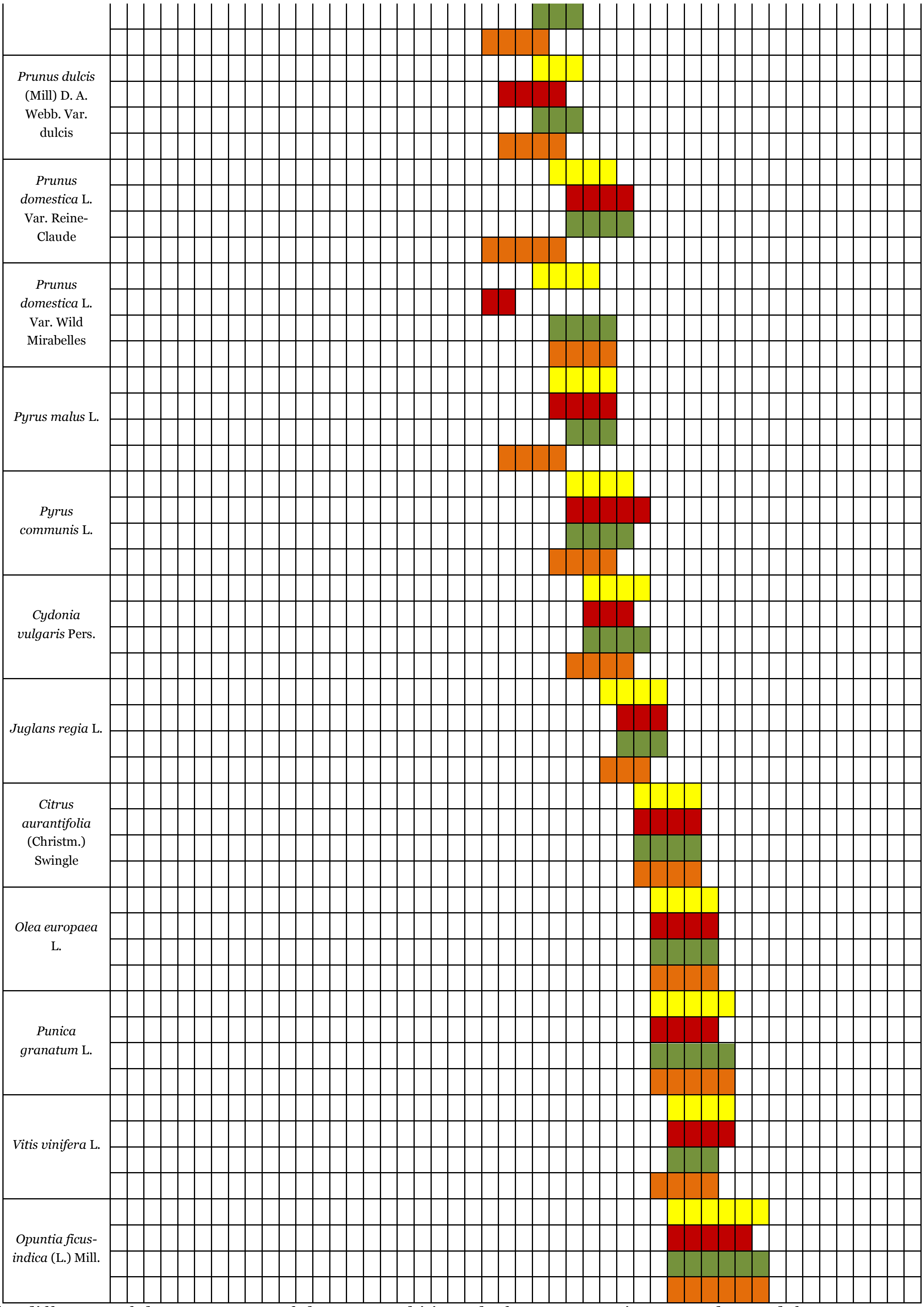
Group 2 composed by species that bloom in the month of March (early spring) when the average temperature is 11.2 ° C. This group is represented by Prunus *cerasus* L. species;

Group 3 consists of species that bloom in April (mid-spring) when the temperature is relatively higher (13.8 ° C). This group is represented by *Juglans regia* L. species;

Group 4 is represented by species that bloom in May (in late spring) when the photoperiod is relatively longer, this group includes *Punica granatum* L. species.

Table 4. Floral calendar of fruit species in the Constantine region during the four surveys (2012/2013, —2013/2014, —2014/2015, — 2015/2016).





The difference of the appearance of the gametophitic cycle from one species to another and from one year to another especially in the beginning of spring.

Climatic changes and Phenological variations

The two periods of 2013/2014 and 2015/2016, compared with each other (Table 5), showed early flowering by an average difference of 7.62 and 11.12 days for the month of March compared with the previous period of 2012/2013.

This precocity may be explained by the increase in recorded temperature (3 ° C during the month of February 2014 and 3.2 ° C during the month of February 2016 comparing to the month of February 2013), so we figure out the effect of the temperature on the flowering of the studied species by the passage from initiation to floral evocation.

Table 5. Early gap at flowering between different study (C) surveys (days).

Species	Flowering month (period 2012/2013)	C2 / C1	Monthly mean of early maturity difference	C3 / C1	Monthly mean of early maturity difference	C4 / C1	Monthly mean of early maturity difference
Eriobotrya japonica (Thunb.) Lindl.	Novembre	7	0	0	0	2	0
Prunus amygdalus L.	January	- 5	- 5	0	0	- 3	- 3
Prunus armeniaca L.	March	- 5	- 11.12	0	0	- 8	- 7.62
Prunus cerasus L.	March	4		4		- 9	
Prunus persica (L.) Batsch	March	- 14		3		- 7	
Prunus dulcis (Mill) D. A. Webb	March	- 18		4		- 13	
Prunus domestica L. Var. 1	March	- 23		7		10	
Prunus domestica L. Var2	March	3		2		- 14	
Pyrus malus L.	March	- 19		2		0	
Pyrus communis L.	March	- 3		3		4	
Cydonia vulgaris Pers.	April	- 4	- 3	2	0	0	0
Juglans regia L.	April	- 2		2		5	
Citrus aurantifolia (Christm.) Swingle	April	- 3		0		1	
Olea europaea L.	May	- 1	- 2.5	0	- 0.5	2	0
Punica granatum L.	May	- 3		2		0	
Vitis vinifera L.	May	- 4		- 2		2	
Opuntia ficus-indica (L.) Mill.	May	- 2		2		2	

These obtained results in our region are comparable with those of Ziello *et al.* (2009) at the European Alpine region, and Morin *et al.* (2010); Wolkovich*et al.* (2013) in the North American.

As a result, three studied species (*Prunus armeniaca* L., *Prunus persica* (L.) Batsch. and *Prunus domestica* L.) bloomed in February instead of March, so they bloomed at the end of winter instead of early spring. Other species such as *Pyrus communis* L. that did not respond to the short warm winter period (false spring) did not bloom and it is requiring a longer cumulative cold time before responding to spring heat and entering flowering as discussed by Cook *et al.* (2012).

These results are supported by a PCA statistical study with which it can be seen from Fig.6A that factor 1 and factor 2 account for 99.15% of the values dispersion for the campaigns of 2012/2013, thus the characters representation on these two factors is sufficient to explain the correlation between the latter. The same applies to the other three campaigns (84.53%, 96.96% and 87.29% respectively).

The projection of the studied characteristics on a two-factor outline shows firstly a very strong correlation between the photoperiod and the beginning of flowering factors, and secondary a relatively strong correlation between these two latest and the themoperiodism factor for three studied campaigns with the exception of the year of 2014/2015, which can be explained by the period during which the harvest took place, coinciding with the flowering of the studied species.

In contrast, there is a very strong correlation between the three different temperatures (minimum temperature, maximum temperature and average temperature).

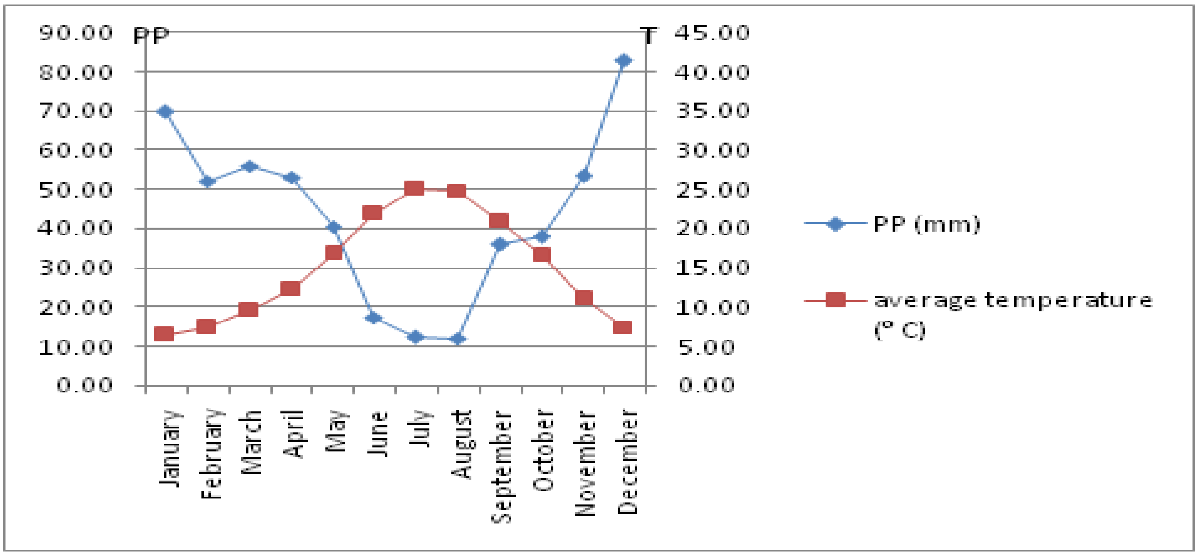


Fig. 2. Ombrothermal diagram of the study area(period of 1981-2010).

According to Fig. 6B, factor 1 may represent the flowering period and factor 2 may represent the flowering temperature progress, while the photoperiod contributes to the dispersion of individuals on the factorial outline where the species distribution can be observed in 4 groups in addition to a fifth species represented by *Eriobotrya japonica* (Thunb.) Lindl.

It should be noted that the recorded flowering earliness during the two campaigns of 2013/2014 and 2015/2016 caused a flowering synchronization by creating three groups only.

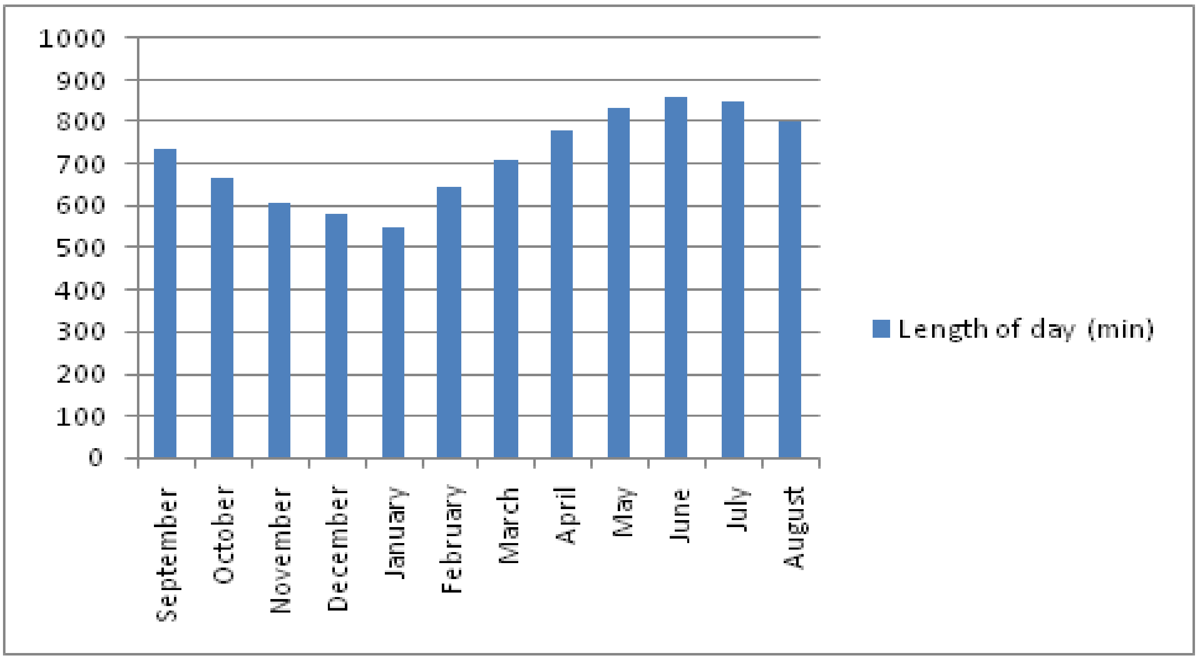


Fig. 3. Histogram of length of day.

This early flowering has adverse effects on the life cycle and particularly on the yield of these species and especially those that are very early such as *Prunus armeniaca* L. (-8 days) and *Prunus domestica* L. (-14 days).

Indeed, we observed the total absence of the production during the campaign of 2013-2014 following the exposure of the flower buds, at the time of the debrowing, and of the bloomed flowers the spring frost. This is represented by symptoms which have been manifested by generalized browning; the flowers were leading to their death and to the absence of fruits, consequently the absence of production (Fig. 7).

This state has already been mentioned by Eccel *et al.* (2009); Legave (2009); Gordo (2010); Cook *et al.* (2012); Ricard (2014) and Mu *et al.* (2015).

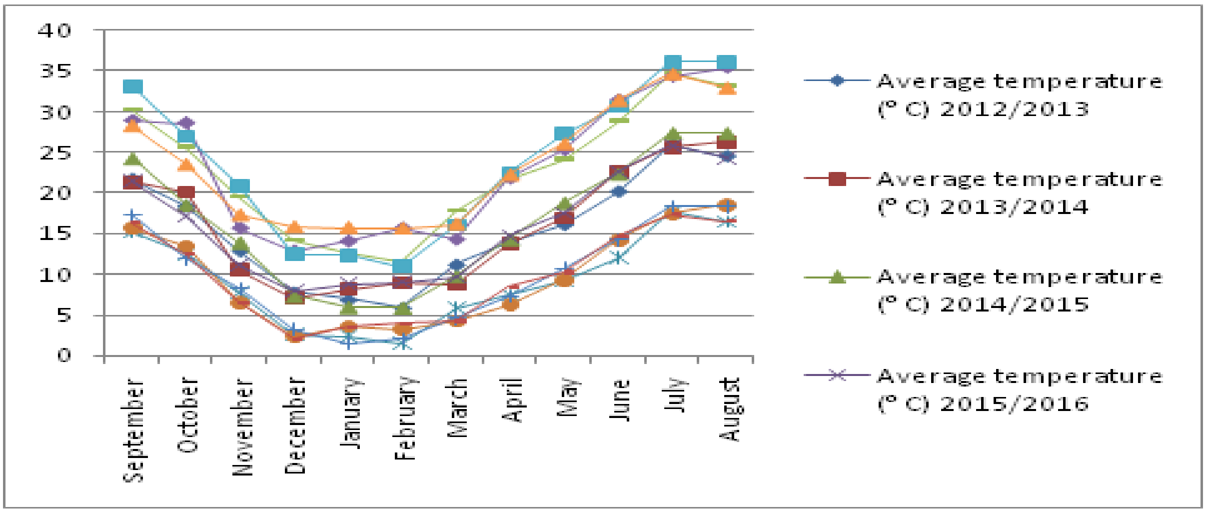


Fig. 4. Curve of average monthly temperatures, maxima and minima recorded during the four study periods.

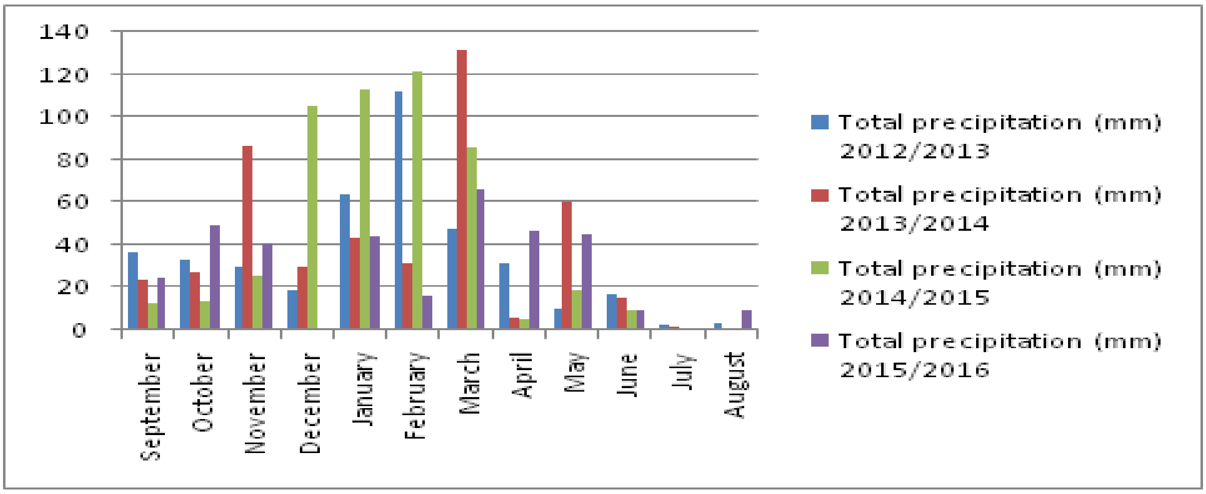


Fig. 5. Average monthly rainfall of the four study periods.

It should be noted that the early flowering time recorded during the season of 2015/2016 did not produce a drop in yield due to the absence of spring frost (Table 3), which agrees with the conclusion of Anandhi *et al.* (2013) in their study of the Catskill Mountani area in New York and Ge *et al.* (2013) in their study of woody plants in temperate China where there is a decrease in the risk of frost that occurs before the early bud burst following climate change.Another phenomenon is observed in the species of

Eriobotrya japonica (Thunb.) Lindl. during the season of 2013-2014.

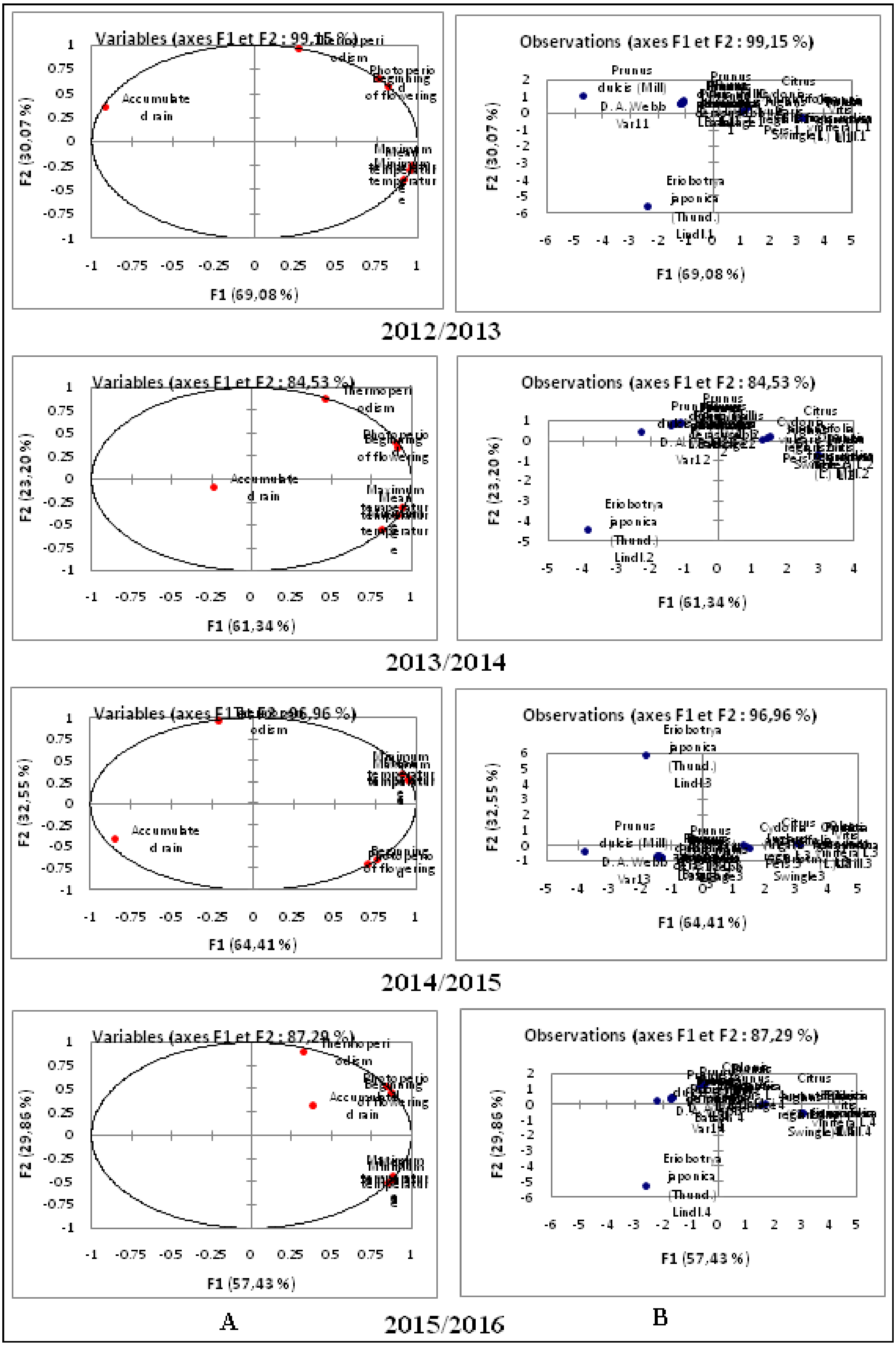


Fig. 6. PCA statistical study for the four crop years.A. Variables Distribution with respect to the correlation circle. B. individuals Distribution on the factorial level.

This species flourished twice during the season, the first time in November (normal period) and the second time during the month of February. The species therefore developed two gametophytic phases during its annual life cycle, thus simultaneously presenting fruits and flowers (Fig. 8).

This can be explained by the increase in temperature in February 2013 which has encouraged floral evocation and subsequently the formation of flowers while the length of the photoperiod is still favorable for floral initiation.

Fig. 7. Browning and death of the reproductive system *Prunus armeniaca* L. under the effect of spring frost.

Flowering from the second gametophytic phase to the fruit failed and the inflorescences dried (Fig. 9). Following a feeding defect insofar as the developed sap is oriented towards the growth and filling of fruits of the first gametophytic cycle. We are thus witnessing a kind of waste of energy resulting from the second gametophytic cycle.

Fig. 8. The annual double gametophytic cycle of *Eriobotrya japonica* (Thunb.).

Phenological comportment

It should be noted that among the studied species, some of them change their behavior from one year to the next with respect to climatic constraints, and there are two cases:The first concerns the species *Prunus domestica* L. which did not record early flowering although it practiced an increase in temperature during the 2015/2016 season in late winter, so the species has to be avoided to bloom during the frost period.

The second case relates to the species of *Eriobotrya japonica* (Thunb.) Lindl. Which did not show a 2nd gametophytic phase during 2015/2016 season as was the case in 2013/2014 when the climatic conditions were similar.

Fig. 9. The death of the reproductive system of the second cycle gametophytic in the species *Eriobotrya japonica* (Thunb.) Lindl. The elaborated sap is used for the fruits formation of the normal gametophitic cycle, so the second inflorescences are dried.

The possibility of species to change their behavior is explained by the presence of a plant memory and consequently the presence of a genetic mechanism that can respond to climatic conditions and changes in several ways in order to ensure the survival of the species.

Conclusion

It can be concluded that the region of the present study is characterized, from one year to the other, by relative climatic changes mainly in precipitation and temperature. This leads to: interannual phenological variability (flowering phase) explained typically by the increase in temperature during the month of February (false spring); to early flowering in some species and a double gametophytic phase for *Eriobotrya japonica* (Thund.) Lindl..

These two phenomena have negative effects on plant production particularly under the effect of the spring frost on earlier species.

Adapting to the same climatic constraints, some studied species have yearly changed their behavior, which can be explained by the presence of a plant memory and consequently the presence of a genetic mechanism that regulates the development of The plant in its midst.

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