Chapter

Flowering of Sweet Cherries "*Prunus avium*" in Tunisia

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Abstract

In Tunisia, the development of cherry growing is limited by two major constraints, namely, the chilling requirements and the self-incompatibility of some cultivars. In order to contribute to the development of this high added-value culture, which is capable to play an important socioeconomic role in rural and semi-forestry places, this study has set the main objective, characterization, and selection of best-suited cultivars to mild winter based on the blooming period. The plant materials used for this study are composed of the introduced cultivars, which are "Napoleon," "Van," "Moreau," "Sunburst," and "Stella," and unknown cultivars, which are "V1," "V2," "V3," "V4," and "V5," and a local one "Bouargoub." Differential behavior between cultivars was shown for phenological stages (budbreak, flowering, maturity, and leaf fall), and this behavior is dependent in some cases on the cold requirement [chilling requirements (CR)]. The local cultivar "Bouargoub" recorded the lowest "CR" with early flowering and maturity.

Keywords: behavior, chilling requirement, flowering, mild winter

1. Introduction

Sweet cherry tree is a hardy species capable of adapting to various soil and climatic conditions; but its development is surrounded by climatic and physiological constraints. The sweet cherry (Prunus avium L.) from Rosaceae family, with a number of chromosomes (2n = 2x = 16), is an allogamous species that is adopted to a self-incompatibility system to ensure cross-fertilization. Self-compatibility in sweet cherry occurs rarely in nature and, consequently, there are a reduced number of self-compatible cultivars [1]. Sweet cherry is the first fruit of summer season and is highly appreciated by consumers, cultivated for its edible fruits and its wood.

According to FAO [2], world production of sweet cherries has been estimated at 2,245,826 tones. The largest cherry-producing countries are Turkey, the United States, Iran, Italy, and Spain [2]. The cultivation of sweet cherries in Tunisia covers an area of about 961 ha [3]. This species is particularly cultivated in the region of northern Tunisia, where the winter is mild and spring frosts are rare. National production is estimated at 5187 tons [3]. Despite the favorable conditions, sweet cherry is poorly valued and only some regions practice this culture in small-scale along Tunisia.

The local cultivar is poorly valued, given the predominance of introduced cultivars which have high productivity and good adaptation to the mild North African climate. The characterization of this variety and the comparison with other introduced varieties is essential for its conservation. In this context, the present work is focused on the study of the phonological characteristics such as blooming stage of some cultivars of sweet cherry trees in relation to the conditions of the environment. Flowering is a determining factor in fruit production based on pollen self-incompatibility. The cultivation of cherry trees is limited in the north of Tunisia in the high altitudes to fill chill requirement. Therefore, this study is part of the evaluation, the development of genetic resources in fruit arboriculture in Tunisia, and the extension of the cultivation of cherry trees in regions at medium altitude.

For sweet cherry, like for other temperate-zone fruit species, when chilling requirements are not adequately satisfied, negative repercussions on productivity occur. Insufficient chilling can lead to erratic, delayed budbreak, and heterogeneous flowering. Chilling increased the flower size, pedicel length, and fruit set [4].

In many perennial species, it has been shown that increase in temperatures during the last dormant stage (autumn, winter) was responsible for advancing blooming dates, leading to an increased risk of damage caused by late frosts, phenological disorders, with a large spread of flowering dates and difficult synchronization of flowering with the activity of pollinators.

In a Mediterranean climate and specifically in Tunisia, development of sweet cherry growing (Prunus avium) shows several problems related to floral biology, chilling requirement, appearance of bud anomalies, and inconstant and extremely low yield**.**

The aim of our study was to investigate the blooming phenophase and the effect of temperature during flowering period on the fruit set and the production of 11 cultivars of sweet cherry in the climate condition of Tunisia, from which researchers and orchard managers will get reliable information for their study or planting.

2. Experimental sites and plant materials

The behavior of the different cultivars was monitored in three experimental sites located in three regions of northwestern Tunisia with different pedo-climatic characteristics:

The site of Ain-Draham is located at latitude 36°46′34″ North and longitude 8°41′05″ East, with an altitude of 800 m. The average annual rainfall was about 1040 mm. The lowest average temperature was about 6.08°C during February and the warmest was 26°C during July. The bioclimatic floor is humid superior with temperate winter. The site of Bousalem is at latitude 36°36′34″ North and longitude 8°58′17″ East, with an altitude of 127 m above sea level. The average annual rainfall was about 57.24 mm. The lowest average temperature was around 10.03°C during February and the highest temperature was 35.50°C during July. The bioclimatic floor is subhumid with temperate winter. The site of Tibar is at latitude 36°31′21″ North and longitude 9°06′22″ East, with an altitude of 328 m. The average annual rainfall was about 540 mm. The lowest average temperature was about 8.37°C during February and the hottest temperature was around 29°C during July–August. The bioclimatic floor is subhumid with mild winter.

The plant materials used in this study are composed of 11 cultivars of local and introduced sweet cherries (Prunus avium L.) of known and unknown origins. These cultivars are unequally distributed between the three experimental sites (**Table 1**).

The different studied flower traits are the length of the pistil (LPIST), the ovary area (SROV) and the number of stamens (NBET), length (Lopt) and width of petals (Larpt) and flower diameter (DFL), shape of petals (SHPE), and the arrangement of petals (ARPE).

DOI: http://dx.doi.org/10.5772/intechopen.93234

		Sites				
Cultivar	**Origin**	**Ain-Draham**	**Bousalem**	**Tibar**	**(In) compatibility groups***	**S allele composition***
Napoléon	Germany	+	—	+	III	S3S4
Van	Canada	+	—	+	II	S1S3
Moreau	French	+	—	+	XVI	S3S9
Sunburst	Canada	+	—	+	**SC	S3S4'
Stella	Canada	+	—	—	**SC	S3s4'
Bouargoub	Tunisia	+	—	—	*XLII	S2S10
V1 unknown	—	—	+	—	XVI	S3S9
V2 unknown	—	—	+	—	**SC	S3S4'
V3 unknown	—	—	+	—	XVIII	S1S9
V4 unknown	—	—	+	—	**SC	S3S4'
V5 unknown	—	—	+	—	II	S1S3

+, indicates that the variety is tested in the relevant site.
**The S-genotype and incompatibility groups [5] according to Schuster [6].*
***SC: Self Compatible.*

Table 1.
Name, origin, distribution, and S-genotype of the studied cultivars per experimental site.

The flowers were collected in full bloom by using five flowers per tree on five trees by cultivar and site. The different measurements were carried out using a vernier caliper for measuring the length and width of petals and flower diameter. However, the ovary area, pistil length, and number of stamens were carried out with electronic scanning microscope (Leica).

- Statistical analyses were performed using SAS 9.1. ANOVA was carried out and means were separated by the LSD test ($\alpha \leq 0.05$).

3. Flowering of sweet cherry

The transition from the vegetative state to a reproductive state is a crucial stage of development in fruit trees, and this transition is marked by floral induction. During the vegetative phase, the vegetative meristems produce leaves and stems necessary for the accumulation of sufficient reserves to eventually lead to the growth of the tree depending on its genotype and environmental conditions [7].

These meristems become inflorescential, producing flowers. The success of this sexual reproduction depends both on the sufficient accumulation of reserves and on a synchronous reproductive phase with optimal environmental conditions for flowering and fruiting [8].

The response of flowering at room temperature is variable depending on the species and genotypes. Studies carried out on different accessions of *Arabidopsis* have shown that high temperature favors flowering [9], which leads to the conclusion that flowering is dependent on warm temperatures.

The trunk and branches carry spurs (**Figure 1**) called "bouquets of May" because their development is generally completed at the end of May. The flowers appear in all cases at the base of the annual shoots of the previous year, whether it is long shoots of the trunk and branches or bouquets of May. On a cherry tree a

Figure 1.
Spurs (bouquet of May) in Ain-Draham site.

few years old, most of the flowering intended for fruit production is carried by the bouquets of May. The good development of these bouquets is very important to maintain a good quality of cherries production [10].

The flower of this genus is generally characterized by the following features: flower with five petals and five sepals, solitary carpel with a terminal style [11]. It is a hermaphrodite flower and the fruit is a drupe [12]. These drupes are most often edible and delicious but sometimes bitter or sour (cherries, sloes), more rarely toxic (fruits of the cherry laurel).

The development of flower buds is under biochemical control. This biochemical signal allows the tissue to change from the vegetative state to the reproductive state [13]. It occurs due to a balance between gibberellic acid, auxin, cytokinins, and ethylene-type hormones [14]. The floral initiation (sepals, petals, stamens, and pistil) of sweet cherry occurs after harvest [14].

3.1 Different characteristics of flowers traits in relation to the environment conditions

The morphology of fruit species provides information on the adaptation and behavior of these species with regard to their environmental conditions. Indeed, the size of the flowers is generally considered to be the most important factor for pollinators.

For each experimental site, the results of the multiple comparisons of means for the different flower traits (**Figure 2**) are presented in **Table 2** and in the study of Azizi-Gannouni et al. [15].

Azizi-Gannouni et al. [15] showed significant variability in the number of stamens for the same variety between the two different sites (Ain-Draham and Tibar). The local cultivar "Bouargoub" has a longer pistil compared to other cultivars, while V4 (Bousalem site) recorded the shortest pistil (**Table 2**). Genotypic differences that control the dependence of these floral parameters on its genetic potential are to be excluded in view of the different behaviors of the same cultivar in pedo-climatically different experimental sites [15] (**Figure 3**).

Flowers with large diameters generally attract more pollinators [16]. This directly affects the pollination of flowers and therefore their setting and their production. Morphological monitoring carried out on all the cultivars in the three sites shows that in Bousalem site the flowers of small diameter have a high fruit production (**Figure 4**), which contradicts the results of the work of Johnson et al. [17] and Wetzstein et al. [18].

DOI: http://dx.doi.org/10.5772/intechopen.93234

Figure 2.
The different studied flower traits of cultivars in Ain-Draham site.

Sites	Cultivars	DFL (mm)	Lopt (mm)	Larpt (mm)	SHPE	ARPE
Ain-Draham	Napoléon	34.60b	13.8b	12.2c	Circular	Intermediate
	Van	28.40c	11.2c	11.6c	Circular	Intermediate
	Moreau	25.80c	11.4c	10.2d	Broad obovate	Disjoints free
	Sunburst	40.40a	18.2a	11.8c	Circular	Disjoints free
	Stella	41.60a	18.8a	14.94b	Medium obovate	Disjoints free
	Bouargoub	41.66a	19.33a	17.96a	Broad obovate	Overlapping
Tibar	Napoleon	44.12a	19.56a	18.9a	Circular	Intermediate
	Van	38.2b	16.6b	15.2c	Circular	Intermediate
	Moreau	39b	17.5b	16.78b	Broad obovate	Disjoints free
	Sunburst	29.16c	12.58c	9.78d	Circular	Disjoints free
Bousalem	V1	41a	18a	17a	Circular	Intermediate
	V2	33.6b	14.8b	14.7b	Medium obovate	Disjoints free
	V3	43.96a	19.48a	15.28b	Circular	Intermediate
	V4	32.04b	15.02b	12.9c	Medium obovate	Disjoints free
	V5	43.8a	18.9a	17.26a	Broad obovate	Overlapping

Different small letters in the same column indicate significantly different values within cultivars at $\alpha \leq 0.05$.

Table 2.
*Mean of the parameters measured on sweet cherry flowers (*Prunus avium *L.) at three sites.*

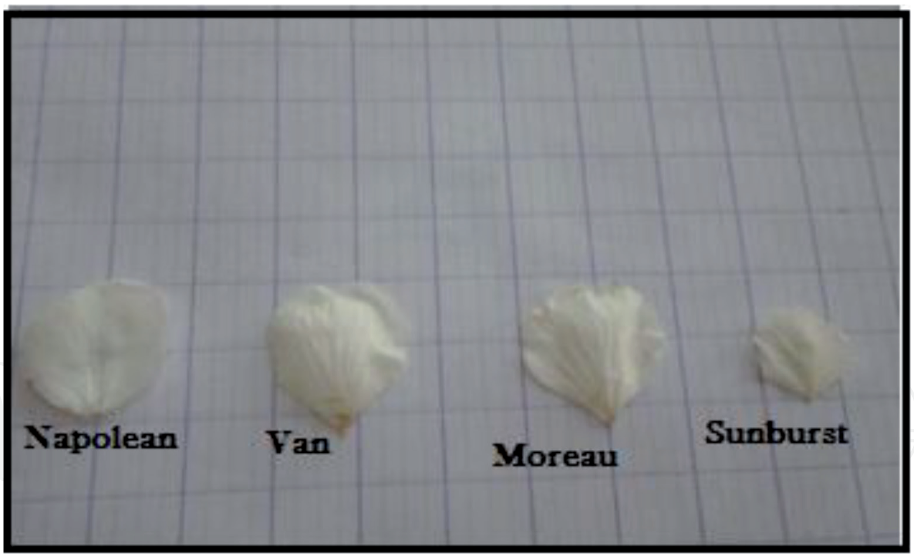

Figure 3.
*Shape of Petals of the four cultivars (*Prunus avium *L.) in Tibar site.*

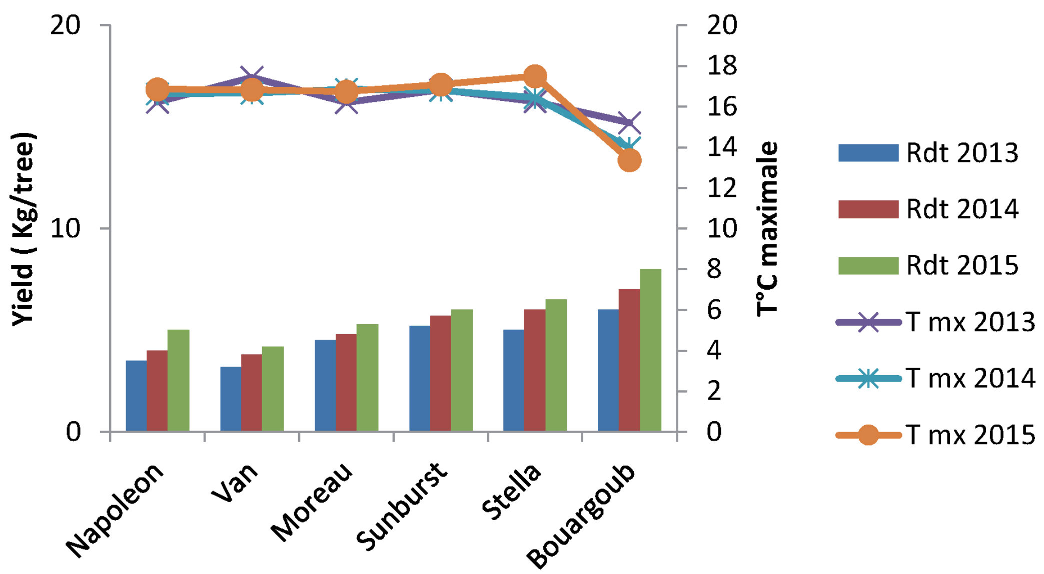

Figure 4.
Yield (Kg/tree; Rdt) and Maximum temperature during blooming at Ain-Draham site.

Furthermore, in the three study sites, the collected data show a significant effect of the site on the morphology and size of all the tested cultivars (identified and unidentified). This confirms the important effect of climatic conditions on this parameter, a result confirmed by the work of Niu et al. [19], who showed that the diameter of the flower is more influenced by daytime temperatures than by night-time temperatures and this dimension has no relation to the difference of temperatures between day and night.

Whereas, in the Ain-Draham site, it is observed that the local cultivar "Bouargoub" has the largest flower diameter compared to "Van" and "Moreau" cultivars (**Table 2**). Likewise, it has the longest style but the smallest ovary surface with an intermediate number of stamens [15].

Lu [20] has shown that cultivars grown in a warm winter climate give flowers with longer styles than these grown in a cold winter climate, which contradicts the results of the present work (**Table 2**), where the cultivar "Napoleon" shows a longer style in Ain-Draham (climate with cold winters) than in Tibar (climate with mild winters).

	DFL	Lopt	Larpt
Site	303.92***	363.73***	854***
Cultivars	102.74***	63.61***	235***
Site*cultivars	334.71***	348.13***	258***

NS, not significant.
**Significant at 0.05.*
****Significant at 0.001.*

Table 3.
Inter-site variance analysis: Values and significance of the F-test for flower traits.

Referring to the hypothesis relating the floral diameter to pollen self-compatibility, our results show the invalidity of this assumption since the self-compatible cultivars "Sunburst," "Stella," and "Bouargoub" show large floral diameters as well as self-incompatible "V1," "V3," and "V5" [5].

The shape and arrangement of the petals do not change according to the pedoclimatic conditions of the experimental site, and it can be said that these two morphological traits depend on the genetic potential of the cultivar.

3.2 The effect of the environment and genotype on the floral parameters

The variance analysis (**Table 3**) makes it possible to test for the different flower parameters, the effect of the cultivars, the effect of the sites, and the effect of the interaction "cultivar x sites." The inter-sites' analyses were done for the four commoncultivars (Napoleon, Van, Moreau, and Sunburst) at the two experimental sites of Tibar and Ain-Draham.

The effect of the interaction "cultivars x sites" was significant ($p < 0.05$ to $p < 0.001$) for the morphometric measured characteristics for the flower (**Table 3**).

The "Genotype × Environment" interactions were observed for flowers' quantitative parameters [15] (**Table 2**). This indicates that the sources of variation are both genetic and environmental. In addition, the differences in altitude and soil-climatic conditions of the two study sites may explain the observed variations. In our study, all of the cultivars cultivated at the three sites showed the inter-varietal variability in flower traits and therefore these three geographical areas should be the priority sites for in situ conservation.

4. Climatic change and chilling requirement

Global warming, the phenomenon of sustainable rise in ocean and atmospheric temperatures, is the main form of climate change. Terrestrial temperature measurements made during the twentieth century show an increase in the average temperature. This warming would have taken place during the twentieth century in two phases, the first from 1910 to 1945, and the second from 1976 to the present [21].

Human activities are therefore the dominant cause of the warming observed over the last 50 years on Earth [22]. This climate change is already having consequences on the biodiversity and ecosystems [8]. Temperature is an influencing factor on the development and growth of plants. Climate change can therefore have a major impact on their phenology. Changes in the phenological stages such as the date of leaf coloring [23] and blooming [24] have already been observed. The advance of the growing period has been linked to climate [25, 26].

Phenology is the main biological parameter of climate change and is one of the main key characteristics of the adaptability of species to these changes.

The exposure to these cold temperatures and the satisfaction of chilling requirements is necessary in several species by the resumption of growth in the spring. Predicting the break of dormancy in fruit trees is essential for producers. Knowing the date of budding makes it possible to estimate the length of the growing season and the risk of frost damage. Global warming can cause a decrease in the number of chill units for certain regions, which will have an impact on the date of bud burst [27]. A limited supply of chill units decreases fruit production [28].

4.1 Chill accumulation in the three studied sites

Sweet cherry trees develop their vegetative and fruiting buds in summer. As winter approaches, the already developed buds remain dormant to protect themselves from the cold. These buds remain dormant until they have accumulated sufficient chill units. They break up in response to high temperatures and following a sufficient accumulation of chill. If the buds do not receive a sufficient chilling requirement during the winter, the trees will develop one or more of the physiological symptoms such as heterogeneous and spreading flowering, a reduction in the quality of fruit (degree of firmness, size of the fruit) and the fruit set rate.

Table 4 shows the mean chilling accumulation registered in Ain-Draham, Bousalem, and Tibar from October 1 to March 1 during the three consecutive years (2012–2013, 2013–2014, and 2014–2015). The chill accumulation is expressed in chill units (CU) (Utah model), chill portions (CP) (Dynamic model), and hours below 7°C (Weinberger model). A noteworthy difference between chill accumulations in three experimental areas was found using any of the three described models.

Under field conditions, the coefficients of variation between October 1 and March 1 during the 3 years at Bousalem were relatively high when using the Utah and Dynamic models (CV = 13.98, 5. 42%, respectively), which indicates that the chill accumulation varies from year to year (**Table 4**). The Ain-Draham station presented CV values slightly lower than those of Tibar. Using the three models, chill accumulation is low in Bousalem, intermediate in Tibar, and significantly higher in Ain-Draham.

The three studied areas registered a different chill accumulation explained by altitude location which is in accordance with results obtained by Alburquerque et al. [29] and geographic distance between sites. Bousalem is at a lower altitude (127 m above sea level). Nevertheless, Ain-Draham is at a higher altitude (800 m above sea level). Tibar is at an intermediate altitude (328 m above sea level).

	Dynamic model			**Utah model**			**Weinberger model**		
	Mean (CP)	**CV%**	**SD**	**Mean (CU)**	**CV%**	**SD**	**Mean (H < 7°C)**	**CV%**	**SD**
Ain-Draham	80.17	2.32	1.86	1840	3.79	69.77	1044	4.36	45.61
Tibar	62.82	2.99	1.88	1014	4.21	42.71	480*	10.42	50.08
Bousalem	55.11	5.42	2.9	767.33*	13.98	107	296.33	3.6	10.96

**Significant at ≤0.05.*

Table 4.
Chill accumulation in the period November-March between 2012 and 2015 in Ain-Draham, Bousalem, and Tibar. Results are expressed in chill units (Utah model), chill portions (dynamic model), and hours below 7°C(Weinberger model).

The Bousalem site is characterized by a mild winter with less chill accumulation calculated according to the three models. The Tibar site is milder than Ain-Draham with less average chill accumulation (**Table 4**).

4.2 Chilling requirement for breaking dormancy

From the beginning of the chilling accumulation (first week of November), five branches of each cultivar (length of 40 cm, base diameter of 8–10 mm) were picked every 3–4 days from trees in the orchards and the bases were placed in a 5% sucrose solution in a growth chamber, making a fresh cut at the base of the branches [30, 31].

The branches were maintained at 25 ± 1°C under white fluorescent tubes (55 mol m^{-2} s^{-1}) with a photoperiod of 16 h and at 18 ± 1°C during a dark period of 8 h, with a constant relative humidity of 70%. The sucrose solution was refreshed and changed every 5 days. Branches were maintained for 10 days for forcing in the growth chamber. The date of breaking dormancy was established when, after 10 days in the growth chamber, 30% of the flower buds had reached the phenological growth stage 53–55 (**Figure 5**) according to the international BBCH scale [32]. The chilling requirements (CRs) coincided with the chilling accumulated until the date of dormancy release.

The chilling requirements for breaking dormancy of the sweet cherry cultivars planted in Ain-Draham, Tibar [31], and Bousalem (**Table 5**) showed different chilling requirements (CR) compared to the geographic area and climatic conditions of the year according to the three models. The Dynamic model is used to determine the chill requirements of different cultivars since it is the adequate model for Mediterranean conditions [29].

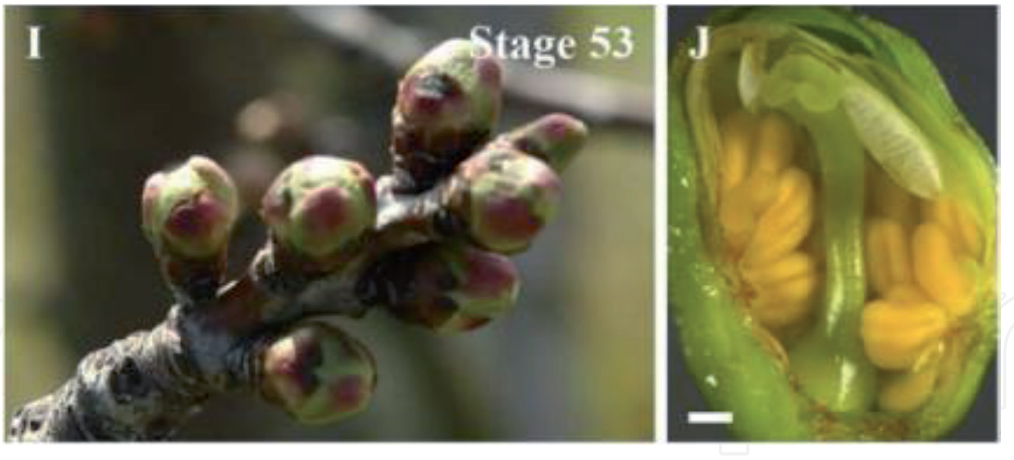

Figure 5.
Stage 53 (Bud burst) [30].

		V1	V2	V3	V4	V5
Bousalem	Mean	23.33b	50.66a	26b	53.66a	54.33a
	CV	24.74	6.02	19.98	5.69	6.46

Different small letters in the same row indicate significantly different values within cultivars at α ≤ 0.05.

Table 5.
Chilling requirements (mean; coefficient of variation, %) for breaking of dormancy expressed in chill portions (CP) for the cultivars in Bousalem site.

These results and the study of Azizi-Gannouni et al. [31] showed that the cultivars "Bouargoub," V1, and V3 registered less chill requirements than the other cultivars.

If we compare our results with those found by Alburqurque et al. [29] in Murcia (southeastern Spain), we can find some cultivars close to that cultivated in Bousalem using the Dynamic model. "V2" required the same chill requirements (48 CP) as "Ruby," "Somerst," and "Burlat." "V4" required the same CP as New Star (53.5 CP). "V1" and "V3" were almost close to Cristobalina (30 CP).

According to the three models, the cultivars "V1" and "V3" do not need a large amount of chill and are better favored in the north of Tunisia. However, "V2," "V4," and "V5" can be grown in this region provided they meet their chilling requirements (CR). Our results suggested that chilling requirements are the main factor for determining the date of flowering in sweet cherry. The date of flowering of the cherry tree in the north of Tunisia was influenced by the cold rather than by the heat and probably, by other biochemical factors of the plant.

In terms of low chilling requirement, "V1" and "V3" were the best cultivars, but they recorded the lowest yield. However, "V2" and "V4" need to accumulate a large amount of chill (CR) to register the highest fruit yield. "V5" was poorly adapted to the North Tunisian climate. It needs large chilling requirements and it has generated the lowest yield. For future improvement programs, we can choose "V1" and "V3" for their low chilling requirements, "V4" and "V2" for their high yields.

5. Determination of flowering date

Phenological monitoring of flowering was carried out on five trees per cultivar per site during the 2012–2013, 2013–2014, and 2014–2015 seasons. Flowering (**Figure 6**) was observed from mid-March to mid-April depending on the region, cultivars, and climatic conditions. The start of blooming was taken as the day on which 10% of the flowers on the tree were opened, full blooming was when 75% of the flowers were opened, and the end of blooming was when 95% of the petals fell [33]. Periodical checks (every 2–3 days) were carried out on the trees for this purpose.

The graphical representations of the different phases of flowering for the three sites during the years 2012–2013, 2013–2014, and 2014–2015 are shown in **Figures 7**–**9**, respectively.

Figure 6.
Blooming of "Bouargoub" cultivar.

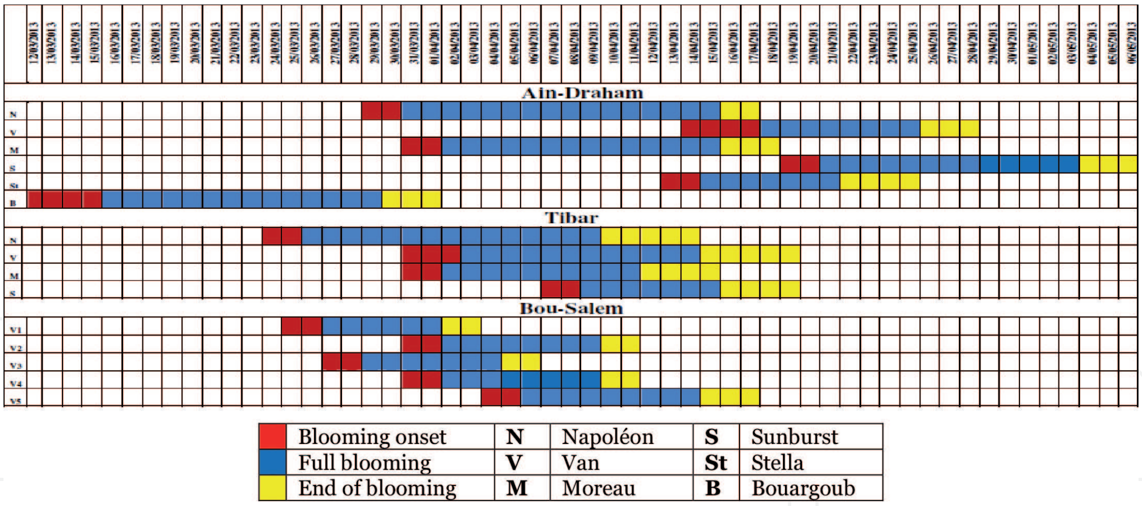

Figure 7.
Spreading of sweet cherry blooming at the three sites during 2013.

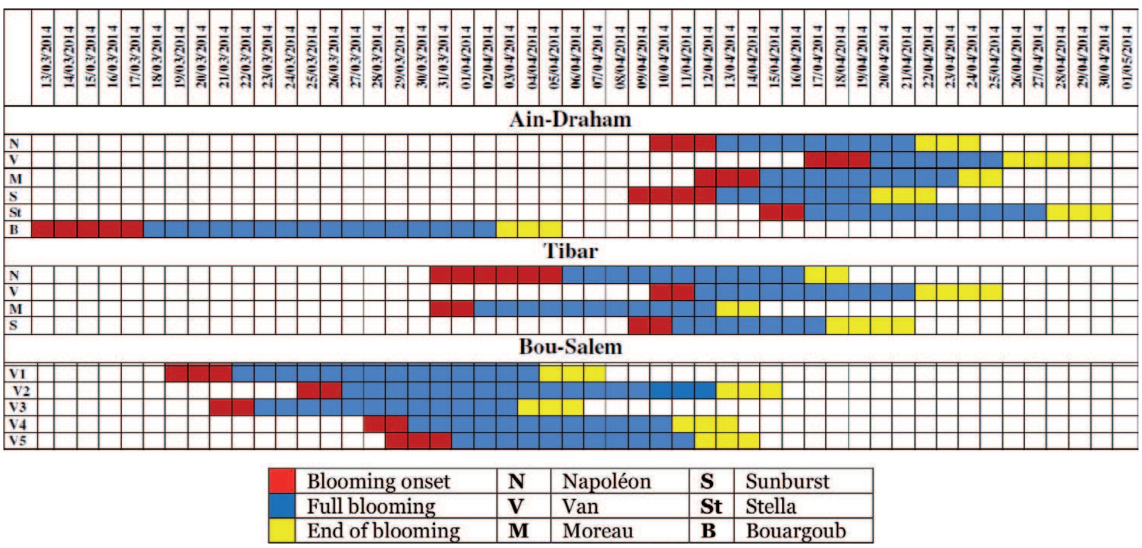

Figure 8.
Spreading of sweet cherry blooming at the three sites during 2014.

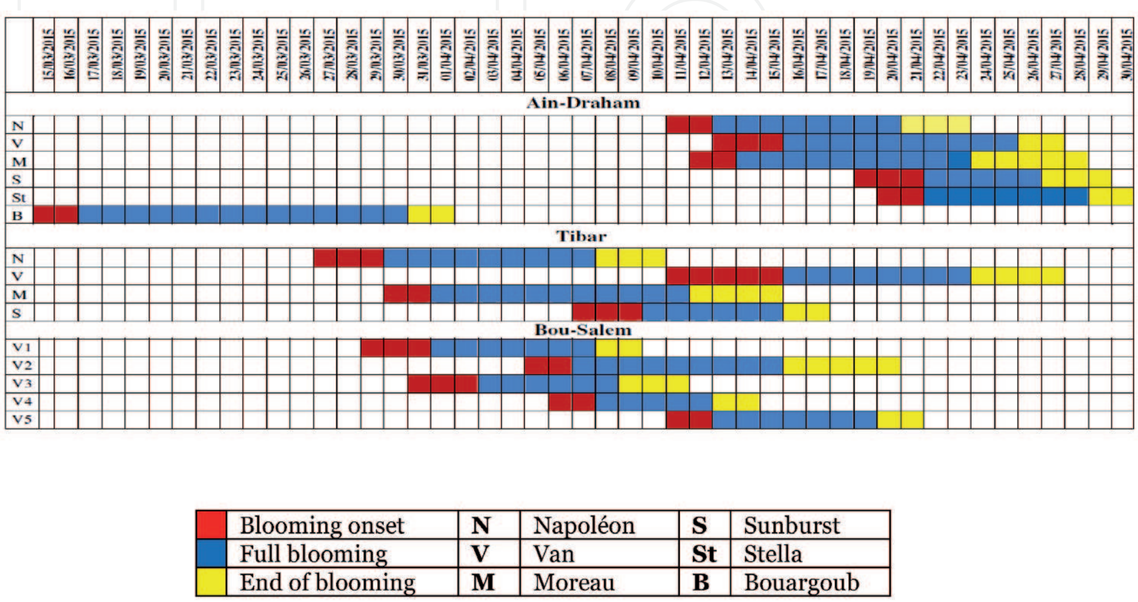

Figure 9.
Spreading of sweet cherry blooming at the three sites during 2015.

5.1 Blooming in Ain-Draham site

The date of blooming of the different cultivars in the Ain-Draham site is offset from Tibar and Bousalem. The local cultivar "Bouargoub" showed an early flowering followed by "Napoleon" during the 3 years of study. The blooming period for "Bouargoub" is more spread out than the other cultivars (18–24 days).

In 2015, the blooming period was reduced, and it was between 11 and 17 days for "Stella" and "Moreau," respectively. The blooming period of all cultivars was reduced during 2015 with the exception of "Bouargoub" which keeps the same period as 2013. "Van" has the same blooming period during 2013 and 2015, with a shortening of 2 days during 2014 (**Figures 7**–**9**).

5.2 Blooming in Tibar site

Blooming was advanced in the Tibar site compared to the Ain-Draham site for the same cultivars and during the 3 studied years. "Sunburst" was characterized by the shortest blooming period and a moderately late start to blooming, while "Napoleon" had the longest period between 15 and 22 days and an early blooming start.

With a high monthly temperature in Tibar, blooming started earlier than in Ain-Draham. Observations of the blooming periods, "Napoleon," "Van," and "Moreau," registered longer periods than that in Ain-Draham. "Sunburst" kept almost the same blooming period (13 days) in 2013 and 2014, with 11 days in 2015 (**Figures 7**–**9**).

5.3 Blooming in Bousalem site

During the 3 years of study, "V1" and "V3" were the earliest, "V2" and "V4" triggered an intermediate blooming date, while "V5" was the last. The blooming period was spread out for all cultivars during the 2015 year and was shortened for the 2 years (2013 and 2014).

The blooming period was between 10 and 14 days during 2013 for "V1" and "V5," respectively. This period was extended during 2014 and varied from 17 to 22 days for "V2" and "V5," respectively. However, during 2015, the blooming period varied from 9 ("V4") to 16 ("V2") days. Flowering began early in 2014, late in 2015, and intermediate in 2013 for all cultivars (**Figures 7**–**9**).

5.4 Comparison of blooming period in the three sites

The dates and period of blooming for the 11 studied cultivars varied between the sites, cultivars of the same site, and between the years of study. The blooming periods of the different studied cultivars were superimposed on each other, which created the conditions for possible pollination between compatible or semi-compatible cultivars. Full blooming was between 6 and 16 days for all early and late cultivars in the three study sites. The cultivars of Bousalem showed a shortened blooming period during 2013 and a spread-out blooming period during 2014, explained by the difference of temperature between the years and the low chill accumulation during 2014. The Ain-Draham site is characterized by the highest chill accumulation and late blooming during the 3 years, which is explained by the effect of climatic conditions on blooming according to Westwood [14]. At each site, the blooming periods of all cultivars overlapped with each other except for the local one "Bouargoub," which was ahead during 2014 and 2015.

For this reason, the latter is not recommended as a pollinating cultivar for the others grown in Ain-Draham. According to Nyeki [34], for the sweet cherry tree, a blooming period of 10–14 days, with at least 4–6 days of full blooming, is necessary. This author mentioned that for stone fruits, a period of 3 days of overlap in full blooming is adequate, which is the case of our study in the three sites for all cultivars except for "Bouargoub" during 2015 and 2014.

In the Ain-Draham site, full blooming can vary from 5 to 16 days. Generally, it occurs during the month of April and rarely extends to the beginning of May. In Tibar, full blooming overlaps between the third week of March and the second week of April. The four cultuvars "Napoleon," "Van," "Moreau," and "Sunburst" behave differently in the two sites which can exclude the genetic potential factor in the triggering and the duration of flowering assuming that this phenomenon depends on the physiological state, age, rootstock, expression of cultivar genes, and other external factors (photoperiod, soil, nutrient supply, rainfall, and temperature).

The difference in the date and duration of blooming among the receiving cultivars (to be pollinated) and the pollinating cultivars is the cause of a fruit set failure, which is confirmed by the works of Bekefi [35], Tosun and Koyuncu [36], Beyhan and Karakaş [37], and Moghadam et al. [38]. These authors have shown that in addition to the gameto-phytic self-incompatibility (GSI), the efficiency of pollination and fertilization in the cherry tree is also affected by the availability of pollinating insects and weather conditions in particular temperature during flowering.

6. Effect of temperature (maximum) during blooming period on fruit yield

The maximum temperature during the flowering period has a negative effect on the yield at the Ain-Draham site. The cultivar "Van" is characterized by the lowest yield (3.2 Kg/tree) during 2013 and a highest temperature during blooming (17.43°C), while "Bouargoub" produced 8 Kg/tree in 2015 and bloomed during a period characterized by a low temperature (13.37°C) (**Figure 4**).

In Tibar site, the year 2015 was characterized by a low temperature during blooming and by a better yield. The cultivars "Moreau" and "Sunburst" registered 6.5 and 7 Kg/tree and a maximum blooming temperature of 20 and 22°C, respectively. While "Napoleon" records the lowest yield and a low blooming temperature (18, 19°C) (**Figure 10**).

Bousalem site, the blooming periods of the cultivars "V2" and "V5" in 2013 and 2014 were characterized by almost the same maximum temperature. The cultivars "V3" and "V1" were also characterized by the same blooming temperature, whereas they showed a difference in yield throughout the 3 studied years. The cultivar "V4" was characterized by the highest yield during the 2 years, 2014 and 2015, while its flowering period was overlapping with that of "V2" (**Figure 11**).

The temperature at the blooming period is a determining parameter for the yield. If the blooming period coincides with a low mean maximum temperature the yield is high, whereas if the blooming coincides with a high mean maximum temperature the yield will be low, which is the case for the local cultivar "Bouargoub" in the site of Ain-Draham and the cultivar "V5" in the Bousalem site. "V5" is characterized by spreading blooming and a low yield despite the highest number of stamens. However, the other cultivars such as "V1" and "V3" bloom during a period characterized by a low mean maximum temperature (19.61–17.51°C and 19.8–18.85°C, respectively) and record low yield.

These results show that the temperature during blooming determines the fruit yield in the sweet cherry tree, but there are other factors that influence

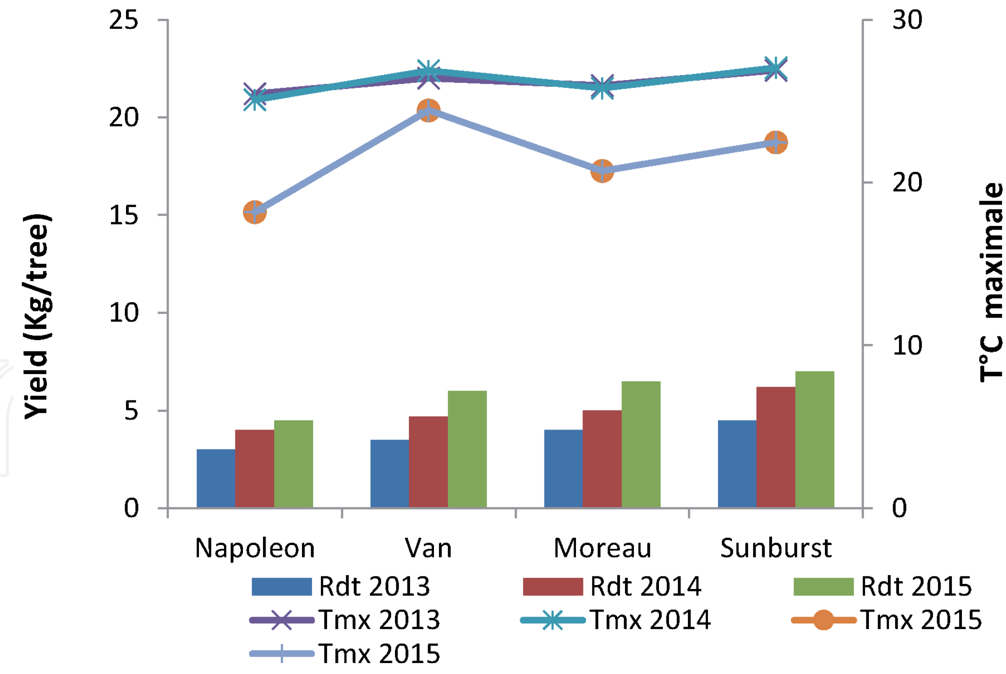

Figure 10.
Yield (Kg / tree; Rdt) and Maximum temperature during blooming at Tibar site.

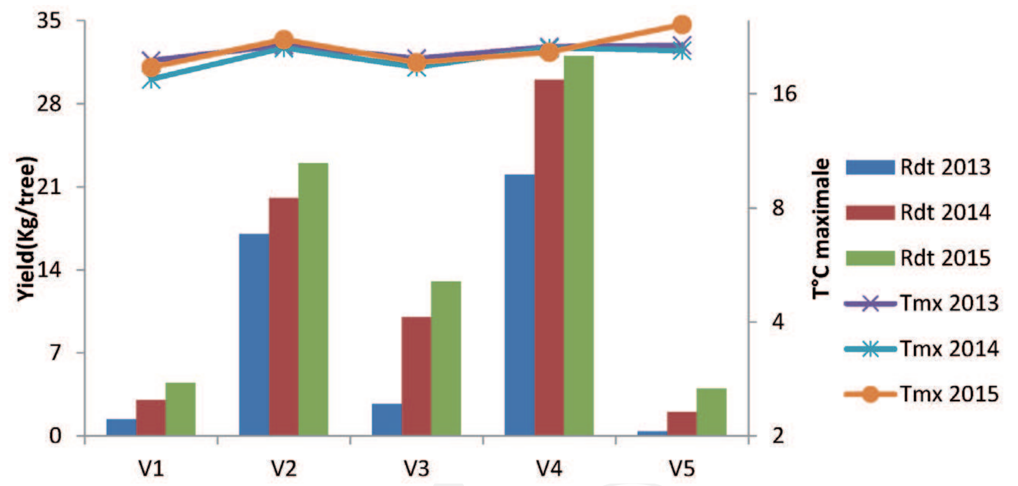

Figure 11.
Yield (Kg/tree; Rdt) and Maximum temperature during blooming at BouSalem site.

this parameter such as the genetic potential and self-fertility of the cultivar. The difference in yield between cultivars and sites can be explained by several factors including the behavior of the flower pieces depending on environmental conditions. The duration of the stigma's viability is influenced by weather factors. Regarding sour cherries, Nyeki [34] observed that the viability of the stigma was 2–3 days during sunny and hot days (mean daily temperature is 15–22°C). The viability was longer (4–6 days) in cool weather and daily temperatures of 4–12°C.

Low temperatures and rainy weather reduce the receptivity of the stigma. This was reported by Davarynejad [39] for apples and, in 1996, for pear trees. Although temperature is the main driver of phenological development, other ecogeographic factors can influence the date of flowering.

Thus, the cold temperature during blooming reduces the rate of growth of the pollen tube and can shorten the effective pollination period [40]. Caprio and Quamme [41] have shown a negative effect of high temperatures before blooming (above 27°C) on the longevity of the ovum and on the efficiency of pollination. In addition, rain and low temperatures negatively affect the activity of pollinating bees and, consequently, the setting rate [42].

7. Conclusion

Sweet cherry is sensitive to temperature profiles during the blooming period. The low productivity is largely due to the nonoverlap of flowering periods and pollen incompatibility among different cultivars in the same experimental site. Our study is based on a mixture of introduced and local cultivars with different characteristics to diversify Tunisian orchards. While, the introduction of foreigner sweet cherry cultivars in areas with mild winters leads to increased yields.

Acknowledgements

This work has been supported by the National Research Institute of Rural Engineering Water and Forests (INRGREF), Tunisia. The authors are grateful to the engineers and technicians who contributed to this work.

Conflict of interest

The authors declare no conflict of interest.

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