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Dormancy related traits and adaptation of sweet cherry in Northern Africa: A case of study in two Tunisian areas

Thouraya Azizi Gannouni[a,b,*], José Antonio Campoy[c], José Quero-García[c], Teresa Barreneche[c], Abderrazak Arif[d], Ali Albouchi[b], Youssef Ammari[b]

[a] Faculty of Mathematical, Physical and Natural Sciences of Tunis, Campus Universitaire 2092, El manar, Tunis, Tunisia
[b] National Researches Institute of Rural Engineering, Water and Forests, R. Hedi Karray, Ctre Urbain Nord, BP 10 1082, Tunis (INRGREF), Tunisia
[c] INRA Bordeaux UMR1332 Biologie du Fruit et Pathologie (BFP), 71, Avenue Edouard Bourlaux, CS 2003233882 Villenave d'Ornon Cedex, France
[d] National Institute of Meteorology B.P. 156, 2035 Tunis-Carthage, Tunis, Tunisia

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ABSTRACT

Chilling requirements of temperate fruit species may vary substantially depending on the climatic conditions where they grow. In addition, in a climate change context, a precise knowledge of these requirements and their effect on productivity is critical for choosing the best suited cultivars to assure long-term adaptation under low-chill environments. To date most studies circumvented the analysis of productivity when assessing chilling requirements in different climatic conditions. Thus, the chilling and heat requirements of different sweet cherry cultivars (*Prunus avium* L.) for breaking dormancy, flowering and fruit set were investigated in two contrasted growing areas in Tunisia: Ain-Drahem (800 m above sea level) and Tibar (328 m above sea level). Additionally, we evaluated several parameters to assess the productivity under these two different conditions. Low chill cultivars showed a higher fruit set in both locations suggesting a better adaption to warm-winter conditions. This three-year study establishes the basis of sweet cherry adaptation under two contrasted locations in Northern Africa.

1. Introduction

Global warming can severely affect the production of fruit trees through the incomplete fulfillment of their chilling requirements (Campoy et al., 2011). Sweet cherry is greatly restricted by climatic conditions especially related to chilling accumulation. Under low latitude conditions such as Tunisia, sweet cherry production is limited to high altitude areas (e.g. North West of Tunisia) where chill accumulation is much higher than at low altitude areas. According to Luedeling et al. (2011), Tunisia is among the countries with the highest predicted losses by the end of the 21st century relative to current winter chill levels. Subsequently, in this region, climate change is likely to severely challenge current production systems, some of which already rely on treatments such as rest-breaking chemicals and artificial defoliation. Many fruit crops require chilling accumulation in winter to break dormancy and each variety needs specific cold requirements. Therefore, significant differences between cultivars have been reported (Erez and Fishman, 1998; Egea et al., 2003; Guerriero et al., 2006; Viti et al., 2006; Ruiz et al., 2007). 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 bud break and heterogeneous flowering. Chilling increased flower size, pedicel length and fruit set (Mahmood et al., 2000). Some researchers have examined the influence of climatic conditions on flowering and on the fruit set. In fact, the reproductive phase is one of the plant developmental stages most sensitive to heat stress (Hall, 1992) and both high and low temperatures at blooming time are known to have a detrimental effect on the subsequent fruit set (Hedhly et al., 2007). Insufficient chilling can lead to uneven leafing and bloom, and can cause varying fruit sizes and maturity times, both of which can reduce the quantity and quality of fruits (Luedeling et al., 2009).

Thus, the precise evaluation of flower bud chilling and heat requirements, as well as the productivity under different conditions is of crucial importance since it could allow assessing cultivars' adaptability.

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* Corresponding author at: Faculty of Mathematical, Physical and Natural Sciences of Tunis, Campus Universitaire 2092, El manar, Tunis, Tunisia.
E-mail addresses: najeh.esak@gmail.com, Thouraya_azizi@yahoo.com (T. Azizi Gannouni), jacc30180@gmail.com (J.A. Campoy), jose.quero-garcia@inra.fr (J. Quero-García), teresa.barreneche@inra.fr (T. Barreneche), abderrazak.001@gmail.com (A. Arif), albouchiali@yahoo.fr (A. Albouchi), Ammari_youssef@yahoo.fr (Y. Ammari).

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A low number of sweet cherry varieties are currently adapted to the Tunisian climate, which explains the deficiency in production, restrained to a limited growing area (1100 ha; UPV, 2012). There is a clear need of selecting adapted low chilling requirements varieties in order to establish new sweet cherry orchards.

The aim of this work was to assess the adaptation of sweet cherry cultivars regarding the fulfillment of chilling requirements grown under different altitude and climatic conditions in Northern Africa. We used three different models for the estimation of the chill requirements of different cultivars, because chill models react differently under different climatic conditions. The two orchards evaluated, Tibar and Ain-Drahem, are characterized by two different climatic conditions due to their altitude and geographical location. We evaluated the appropriate model (s) adapted to Tunisian climate.

2. Material and methods

2.1. Plant material

The cultivars studied were 'Napoleon' (Germany), 'Van' (Canada), 'Moreau' (France), 'Sunburst' (Canada), 'Stella' (Canada), and the local cultivar 'Bouargoub' (Tunisia). The latter was planted only in one site (Ain-Drahem). Trees in both locations were drip irrigated and received similar orchard management; they were eight years old at the beginning of the study.

2.2. Experimental design

This study was carried out during three consecutive seasons, 2012–2013, 2013–2014 and 2014–2015, in two different ecological conditions in Northern Tunisia, Ain-Drahem (Longitude 8.70; Latitude 36.78; Altitude 800 m above sea level) and Tibar (Longitude 9.10; Latitude 36.15; Altitude 328 m above sea level). Hourly temperatures were collected from National Meteorological Institute (INM, Tunisia).

2.2.1. Determination of chilling requirements (CRs)

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. The branches were maintained at 25 ± 1 °C under white fluorescent tubes (55 μmol 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 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 55 (single flower buds visible) according to the international BBCH scale (Meier et al., 1994). The chilling requirements (CRs) coincided with the chilling accumulated until the date of dormancy release. Three models were used to determine the chilling requirements: chill units (CU) for the Utah model (Richardson et al., 1974), chill portions (CP) for the Dynamic model (Fishman et al., 1987) and hours below 7.2 °C (CH) for the Weinberger model (Bennett, 1949; Weinberger, 1950). For the Utah Model, the start date for chilling accumulation corresponded to the minimum value of achieved chill accumulation.

2.2.2. Determination of heat requirements (HRs)

Heat requirements (HRs) were calculated as growing degree hours (GDH), following the model proposed by Anderson et al. (1986). For each cultivar, heat requirements were calculated as the number of GDH accumulated between the end of dormancy and the flowering date, when 50% of flowers were open (F50) in the orchard. The length of this period was expressed as the increment of Julian Days (ΔJD).

Eq. (1) determines GDH accumulation at temperature between the base and optimum temperatures.

$$\mathrm{GDH} = \mathrm{FA}/2(1 + \mathrm{COS}(\Pi + \Pi(\mathrm{TH\text{-}TB})/(\mathrm{TU\text{-}TB}))) \quad (1)$$

Eq. (2) was developed to describe effective GDH accumulation at temperatures above the optimum.

$$\mathrm{GDH} = \mathrm{FA}(1 + \mathrm{COS}(\Pi/2 + \Pi/2(\mathrm{TH\text{-}TU})/(\mathrm{TC\text{-}TU}))) \quad (2)$$

Where GDH = the accumulation of growing degree hours during an hour when:

TH = the hourly temperature
TB = the base temperature (4 °C for fruit trees)
TU = the optimum temperature (25 °C for fruit trees)
TC = the critical temperature (36 °C for fruit trees)
A = TU-TB (the amplitude of growth curve)

F = stress factor which can be used to represent various forms of plant stress (low humidity, soil moisture deficit, disease, competition, insect damage, nutrient deficiency, or a combination of these). It is assumed to be 1.0 unless tree is under stress. If the values of TH were less than TU, Eq. (1) was used in the accumulation of GDH; if the values of TH were greater than TU, Eq. (2) was used.

2.2.3. Determination of flowering date, fertility index, blooming percentage and fruit set

Under field conditions, flowering date was recorded when 50% of flowers were open (F50). Periodical checks (every 2–3 days) were carried out on the trees for this purpose. To assess productivity losses related to incomplete break of dormancy, we evaluated three parameters: The fertility index (flower buds/cm), the blooming percentage (flowers*100/flower buds) and the fruit set (fruits/flowers at 40 days after full blooming) as described in Campoy et al. (2010). Observations were carried out on 10 one-year-old fruiting branches (about 500 flower buds).

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. Results

3.1. Temperature and chilling accumulation

The maximum and minimum daily temperatures during the period October to March from 2012 to 2015 in Ain-Drahem and Tibar are shown in Fig. S_1.

In Ain-Drahem and Tibar, the 2012–2013 and 2014–2015 periods were characterized by warm winters, especially November-December, while the winter of 2013–2014 was the coldest.

During the three years, Tibar was characterized by warmer and later winters than Ain-Drahem, due to the altitude of the latter (Fig. S_1).

The chilling accumulation registered in Ain-Drahem and Tibar from October 1 to March1 during the three consecutive years (2012–2013, 2013–2014 and 2014–2015) is shown in Fig. 1. The chill accumulation is expressed in CU (Utah model), CP (Dynamic model) and hours below 7 °C (Weinberger model).

A noteworthy difference between chill accumulations in both experimental areas was found using any of the three described models.

In Tibar, chilling accumulation differed from year to year when using Weinberger model. However, lower variation between years was observed when using Dynamic and Utah models. The Ain-Drahem chilling accumulation showed slightly lower differences between three years than those of Tibar (Fig. 1).