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Chilling trends in a warm production area and their impact on flowering and fruiting of peach trees

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ABSTRACT

Biological effects of contrasting chill accumulation on scion-rootstock combinations of peach were investigated using field observations during 2006–2010. Early and mid-season ripening peach cultivars (Early May Crest and Royal Glory, respectively) grafted on GF677 and Cadaman rootstocks were monitored over a five year period in the region of Mornag in northern Tunisia (36°41′N, 10°15′E). Flowering date, flowering duration and double fruits rate were observed over the entire experimental period. The phenological behavior, expressed as fruit set and flower buds abscission, was also surveyed. At harvest, yield, fruit size and number of commercial fruits were determined. Trends of chilling accumulation were characterized over twenty years using two chilling hours models (0–7.2 °C model, CH and Crossa-Raynaud model, CH_{CR}), Utah and Dynamic models. Correlations among chilling models showed that the Dynamic model is more appropriate to estimate chilling accumulation in our warm production area. Climatic conditions during the five experimental years were variable, with chill accumulation in the range 127–421 CH, 82–294 CH_{CR}, 298–860 chill units (CU) and 19–50 chilling portions (CP). Exceptionally warm conditions were observed in winter 2006–2007 and 2009–2010 with significant drop of chill accumulation to levels less than 50% of average chill accumulation. Flowering and fruiting of both early and mid-season maturing commercial cultivars were affected by chill accumulation variability. Warmer winter delayed flowering, extended flowering duration, increased bud abscission and affected fruit set. A chill accumulation less than threshold values of 25 CP, 200 CH, 100 CH_{CR}, and 350 CU resulted in substantial decrease of yield and fruit quality. Cultivar responses to chilling conditions in term of flowering date and yield seemed to be rootstocks dependant. Adoption of appropriate scion-rootstock combination and cultural practices based on chill accumulation could be used in peach industry as means to adapt to increasing frequency of warm winters.

1. Introduction

Productivity and sustainability of fruit orchards depends on the climatic requirements such as the temperature regime. In a mild winter climate, flowering and cropping of fruit trees highly depends on winter chill (Campoy et al., 2011; Viti et al., 2010). Winter chilling accumulation is one of the major production factors. Trees require winter chill to break dormancy and initiate fruiting. Significant differences in chilling requirements between species and between cultivars within a given species have been reported (Erez and Fishman, 1998). Vegetative growth and fruiting of temperate fruit species are highly dependent on chilling. The lack of chilling results in abnormal patterns of bud break and development in fruit trees (Erez and Couvillon, 1987; Legave et al., 1982; Viti et al., 2010).

Mediterranean climate is suitable for peach growing. This species is considered among the most important fruit trees in the Mediterranean area which represents the main production zone. In Tunisia, it is considered as a strategic crop and showed during the last decade an important increase of cultivated area, production and length of maturity season (April–September) (Ghrab et al., 2014). However, significant weather variations were observed in the main production areas during the last decade, with more warm winters (Ben Mimoun, 2008; Ghrab et al., 2014). Moreover, the Inter-governmental Panel for Climate Change (IPCC) has

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provided evidence of accelerated global warming and climate change (IPCC, 2007). Chilling accumulation has already showed substantial reduction in the recent years in different subtropical areas (Luedeling et al., 2009a,b, 2011). This reduction will be especially adverse in the coming decades in warm Mediterranean climate areas (Luedeling et al., 2011). Recent climate conditions across production areas of Tunisia may have impacted chill accumulation, while analysis of chilling trend has not yet been conducted.

Orchards must remain productive over several decades to be economically viable. It is thus crucial for the sustainability of an orchard operation to accurately estimate the effect of changing climatic conditions on the biology of the cropping systems mainly in order to assess sustainability of orchards. Dormancy period is particularly important since insufficient chilling can severely compromise fruit yields and productivity. In many regions where winter chilling is marginal, the growth of deciduous fruit trees is achieved through the use dormancy breaking chemicals agents such as hydrogen cyanamide (Campoy et al., 2010; Elloumi et al., 2013; Ghrab and Ben Mimoun, 2013; Jackson and Bepete, 1995; Mohamed, 2008; Theron et al., 2011). A number of chill models were developed in order to quantify winter chilling, identify potential temperate fruit growing areas and the impact of warming on chill accumulation (Crossa-Raynaud, 1955; Erez et al., 1990; Fishman et al., 1987a,b; Richardson et al., 1974; Weinberger, 1950). Phenological observations were used to determine chill requirement and evaluate model suitability (Legave et al., 2008; Luedeling, 2012; Luedeling et al., 2009c, 2013a,b; Rea and Eccel, 2006). It was reported that chill models do not perform similarly under different climate conditions and consequently trends in chill were shown to differ between models (Darbyshire et al., 2011; Luedeling and Brown, 2011). The need for multi-model analysis for chill trends especially in a climate change context was highlighted.

Expanding peach adaptability to different growth conditions needs accurate evaluation of scions and rootstocks and identification of their best combinations (Albas et al., 2004; DeJong et al., 2004; Giorgi et al., 2005). The biological, physiological and biochemistry responses of plants showed that drought resistant rootstocks could transmit resistance to the scion (Qi et al., 2007). The use of new rootstocks that are more resistant to abiotic and biotic stresses in addition of their capability to ensure adequate growth represents an important step to increase productivity and efficiency of peach orchards (Jiménez et al., 2011). Moreover, breeding programs resulted in a large extended ripening season for peach cultivars.

In Tunisia, climatic conditions of the peach producing areas are highly variable. They are characterized by frequent warm winters with large temperature fluctuations, typical of Mediterranean region. The current study focused on the behavior of peach cultivars in the main horticultural area in northern Tunisia characterized by high annual variations of temperature. Fruit trees are formed by a combination of the rootstock that provides the root system and the scion that produce the commercial crop. We considered the use of scion-rootstock combination as mean to reduce the effect of warm conditions on peach behavior. Investigation concerns chilling trends using several models and evaluation of chilling impact on flowering and fruiting of two commercial peach cultivars grafted on two rootstocks.

2. Materials and methods

2.1. Experimental design

A field experiment was carried out at the experimental station of Institut National Agronomique de Tunisie (INAT) in the region of Mornag (36°41′N, 10°15′E) northern Tunisia. This region is characterized by Mediterranean climate with average annual rainfall and ETo of 450 and 1240 mm, respectively. Precipitation is characterized by a rainy fall-winter season with low evaporative demand and a prolonged dry-high evaporative demand season. Averages of minimum and maximum winter temperatures are 6 and 17 °C, respectively. Four-year-old peach trees of Early May Crest and Royal Glory as, respectively, early and mid-season ripening cultivars were considered. Trees grafted on GF677 (*Prunus persica* × *Prunus dulcis*) and Cadaman (*P. persica* × *Prunus davidiana carr. Franch.*) were monitored during five growing seasons (2006–2010). Trees were planted on a loamy-clay soil at 4 × 6 m spacing, drip irrigated and trained according to open vase model. The experimental trial consisted of 15 trees of similar size per combination (scion-rootstock) with contiguous three rows of five trees. The agronomic survey was carried out on the five trees of the central row of each combination.

2.2. Climatic data and chilling trends accumulation

Daily weather data collected from meteorological station located in the field were used to characterize climatic conditions. Field chilling trends were analyzed over a long monitoring period (1990–2010). Temperature data were considered annually between October 1st and February 28th and the date of chilling initiation (DCI) was considered when positive chilling accumulation was recorded. Chilling accumulation was determined using chill hours of the 0–7.2 °C model (CH) (Bennett, 1949) and Crossa-Raynaud method (CH_{CR}) (Crossa-Raynaud, 1955), chill units (CU) of the Utah model (Richardson et al., 1974), and chilling portions (CP) of the Dynamic model (Fishman et al., 1987a,b). The 0–7.2 °C model, Utah and Dynamic models require hourly temperature, which was derived in our case from daily maximum (T_{max}) and minimum (T_{min}) data. Accordingly, an hourly interpolation function applied to daily maximum-minimum data was used (Darbyshire et al., 2011). A sine function (Eq. (1)) was used to estimate daytime temperatures with the maximum temperature supposed to occur two hours after solar noon. A logarithmic function (Eq. (2)) was used to represent night-time cooling with the daily minimum temperature set to occur at sunrise.

$$T_{t_D} = T_{\min} + (T_{\max} - T_{\min}) \times \sin\left[\frac{(\pi \times t_D)}{(DL + 4)}\right] \quad (1)$$

where T_{t_D} is the daytime temperature (°C) at t_D hours after sunrise, $T_{\min}$ is the minimum temperature (°C), $T_{\max}$ is the maximum temperature (°C) and DL is the day length in hours calculated using Julian day and latitude (Allen et al., 1998).

If t_D is set to day length (DL) the sunset temperature T_s (°C) can be determined and used in the night-time temperature function:

$$T_{tN} = T_S - In(t_N) \times \left[\frac{(T_S - T_{\min})}{In(24 - DL)}\right] \quad (2)$$

with T_{tN} the night-time temperature (°C) at $t_N > 1$ h after sunset.

The chilling hours less than 7.2 °C per day (N) were calculated by Crossa-Raynaud model as: $N = [(7.2 - m)/(M - m)] \times 24$, for $m < 7.2$ °C and $N = 0$, for $m \geq 7.2$; where M and m are, respectively, maximal and minimal temperature (°C) (Crossa-Raynaud, 1955).

2.3. The magnitude of flowering

Six shoots per tree and five trees per scion-rootstock combination of peach were chosen after pruning to analyze the phenological behavior. Full bloom, flowering period and double fruits rate were determined for the different scion-rootstock combinations of peach over five-year monitoring period (2006–2010). Flowering date is considered as the date when 50% of flowers are open indicating