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Climate change and viability of fruit tree orchards in arid area

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Abstract

The Mediterranean region is facing temperature increases due to climate change. More warm conditions across the fruit and nut growing regions are expected to have a great and negative impact in Tunisian arid regions. Chilling trends among the agricultural production areas and their incidence on flowering and fruiting of typical fruit species were investigated. The results showed important declines in winter chill accumulation over the main arid production areas. This lack of chill jeopardizing the flowering and fruiting of fruit species. However, fruit species and cultivars within each fruit species expressed different flowering and fruiting behaviors to warm climate depending on their chilling and heat requirements. Consequently, thermal requirements are a key factor for sustainable fruit trees' orchards and to select suitable cultivation area. Adoption of appropriate genetic resources could be used to mitigate the harmful effect of global warming in arid regions.

1. INTRODUCTION

In North African countries, the agricultural sector is particularly vulnerable to climatic changes (Benmoussa et al., 2020). Projected climate change expected rising temperatures and decreasing precipitation (Schilling et al., 2012), which imposes high risks for farmer's subsistence.

In arid areas, successful fruit and nut trees production is closely related to climatic conditions. Darbyshire et al. (2013) reported that climate is a key factor for the prosperous production of trade fruit and nut products. Climate control important phases during the annual cycle as winter dormancy. In fact, to overcome dormancy, fruit and nut trees require cold temperature and then heat to achieve homogeneous flowering and regular crop yields (Ruiz et al., 2007). These climatic needs known as chilling and heat requirements are specific to each cultivar within fruit species. To ensure sustainable and profitable fruit tree orchards, an appropriate choice of cultivar and cultivation area must be done based on chill accumulation in this region as well as the chilling requirement of cultivars (Gao et al., 2012).

Increasing temperatures initiated by global warming results in warmer winters and lack of chill became frequent in the Mediterranean region (Benmoussa et al., 2020; Ghrab et al., 2016). Uncovered fruit trees chilling requirements induced sporadic and incomplete or low bud break, delayed bloom and extended flowering period, poor fruit quality and yield (Atkinson et al., 2013; Ghrab et al., 2014). Particularly since the exceptionally warm winter of 2007, many fruit trees in Tunisia's orchards showed abnormal physiological behavior, irregular fruit development and low yields of poor quality (Elloumi et al., 2013; Ghrab et al., 2014).

In Tunisia, fruit and nut trees spread over two million hectares, most of them need to fulfill their chilling requirements such as almond, pistachio, peach, apricot, apple and pear. For the sustainability of fruit trees' orchards, an accurate evaluation of climate change impacts on flowering and fruiting is needed. In this context, the historical chilling trends were investigated in three main fruit production areas. Then the impact of these trends on the flowering and fruiting of typical fruit species and cultivars within each fruit species was considered.

2. MATERIAL AND METHODS

2.1. Winter Chilling Trends

Three reference production zones were considered from the north to the south of Tunisia to characterize the temperature variation over a long monitoring period. The region of Mornag (Northern Tunisia), Sfax (Central Tunisia) and Zarzis (Southern Tunisia) were selected for evaluating winter chilling trends.

Chill accumulation was computed using the Dynamic Model (Chill Portions, CP) (Fishman et al., 1987a, 1987b). Daily minimum and maximum temperature records were considered annually between October 1st and February 28th from 1974 to 2016. Since the Dynamic Model as chill model requires daily hourly temperatures to compute daily chill accumulations, this is possible by the interpolation functions (Almorox et al., 2005; Darbyshire et al., 2011; Linvill, 1990; Spencer, 1971).

2.2. Experimental site and plant material

Three typical fruit species as peach, almond and pistachio were selected to carry out this study (Table 1). A drip-irrigated peach orchard was investigated in Mornag, northern Tunisia with two cultivars Early May Crest and Royal Glory as an early and a mid-season cultivar. The target region is characterized by a Mediterranean climate. In Sfax region (Central Tunisia), two rain-fed orchards of almond and pistachio were surveyed. Two almond cultivars Fakhfekh and Tuono as local and Italian cultivars grafted on Fasciuneddu seedling were surveyed. While for pistachio, the main local cultivar Mateur and the Iranian Ohadi cultivar grafted on *P. vera* were selected.

Table 1. Fruit species and cultivars within each fruit species, and characteristics of production areas

Region	Climate	Species	Cultivar
Northern Tunisia	P. 450mm ETo. 1240 mm	Peach	Early M. Crest Royal Glory
Central Tunisia	P. 200mm ETo. 1390 mm	Almond	Fakhfakh Tuono
		Pistachio	Mateur Ohadi

P. precipitation; ETo. reference evapotranspiration

2.3. Agronomic Survey

For all fruit species and cultivars, bloom dates were registered. The beginning and the end of bloom were noted when 5% and 90% of opened flowers were achieved. The bloom period was consequently estimated.

After the fruit set, double fruits rates were determined on selected fruiting shoots for peach and almond cultivars. At harvest, fruits and nuts yields were recorded and the proportion of commercial fruits (diameter>61mm) for peach were determined.

2.4. Statistical Analysis

Collected data were subjected to analysis using a one-way analysis of variance with the SPSS statistical package, using the Duncan test for means comparison ($P < 0.05$).

3. RESULTS AND DISCUSSION

3.1. Chilling trends

Based on long-term weather data, a substantial decline of winter chill accumulation was observed over the production areas from the north to the south (Fig. 1). Similar trends were obtained for the north and the south with a significant decrease throughout 1974-2016, compared to the central region.

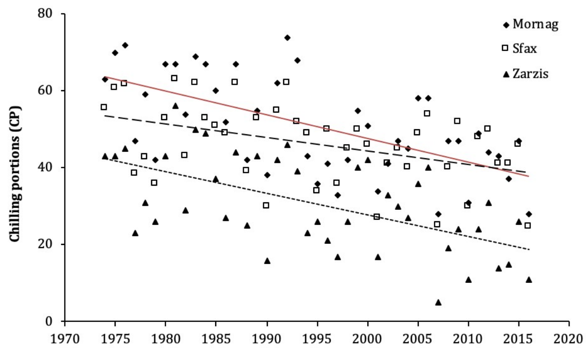

Fig. 1. Declining of winter chill accumulation as Chill Portions over three production areas: —— Mornag, ---- Sfax and ······ Zarzis located northern, central and southern Tunisia, respectively.

This trend is expected to continue based on climate change scenarios, which forecast major warm winters with increasing temperatures in the Mediterranean areas (Benmoussa et al., 2020). Similar tendencies were observed in many parts of the globe, which confirm that a decline in winter chill became evidence (Baldocchi and Wong, 2008; Luedeling et al., 2011). Moreover, our analysis revealed high annual variation in chill accumulation, with more frequent warm winters each 3-4 years as 2001, 2007, 2010, 2016 and 2020 as previously suggested (Ghrab et al., 2016).

3.2. Winter chill vs. Flowering

For peach, almond and pistachio, bloom dates were highly affected by winter chill accumulation. Significant correlations between flowering date and chill accumulation were obtained for the three species as presented for pistachio in Fig. 2 as an example.
For all cultivars, a delayed bloom and extended flowering period occurred subsequent warm winter (Table 2). In a normal year, the flowering period was in the range of 15-16 days, 10-12 days and 15-20 days for peach, almond and pistachio cultivars, respectively. A delayed-bloom occurred subsequent warm winter by 8-10 days for peach cultivars, 7-10 days for almond and 16-18 days for pistachio. Moreover, the flowering period was extended by about 5 days for peach and almond cultivars and by 10 days for pistachio cultivars. These features are closely related to chill accumulation in stone fruit species (Alonso et al., 2005; Egea et al., 2003). Previous reports noted that lack of chill affected flowering dates and a significant negative correlation was obtained between flowering dates and chilling accumulations (Elloumi et al., 2013; Legave et al., 2013; Viti et al., 2010).

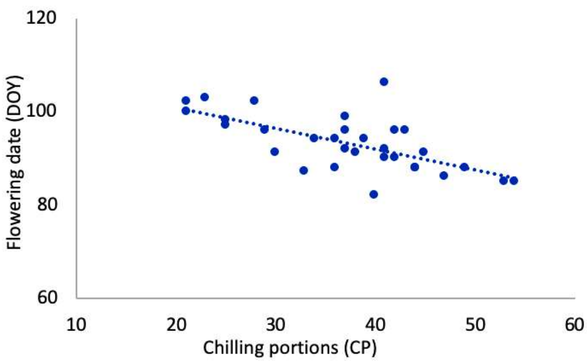

Fig. 2. Relationship between flowering date (day of the year, DOY) of pistachio and chill accumulation as chilling portions.

Warm winter induced a significant increase of flower bud fall depending on fruit species and cultivar (Table 3). High bud fall rates ranged between 9 and 23% were obtained for Early May Crest (EMC) compared to 7% for Royal Glory (RG). Local almond and pistachio cultivars seem to be less affected by warm winter. Bud fall rate increased from 3 to 7% for Fakhfekh, while it passed from 12 to 16% for Tuono. Pistachio cultivars presented high bud fall of 38% and 57% in a warm year for Mateur and Ohadi, respectively.

Table 2. Flowering period in normal (FP_{NY}) and warm year (FP_{WY}) and bloom delay in warm year (BD_{WY}) in days

	FP_{NY}	FP_{WY}	BD_{WY}
Peach			
EMC	15	20	8
RG	16	21	10
Almond			
Fakhfakh	10 a	15 b	7
Tuono	12 a	16 b	10
Pistachio			
Mateur	15 a	24 b	16
Ohadi	20 a	30 b	18

Different letters (a,b) indicate significant differences within a line by Duncan's test (*p<0,05*).

3.3. Winter chill vs. Fruiting

The two peach cultivars presented different behavior subsequent warm winter (Table 3). The early cultivar Early May Crest (EMC) presented high rates of double fruits, whereas it didn't exceed 3% for the mid-season cultivar Royal Glory (RG). Early May Crest cultivar seems to be sensitive to chill accumulation, its double fruits rates averages were about 31% during a warm year and 11% during a normal year.

Table 3. Bud fall in normal (BF_{NY}) and warm year (BF_{WY}) and double fruits rate in normal (DF_{NY})and warm year (DF_{WY}) recorded for almond and pistachio cultivars

	BF_{NY}	BF_{WY}	DF_{WY}	DF_{NY}
Peach				
EMC	9.2b	23.4a	11.4b	30.8a
RG	7.4a	6.9a	1.7a	2.1a
Almond				
Fakhfakh	3.0 b	7.2 a	0.3b	5.1a
Tuono	12.4 b	16.6 a	5.3b	14.7a
Pistachio				
Mateur	12 a	38 b	-	
Ohadi	17 a	57 b	-	

Different letters (a,b) indicate significant differences within a line by Duncan's test (*p<0,05*).

Double fruits and commercial fruits rates were significantly affected by chill accumulation (Fig. 3). The early peach cultivar EMC presented significant degradation of yield quality with increasing double fruits rate and decreased commercial fruits rate during years with lack of winter chill as observed in 2007 and 2010. With chill accumulation less than 35CP, a high percentage of double fruits and uncommercial fruits were produced at harvest.

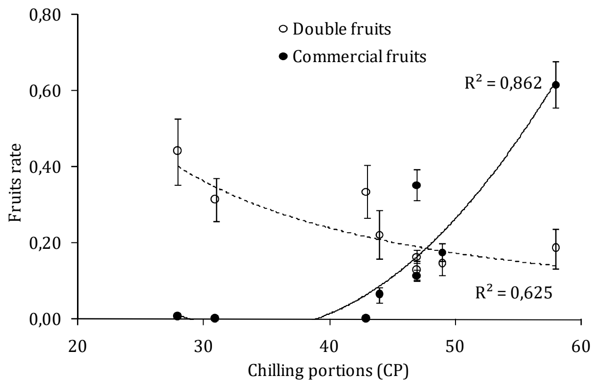

Fig. 3. Double and commercial fruits rates obtained for EMC peach cultivar subsequent contrasting winter chill accumulation as chilling portions.

The fruit quality disorder, as double fruits, was assigned to be a result of negative effects on the carpel differentiation phase (Handley and Johnson, 2000). However, the significant increase of double fruits observed in the warmer year suggests a negative effect of temperatures as previously reported (Ghrab et al., 2014).

4. CONCLUSION

In warm and arid areas, fruit and nut trees were highly affected by the lack of winter chill. Their responses were variable depending on cultivars. Early and local cultivars seem to be less sensitive related to their low chilling requirements. With projected climate change, more attention must be accorded to genetic resources to promote the suitable cultivars depending on local conditions.

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