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Future climate change impacts on apple flowering date in a Mediterranean subbasin

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ABSTRACT

Chilling temperatures are important in apple and other fruit production because they are needed to break full dormancy, which is a prerequisite for effective and synchronous bud-break and flowering. Temperature increase related to climate change could lead to inadequate chilling in certain areas, which could affect the suitability for some species or cultivars to survive or yield in that location. The aim of this study was to estimate how climate change could affect flowering date and, consequently, feasibility of the most significant apple cultivars in the lower Fluvià subbasin (correspondent to the Protected Geographical Indication "Poma de Girona"). The estimations are based on a chilling and forcing requirements approach for each apple cultivar in this region, through a statistical analysis. The chilling-forcing sequential model, together with meteorological projections based on two climate change scenarios (B1 and A2), were used to estimate apple flowering dates along the 21st Century. Results show, in general, that apple cultivars could suffer delays on flowering date since the mid century and they could present serious disorders as a consequence of insufficient chilling in the long term in A2 scenario, which could affect crop feasibility in the region.

1. Introduction

In temperate climates, the buds of deciduous fruit trees are dormant during the autumn and winter (Lang et al., 1987). Deciduous fruit trees enter this dormant stage to survive winter conditions and avoid cold weather damage (Faust et al., 1991; Saure, 1985). It is commonly assumed (Cesaraccio et al., 2004; Fenell, 1999; Legave et al., 2008; Rea and Eccel, 2006) that this rest period is composed of an endodormancy phase followed by an ecodormancy phase: after accumulating enough winter chilling, endodormancy ends and is followed by ecodormancy (Lang et al., 1987), when flower bud development initiation depends on heat accumulation, or forcing in phenology literature.

Hence, chill requirements are needed to overcome endodormancy, and reaching a heat or forcing requirement is needed to bloom. These requirements have been widely used to model the dates for blooming and overcoming dormancy (Campoy et al., 2012 and see review in Campoy et al., 2011b). These parameters are considered to be cultivar-specific and are useful for predicting the probability of the successful adaptation of a cultivar to a pre-determined environment (Campoy et al., 2012; Fenell, 1999)

Campoy et al. (2011b) propose to determine the potential of certain areas to support growing fruit cultivars according to their chill requirements, based on data from the network of stations maintained by meteorological services and long-term predictions of temperature changes. This potential would serve growers to establish, at the proper time, orchards adapted to future changing environmental conditions.

Chilling temperatures are important in apple and other fruit production because they are needed to break full dormancy, which is an essential prerequisite for effective and synchronous bud-break and flowering (Erez, 2000; Saure, 1985). A common symptom for sub-optimal chilling is poor and protracted bud-break, which can lead to extended and partial flowering, followed by poor fruit set and final yield (Sunley et al., 2006).

Therefore, the knowledge of the chill requirement of a cultivar has significant practical and economic impacts on the control,

Abbreviations: BBCH, biologishe bundesanstalt bundessortenamt and CHemische industrie; GDH, growing degree hour; CP, chill portions; CR, chill requirement; HR, heat requirement; CR_{10}, percentile 10 of estimated CR; PGI, protected geographical indication; RCP, representative concentration pathways.

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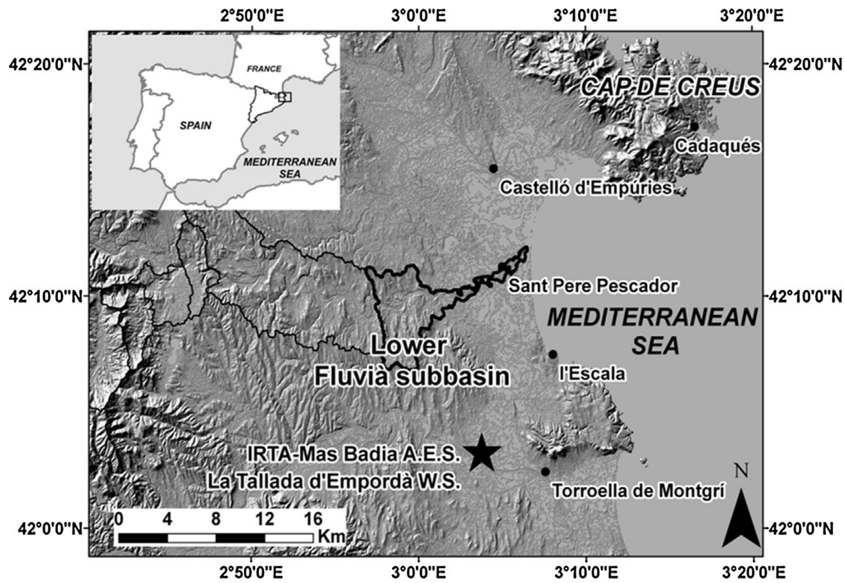

Fig. 1. Location map of the study area, the lower Fluvià subbasin. Black Star indicates location in the map of IRTA-Mas Badia Agricultural Experimental Station and La Tallada d'Empordà Weather Station.
Source: Department of Agriculture, Catalonian Governenment (DAAM, 2013a,b).

maintenance and production of woody plants (Fenell, 1999). Predicting when dormancy period ends is important for growers, as global warming could lead to inadequate chilling in certain areas, which could affect the suitability for some species or cultivars to survive or produce in that location (Cesaraccio et al., 2004).

It is commonly known that rising temperatures are a first order factor driving phenological disorders (see review in Campoy et al., 2011b; Legave et al., 2013) such as changes in phenological phases timing or duration, flowering anomalies, disorders in cross-pollination and plant-insect interactions, changes in plant diseases and pests patterns, higher frost risk or changes in fruit quality and maturation, that could affect crop production and trade (see review in Campoy et al., 2011b; Legave et al., 2013; Cesaraccio et al., 2004).

Mediterranean climate is characterized by a double stress (hot and dry summers and rainy cold and very cold winters) with a high level of variability along the geographical locations and years (SMC, 2012; Terradas and Savé, 1992). In general, projections by the end of the century for the Mediterranean basin show greater increases in annual mean temperature comparing to the global world mean (IPCC 2007, 2014). Global warming might reduce ecodormant phase in some species, advancing their phenology, but in other species, the effect could be deficient dormancy release, resulting in a delay of phenology (Campoy et al., 2011b), which could directly impact on yield formation processes and so on final crop yield (Chmielewski et al., 2004; Lobell and Asner, 2003). In Catalonia an increase in temperature between 1.1 °C and 1.4 °C during the period 1950–2008 has been observed (Martín-Vide et al., 2010), and climate change projections based in A2 and B1 scenarios (IPCC, 2007) would suppose a global increase in temperature of 4 °C and 2.6 °C by the end of the Century (2081–2100), respectively (Calbó et al., 2010). New RCP scenarios (IPCC, 2014) keep basically the same spectrum of projections for the Mediterranean basin in terms of temperature behavior.

Catalonian region, NE Spain, is one of the main apple growing regions in Spain with about 11000 ha in surface, supposing 40.4% of the apple growing surface all over Spain. 'Golden Delicious' cultivars reach 52.2% of the apple surface distribution by cultivar in Catalonia, 'Gala' 16.5%, 'Fuji' 10.1%, 'Granny Smith' 6.7%, 'Cripps pink' 3.4% and 'Red delicious' 8% (MAGRAMA, 2012).

The aim of this study was to analyze how climate change could affect dormancy phase release and, consequently, flowering time of some apple cultivars in a certain region of NE Spain (Fluvià river lower course subbasin) based on the establishment of a cultivar-specific chilling and forcing requirements approach for this region.

2. Material and methods

2.1. Study area

The study area (Fig. 1) was the Fluvià river lower course subbasin (delineated in Savé et al., 2012 see also Lopez-Bustins et al., 2013 and Pascual et al., 2014), located at the Northeast of the province of Girona (NE Spain). The subbasin has an area of 36.14 km^2 and 0, 57 to 162 m sea level elevation (minimum, mean and maximum, respectively). The average annual mean, maximum and minimum temperatures are 14.9 °C, 20.5 °C and 9.4 °C, respectively, and the average annual rainfall is 694 mm. The study area temperature details are described in Table 1 for winter and spring months.

Part of the study area belongs to the PGI 'Poma de Girona', which is a relevant apple growing area (approximately 2260 hectares, 20% of apple surface in Catalonia; DAAM, 2012) in NE Spain because of its history, quality production and territory links, being the pattern cultivar distribution very close to the whole Catalonian pattern.

2.2. Phenological and meteorological data

Flowering dates were recorded as the anthesis of 50% of the flowers: F2 stage (Fleckinger, 1945), correspondent to stage 65 in

Table 1
Study area (Fluviá, Subbasin 13) temperature details. Winter temperature considered as the mean of December–February. Spring temperature is the mean of March–May. The means were calculated from daily data temperature regionalized for subbasin 13 using SWAT Model for the period 1984–2008 (reference period).

	Winter			Spring		
	January	February	March	April	May	June
T mean (°C)	7.9	9.3	11.3	13.0	17.0	20.8
T max (°C)	13.2	15.0	17.0	18.6	22.4	26.2
T min (°C)	2.5	3.7	5.6	7.4	11.5	15.3