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Spatio-temporal variation in phenological response of citrus to climate change in Iran: 1960–2010

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ABSTRACT

Recent studies investigating floral and faunal phenological responses to climate change have highlighted the extent to which these relationships are species and location specific. This study investigates temporal responses of citrus peak flowering to climate change in the cities of Kerman, Shiraz and Gorgan, Iran. Phenological data comprise peak flowering dates of five citrus types: orange, tangerine, sweet lemon, sour lemon and sour orange, collected daily from government heritage gardens located within each of the cities over the period 1960–2010. For the same period, daily T_{max}, T_{min} and rainfall data were acquired from the Iranian Meteorological Organization. Time trend analyses were undertaken for both the phenological and meteorological data, followed by linear regression to determine the nature and extent of relationships between these variables. We find that the mean peak flowering dates, and their long-term trends over the 51-year period, are similar across the five citrus types within each city, but demonstrate significant differences between cities. Flowering date advances of 0.12–0.17 d/yr are recorded for Kerman, and more rapid advances of 0.56–0.65 d/yr for Shiraz. Notably, progressive delays in flowering dates occur in Gorgan (0.05–0.1 d/yr). The peak flowering dates in the former two cities demonstrate strong relationships with mean annual T_{min}, ranging from $r = 0.47–0.61$ ($p = 0.0045$; $p < 0.0001$) for Kerman to $r = 0.53–0.67$ ($p = 0.0386$; $p < 0.0001$) for Shiraz, and equate to peak flowering advances of 3.15–3.39 d/°C and 4.34–5.47 d/°C, respectively. By contrast, the strongest relationships between peak flowering dates and annual climate in Gorgan are with rainfall ($r = 0.02–0.3$, $p = 0.8874$; $p = 0.0528$), indicating a weak phenophase response of 0.01 d/mm. For Gorgan, the strongest relationships ($r = 0.43–075$, $p = 0.0002$ to $p < 0.0001$) are between peak flowering date and mean T_{max} for May, the month during which peak flowering occurs, with a delay in flowering of 1.26–1.86 d/°C cooling. This suggests a relatively more influential climatic role directly preceding peak flowering, which may be associated with anomalous cooling in May. However, Kerman and Shiraz demonstrate more consistent strength in correlation between peak flowering and climate variables across the months of the year, with only slight peaks for the months flanking peak flowering. Our study highlights the importance of considering location-specific phenophase shifts within given regions, as dissimilar trends may occur within a country; this has important implications for future agricultural planning and fruit crop supply to local and international markets.

1. Introduction

Phenology is broadly defined as the timing of annually recurrent biological events (Badeck et al., 2004). The phenological response of plants to climate change over recent decades is considered to be both location and species specific (Parmesan, 2007; Miller-Rushing & Primack, 2008). The extent of this variation across species and location is increasingly evident through the accumulation of phenological research. Phenologies of the same species are responding at different rates to climate change in locations of different latitude and altitude (Ruml et al., 2011) and with distance from the nearest coastline (Wielgolaski, 2003). Within individual locations, there are likewise substantial differences in the rate of phenological change between plant species. For example, Wang et al. (2008) report advances in cotton flowering of 0.66 d/°C in Beijing, whilst wheat flowering in the city advances by a considerable 3.4 d/°C. An analysis of 500 plant and animal species' phenophase shifts in

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Concord, Massachusetts, similarly found considerable differences in their phenological responses to climate change (Miller-Rushing & Primack, 2008). This is partly because species differ in their phenological triggers, including chilling and heating requirements, and determinant ambient conditions including temperature, rainfall, snow, and soil nutrient balance (Zavalloni et al., 2006; Inouye, 2008). Such differences are compounded as climate variability and change differ considerably between global regions (Walther et al., 2002). However, when measuring the impact of one unit temperature change on phenophase shifts for a species occurring at different locations, discrepancy remains in the magnitude and direction of the phenological response (Parmesan, 2007). This warrants continued studies on ground-level phenological responses to climate variability and change, for as many species, and in as many locations, where data exist (Parmesan, 2007; Miller-Rushing et al., 2008; Siebert & Ewert, 2012). It also necessitates further analyses comparing phenological responses of different species within a single location, and single species across locations, to better understand the dynamics of these variable responses under current and projected climate change.

Few studies have examined phenological responses of plants to climate variability and change in Iran, or the long-term phenological shifts of citrus flowering globally. Citrus phenology is particularly sensitive to changes in temperature and precipitation. The initiation of flowering requires a period of either cool or drought conditions to release dormancy, followed by a period of warm conditions with sufficient moisture availability to induce budburst (García-Luís et al., 1992; Rosenzweig et al., 1996; Srivastava et al., 2000). Despite these restrictive spring phenological requirements, citrus varieties are cultivated in over 140 countries with climates ranging from temperate through to tropical (UNCTAD, 2005; CGASA, 2011). Iran remains the 8th largest global citrus producer with annual yields of 3.5 million tonnes in 2009/2010, (CGASA, 2011). Furthermore, the considerable geographic and climatic variability across the country make both rainfall and temperature likely limiting factors to phenophase fidelity (Modarres & de Paulo Rodrigues da Silva, 2007; Sharifan et al., 2010). Any shifts in citrus peak flowering dates are thus likely to influence the success of citrus agriculture in Iran.

We investigate shifts in the peak flowering dates of five citrus types (orange, tangerine, sweet lemon, sour lemon and sour orange), and their response to changes in temperature and precipitation, in the Iranian cities of Gorgan, Kerman and Shiraz, for the period 1960–2010. In particular, we explore the extent to which shifts in peak flowering date occur at rates specific to the location and/or citrus type. Through investigating both the spatial and temporal nature of changes in peak flowering dates, the study aims to determine patterns of phenological similarity and divergence across Iran, to compare the results with phenological responses to climate change reported globally, and to explore the implications of such phenophase shifts on the Iranian citrus industry.

2. Materials and methods

2.1. Setting

Iran covers an area of 1 648 000 km^2, of which approximately half is mountainous, with the Zagros Mountain range extending along the west of the country and the Alborz Mountains in the north (Gholipoor, 2008). The country borders the Caspian Sea to the north and the Persian Gulf to the south (Fig. 1). This varied relief, high evaporation rates and dominant north-westerly winds transporting dry air to the interior, results in an arid to semi-arid environment, with less than 50–350 mm of annual rainfall received over 60% of the country (Modarres & de Paulo Rodrigues da Silva, 2007). Winter rainfall occurs in all three study cities, governed by the Siberian High, Westerly Depressions and South Westerly Monsoon (Kehl, 2009). Gorgan is located in the Caspian Lowlands, in the northern coastal region of Iran (Fig. 1), and has a warm semi-humid climate. Kerman is located on the Central Iranian Plateau (Fig. 1),

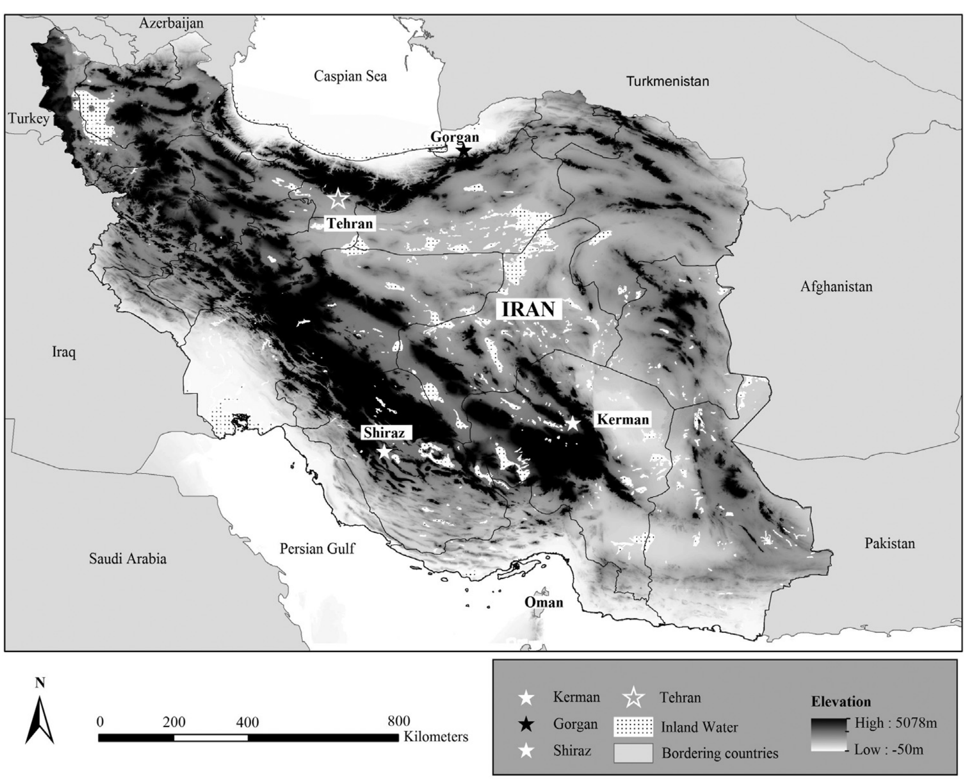

Fig. 1. Topographic map of Iran indicating the three study cities and Tehran, the national capital.