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Research paper

Complexity in chill calculations: A case study in cherries

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ABSTRACT

This study seeks to highlight the range of chilling requirement values that can be obtained for one cherry cultivar ('Lapins') across different Australian locations by using the same data but different approaches in calculating chilling requirement (CR). We seek to test the assumption that chill thresholds are fixed. The physiological and in-field implications for management are explored. All sites and years showed a steady increase in chill accumulation during the year. Bud burst in relation to accumulated chill portions (CP) was not consistent between sites or years, but all sites exhibited a sharp increase in bud burst after 40 chill portions (CP). Using a 50% bud burst threshold performed statistically better than a 30% bud burst threshold, and observed CR values performed slightly better than modelled CR values. The spatial analyses of safe winter chill for the range of CR determined in this study confirm the variability in values between the 30% and 50% bud burst approach. Imposing a fixed start date for chill accumulation excluded varying amounts of chill compared with using the self-regulating start time and increased the variation of CR values. The implications of using different methods to estimate CR, using projected estimates of chill accumulation under climate change, are provided. This study has e xposed the complexity in not only comparing CR values from previous studies, but the inherent confusion in the communication of such knowledge, especially with the additional consideration of a warming climate.

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1. Introduction

It is well established that a certain accumulated amount of low temperatures, termed chill, is required for the production of fruit on perennial fruit trees and that inadequate chill is linked to reduced fruit quality and yield (Saure, 1985; Mahmood et al., 2000; Oukabli et al., 2003; Petri and Leite, 2004). Acknowledging this requirement, many studies have commented on the need to quantify this chilling requirement in order to match production regions with cultivars and hence optimise production (Alburquerque et al., 2004; Allderman et al., 2011; Campoy et al., 2011b; Luedeling et al., 2011; Mohamed, 2008; Measham et al., 2014).

As climate changes are expected into the future, the interest in providing information aligning regional climate projections with fruit tree chilling requirements is increasing (Darbyshire et al., 2016a, 2016b). A number of studies have recently focussed on such efforts in Australia (Darbyshire et al., 2011; Webb 2012; Darbyshire et al., 2013a, 2013b; Measham et al., 2014) and worldwide (Luedeling and Brown 2011; Luedeling et al., 2011; Luedeling 2012) and are using the outcomes to direct practical management of perennial fruit tree production (Erez et al., 1990; Alburquerque et al., 2004; Viti et al., 2010; Allderman et al., 2011; Campoy et al., 2012; Zion et al., 2012; Measham et al., 2014). Manipulation of the dormancy period and subsequent flowering conditions are desirable management practices to allow greater control over cultivar responses to climate conditions (Campoy 2010; Allderman et al., 2011; Seif El-Yazal and Rady, 2012).

Controlled environment methods have been used to quantify varietal chill requirements using two different approaches. Firstly, by placing bud wood into cool storage for a specified simulated dormant period, from which chill is modelled, followed by a forcing (or warming) environment to stimulate dormancy release (Cortes and Gratacos, 2008; Charrier et al., 2011). Secondly, in-field chill accumulation in line with natural dormancy is used, and bud wood is collected at specified times throughout winter and placed directly into a forcing environment to stimulate dormancy release (Petri and Leite, 2004; Guo et al., 2013).

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Whichever approach is used, models of chill need to estimate the beginning and end of bud dormancy in order to calculate the chilling requirement (Campoy et al., 2011b). Differences in this determination have implications for quantifying the chilling requirement and may lead to considerable variation in the estimation of chilling requirements. Measham et al. (2014) cites several studies that use different start points in chill requirement calculations; ranging from visual cues to arbitrarily set dates and dates set by models. They conclude that use of visual cues, such as leaf fall (Gariglio et al., 2006; Charrier et al., 2011) will result in artificially low values. Gariglio et al. (2006) found different responses of fruit and leaf buds to climate further confounded efforts to relate leaf responses to floral bud behaviour. Many studies use self-regulating chill models to evaluate the start of dormancy (Luedeling et al., 2011; Darbyshire et al., 2016a, 2016b) due to the lack of a reliable physiological marker and the inability of fixed dates to account for seasonal climate variability.

Identification of the end of endodormancy when chilling requirements have been met also varies between studies. Often the chilling requirement is regarded as satisfied when a percentage of buds break or burst after being exposed to a forcing (warming) environment. The percentage threshold used is somewhat arbitrary with studies using 30% (Guo et al., 2013; Campoy et al., 2012) and 50% (Cortes and Gratacos 2008: Measham et al., 2014) bud break levels as indicators of sufficient chill accumulation for dormancy release. A lower bud break level, such as 30%, could lead to artificially low chilling requirement thresholds.

Chilling requirement values have been generated using various models of chill (Luedeling and Brown, 2011; Darbyshire et al., 2011), and in units that are not convertible (Luedeling and Brown, 2011; Measham et al., 2014) such that critical comparisons of studies are often not possible.

The Dynamic model (Erez et al., 1990) has gained favour in recent years due to robust design and performance (Darbyshire et al., 2011; Zhang and Taylor, 2011; Luedeling and Brown, 2011; Guo et al., 2013; Miranda and Santesteban, 2013) and has been applied across a number of crops including cherries (Erez, 2000; Measham et al., 2014) but consensus of cherry chilling requirements is still lacking.

This study seeks to highlight the range of chilling requirement values that can be obtained for one cherry cultivar ('Lapins') in different locations by using the same data but different approaches in calculating chilling requirement (CR). Approaches include altering the start date for accumulation of chill and varying the percentage of bud burst used to indicate CR has been met, and if that value is discrete or modelled. A single cultivar was selected for these analyses to explicitly highlight the level of complexity in determining chill requirements. Guo et al. (2015) found complexity in chill calculation for one cultivar in one location, and discuss the need for standard protocols for better comparison across sites. This is critical given that threshold values are ultimately used to predict climate impacts (Darbyshire et al., 2016a).

We seek to test the assumption that chill thresholds are fixed. Furthermore the physiological and in-field implications for management are explored by; (a) assessment of safe winter chill (SWC) across Australia under current climates (b) determining the difference in the day of the year (DOY) that CR is met in the current climate and (c) determining the likelihood of reaching CR under future climate scenarios – all under the various CR values determined for the same cultivar in this study.

2. Methods

Experiments were conducted in 2014 and 2015 to evaluate the chilling requirement (CR) of 'Lapins' cherry (*Prunus avium*) across different Australian locations. Chill was calculated using the Dynamic model (Erez et al., 1990) which provides CR units in chill portions (CP). Temperature data was collected hourly with HMP155, TGP-4017 Tiny Tags or RTH–11 m on a PM-11 phytomonitor weather station.

2.1. Site selection

Sites were selected based on known differences in winter chill (Darbyshire et al., 2011; Measham et al., 2014) and cultivar selection was based on availability, with Lapins a major cultivar in most cherry production regions in Australia (James, 2011). 'Lapins' originates from British Columbia, Canada, and has been previously reported to require from 400 to 700 h of chill (temperature below 7.2 °C) dependent upon climatic region and elevation (Cortés and Gratacós 2008; Kuden et al., 2012). All trees were mature, commercially productive trees, grown on Mazzard rootstock and managed according to industry standards (James, 2011). The sites were Huonville (-43.01S 147.06E) and Plenty (-43.74S 146.97E) in Tasmania, Tatura (-36.43S 145.26E) in Victoria, and Manjimup (-34.13S 116.07SE) in Western Australia.

2.2. Sample selection

Bud sticks were collected from each site on a weekly basis from five replicate trees. To ensure random selection of trees, previously sampled trees were labelled to avoid re-sampling. A minimum of 3 shoots were collected with at least 20 floral buds in total at each sampling time from each of the five trees. Shoots for collection were healthy and approximately 15–20 cm in length. First year wood was not taken.

In 2014, bud sticks were collected from Huonville, Plenty and Tatura, commencing as close as practicable from the in-field chill accumulation of 20 CP. In 2015, sampling occurred in Huonville, Tatura and Manjimup with commencement of sampling from the beginning of March in order to include samples prior to the beginning of in-field chill accumulation.

2.3. Assessing bud burst

Bud sticks were transported immediately from the field sites to a nearby laboratory in a sealed container to keep samples cool and moist. Upon arrival at the laboratory, samples were visually reassessed for condition, labelled and placed into containers of water with 0.5% bleach. Water levels were monitored weekly. Containers were housed in controlled environments set to a constant temperature (25 °C ± 1 °C) and 24 h of light. Bud burst was assessed from bud sticks by visual inspection of bud burst, as indicated by 'side-green', as per Zavalloni et al. (2006). Visual inspection and a record of bud movement occurred three times weekly for a minimum of 14 days.

2.4. Analyses

For each site, sample date and observation time, all samples were pooled and bud burst percentage calculated. The chilling requirement was defined as met if a threshold percentage of buds had burst. Two thresholds were tested, 30 and 50%. Given that 30% or 50% bud burst may not occur discretely two options were used to calculate CR. These were to use the accumulated CP on the observed day which the bud burst percentage was above the prescribed threshold (Obs_30 and Obs_50) and to model the CP using linear regression to estimate the CP at 30 or 50% (Mod_30 and Mod_50).

These assessments using two percentage thresholds and two options to define CR using those thresholds were repeated using two different start times of chill accumulation. Firstly, chill was

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