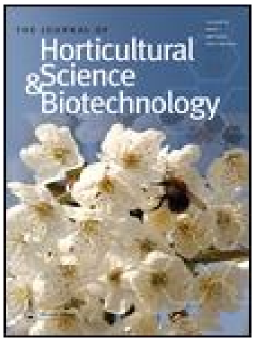

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Chill unit models for the sweet cherry cvs Stella, Sunburst and Summit

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SUMMARY

Bud break of one year old cut shoots of sweet cherry cvs Stella, Summit and Sunburst was recorded to quantify the effect of chilling on dormancy release. Chilling was applied in the dark at constant temperatures of –1.2°C, 3.8°C, 6.8°C, 9.4°C, 11.9°C and 15.4°C (± 0.5°C) for 0, 168, 336, 504, 672, 840, 1008, 1176 and 1334 h. Multiple regression analysis showed that at temperatures of –1.2°C, 3.8°C, 6.8°C, 9.4°C the proportion of bud break increased through successive chilling durations, up to approximately 1000 h of chilling. However, chilling for more than this duration reduced the percentage bud break. The control treatment (no chilling), chilling for 168 h and chilling at average temperatures of 11.9°C or 15.4°C did not break dormancy. The data collected were used to develop a chill unit model which predicted that chilling temperatures of 3.2°C, 3.2°C and 3.7°C were optimum for cvs Stella, Summit and Sunburst respectively. The chilling requirements for these cultivars were estimated to be saturated after 1131, 1081 and 1214 hours respectively.

Bud break and the timing of blossoming of many deciduous fruit trees are usually dependent upon exposure to a particular duration of cool temperatures, often referred to as chilling, to release dormancy and subsequently an appropriate temperature to cause growth in the spring. Mahmood *et al.* (2000) described an increase in the number of branches, leaf fresh and dry weights and a reduced time to bud break with increased chilling. Flower size, pedicel length and fruit set also increased with increasing chilling duration. In this paper, the effect of chilling on bud break was examined in more detail by investigating the effect of chilling temperature.

The chilling duration needed to release dormancy varies among species and also cultivars within species. Little is known about the causes of the differences in chilling requirement, although it has been established that different temperatures vary in their effectiveness in releasing buds from dormancy. In addition, few studies have been conducted to determine specific temperature responses such as the optimum chilling temperature and the range of temperatures which are effective in satisfying chilling. Chandler and Tufts (1933) showed that a temperature between –1°C and 0°C was effective in promoting bud break of peach. However, Chandler *et al.* (1937) later reported that temperatures of between 0.5°C and 4.5°C were as effective or even better than freezing temperatures, whereas temperatures of 9°C were less effective. Erez and Lavee (1971) and Erez and Couvillon (1987) working with peach found that the effect of temperature on dormancy release of buds was greatest at 6–8°C; 10°C was only half as effective as 6°C in breaking dormancy. Thompson *et al.* (1975) found 2°C to be more effective than 6°C and 6°C more effective than 10°C in breaking dormancy in apple.

Richardson *et al.* (1974) developed a model for estimating dormancy release in peach cultivars, based on a summation of the effective chilling hours in the winter season, where one chill unit is equal to one hour of exposure to 6.1°C and the chilling contribution becomes less as the temperatures rise above or fall below this. In a similar way Anderson *et al.* (1986) described the response to chilling of sour cherry, using an optimum temperature of approximately 5.5°C. Studies by Gilreath and Buchanan (1981) indicated that there are cultivar differences in the effectiveness of different chilling temperatures and accumulated chill-unit requirements. Shaltout and Unrath (1983) used this chill-unit concept for the prediction of dormancy completion by apples grown in North Carolina.

Various criteria for determining the time of dormancy release have been reported including 50% bud break (green sepal stage) of peach after three weeks of forcing (Erez and Lavee, 1971), and 50% bud break (green tip stage) of sour cherry after 14 d of forcing (Mielke and Dennis, 1975). Cut shoots have been used successfully as a tool for studying bud dormancy in sour cherry (Felker and Robitaille, 1985); in apple (Eggert, 1951; Paiva and Robitaille, 1978) and in peach (Weinberger, 1950).

Very little is known about the chilling requirement of sweet cherry, the optimum chilling temperature or the variation in these parameters amongst sweet cherry cultivars. In the current study, the responses of sweet cherry cultivars to a range of chilling temperatures were determined, and the information used to build models for the accurate prediction of dormancy release. The cultivars were chosen because their ripening times were similar, all being moderately late fruiting. Cvs Stella, Summit and Sunburst ripen approximately 15 d, 16–18 d

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and 18–20 d after Burlat, respectively (Webster and Looney, 1996). Cut shoots were evaluated as a tool for studying dormancy completion in sweet cherry buds by comparison with intact plants.

MATERIALS AND METHODS

Two year old plants of three sweet cherry cultivars (Stella, Summit and Sunburst) were maintained outdoors prior to the experiment in pots containing peat based potting compost. During this time the plants were checked for flower bud development under a stereo light microscope. After completion of flower development on 30 September 1997, approximately 300 one year old bud sticks, 30 cm long and each with 15–20 leaf and flower buds were collected randomly from each cultivar. Bundles of bud sticks from each cultivar (each bundle containing 50 shoots) were wrapped in moistened paper and placed in each of six controlled temperature cold rooms in the dark at average temperatures of –1.2, 3.8, 6.8, 9.4, 11.9 and 15.4°C (± 0.5°C). In addition, 16 two year old plants of cv. Stella were stored at each temperature. The cut bud sticks were sprayed with water as necessary to avoid drying during the chilling period.

Two plants of cv. Stella and six bud sticks from each cultivar were removed from each chamber after they had received 0, 168, 336, 504, 672, 840, 1008, 1176 and 1344 h of chilling. Following removal, the bases of the bud sticks were placed in 10 cm square plastic pots containing moist sand. Both plants and bud sticks were then maintained in a heated glasshouse at an average temperature of 20°C with a daylength extended to 16 h d^{-1} with tungsten bulbs providing a light intensity of 5 $\mu mol m^{-2} s^{-1}$ at ground level. Bud sticks were sprayed with water twice a day during the experimental period. All plants and bud sticks were examined visually and bud break was recorded for a period of six weeks, until no further change was observed. Dormancy was considered to be broken when no further significant increase in the proportion of bud break was recorded.

Multiple regression analysis was performed to determine the relationship between chilling temperatures and proportion of bud break. Chilling hours were converted to chill units according to the Utah model method (Richardson *et al.*, 1974).

RESULTS

Bud break did not occur during the duration of the experiment when plants and bud sticks received 168 h or fewer of chilling, nor at chilling temperatures of 11.9°C and 15.4°C. Increasing the period of chilling up to 1008 h increased the proportion of bud break of bud sticks of cv. Stella (Figure 1A). Bud break declined slightly with a further increase in chilling. A similar trend in bud break was found at average temperatures of –1.2, 3.8, 6.8 and 9.4°C. The highest proportion of bud break occurred at 3.8°C after 1008 h of chilling. Generally, similar responses were found for cvs Summit and Sunburst (Figures 1B and 1C).

Plants of cv. Stella responded in a similar way to bud sticks to the chilling temperatures and chilling durations, despite the difference in total percentage bud break which was higher than in bud sticks (Figure 1D).

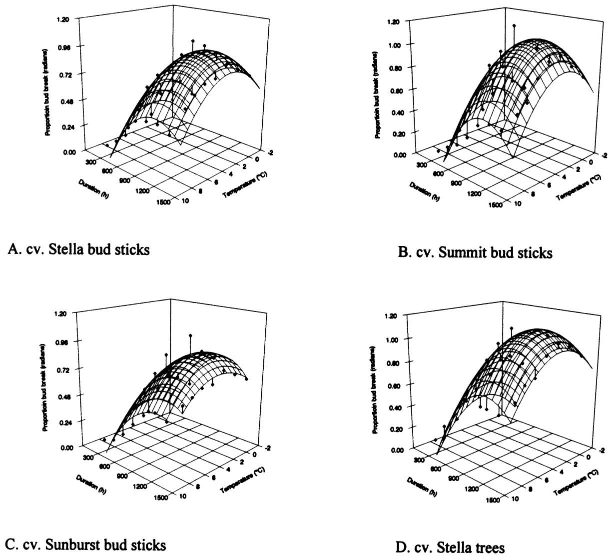


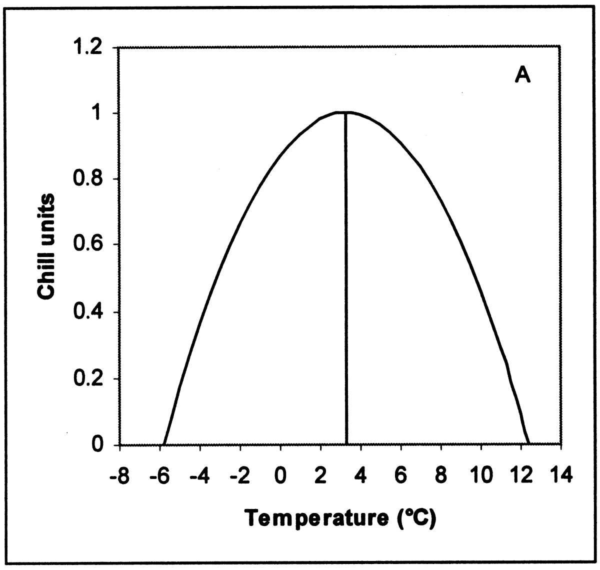
FIG. 1
The effect of chilling temperature and chilling duration on the proportion of bud break in the cultivars shown. The planes were fitted by multiple regression analysis.
A. cv. Stella bud sticks. Proportion bud break (radians) = – 0.36 + 0.076t – $0.011t^2$ + 0.0021d – $9.4x10^{-7}d^2$ where standard errors were 0.08, 0.008, 0.001, 0.0002 and 1.27 × 10^{-7} respectively.
B. cv. Summit bud sticks. Proportion bud break (radians) = –0.51 + 0.090t – $0.014t^2$ + 0.0027d – 1.2 × $10^{-6}d^2$ where standard errors were 0.13, 0.01, 0.002, 0.0003 and 1.97 × 10^{-7} respectively.
C. cv. Sunburst bud sticks. Proportion bud break (radians) = –0.33 + 0.083t – $0.011t^2$ + 0.0018d – 7.4 × $10^{-7}d^2$ where standard errors were 0.09, 0.009, 0.001, 0.0002 and 1.37 × 10^{-7} respectively.
D. cv. Stella trees. Proportion bud break (radians) = –0.42 + 0.073t – $0.011t^2$ + 0.0025d – 1.1 × $10^{-6}d^2$ where standard errors were 0.09, 0.009, 0.001, 0.0002 and 1.43 × 10^{-7} respectively.

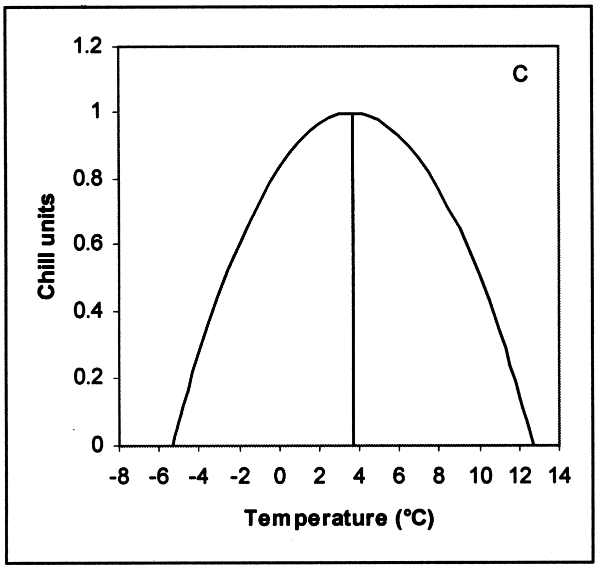
Regression analysis showed a curvilinear relationship between the proportion of bud break and chilling temperature and chilling duration.

As no significant interaction was observed between chilling duration and chilling temperature for bud break for these cultivars (Figures 1A, B and C), the regressions were used to estimate the optimum chilling temperature and duration. According to the relationship shown in Figure 1A for cv. Stella, 3.2°C gave the highest percentage bud break; thus one hour at 3.2°C (optimum chilling temperature) can be considered as one chill unit. The duration of chilling at the optimum chilling temperature required to break bud dormancy of cv. Stella was 1131 h. Chill unit values for other temperatures above and below the optimum temperature were calculated. Table I shows the optimum, base and ceiling temperatures and Figure 2 the chill unit values at temperatures within this range. The minimum (–5.8°C) and maximum temperatures (12.4°C) are those with a chill unit value of zero. Temperatures below –5.8°C and above 12.4°C negate chill unit accumulation.

TABLE I
Base, optimum and ceiling temperatures of the chill unit models for cvs Stella, Summit and Sunburst.

Temperature (°C)	cv. Stella	cv. Summit	cv. Sunburst
Base	–5.8	–5.6	–5.3
Optimum	3.2	3.2	3.7
Ceiling	12.4	12.0	12.7





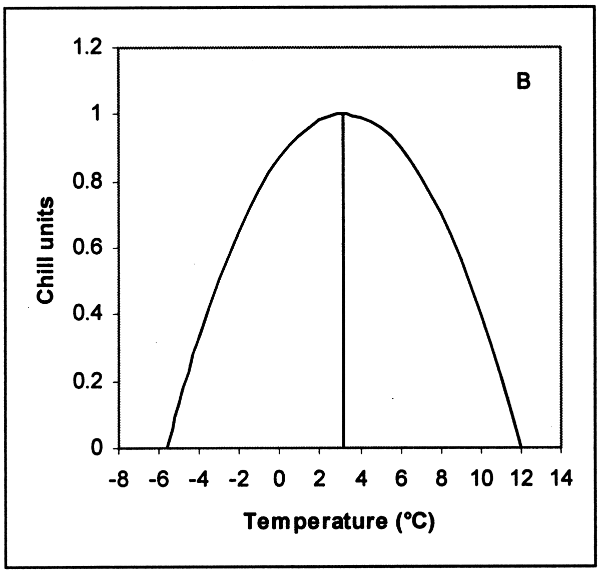


FIG. 2

Temperature chill unit models for cvs Stella (A), Summit (B) and Sunburst (C) as shown in Table I. Lines were fitted using the method of Richardson *et al.* (1974) such that:

A. cv. Stella. CU = 0.87 + 0.079t – $0.012t^2$ where standard errors were 0.08, 0.008 and 0.001 respectively.

B. cv. Summit. CU = 0.87 + 0.083t – $0.013t^2$ where standard errors were 0.13, 0.01 and 0.002 respectively.

C. cv. Sunburst. CU = 0.83 + 0.091t – $0.012t^2$ where standard errors were 0.09, 0.009 and 0.001 respectively.

Similar procedures for cvs Summit and Sunburst indicated optimum chilling temperatures of 3.2°C and 3.7°C respectively, at which 1081 h and 1214 h respectively were required for maximum bud break. Minimum (–5.6 and –5.3°C respectively) and maximum chilling temperatures (12.0 and 12.7°C respectively) were also calculated. Within these extremes, the chill unit values varied with temperature in a very similar way to those for cv. Stella (Figure 2).

The chill unit model developed from cv. Stella bud sticks was validated against the data from the trees (Figure 3). The proportion of bud break as predicted from the bud stick data was lower than observed for plants stored at 9.4°C, especially when the proportion of bud break was high. At lower storage temperatures, there was close agreement between actual bud break in trees and bud break predicted from shoot data.

DISCUSSION

The approach used here to quantify the chilling response of sweet cherry cultivars is based on that of Richardson *et al.* (1974), in which one chill unit is equal to one hour's exposure to the optimum chilling temperature. The optimum temperatures for satisfying the chilling requirements determined here were 3.2°C, 3.2°C and 3.7°C for cvs Stella, Summit and Sunburst, respectively. The efficiency of temperatures both above and below these optimum temperatures was calculated as a proportion of the bud break at the optimum temperature. Chill units accumulated above and below these optimum temperatures were calculated using the same method to allow the chilling requirement of the cultivars to be quantified. This appears to be the first study to provide a method which can clearly define the relative efficacies of low temperatures for breaking dormancy in sweet cherry. This is surprising given the commercial importance of bud break, flowering time and fruit set in cherry, the potential value of predicting these events, and the potential limitations placed on protected cropping of cherry by the need for chilling.

Previous research on the chilling requirements of sweet cherry (Seif and Gruppe, 1985) and sour cherry (Felker and Robitaille, 1985; Eisensmith *et al.*, 1980) indicated that chilling hours accumulated when shoots were held at 5°C, whereas chilling was nullified at 15°C.

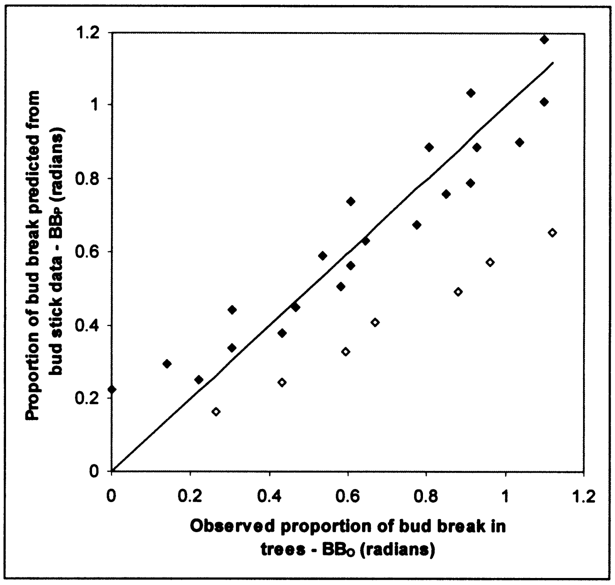


FIG. 3
Relationship between observed (BBo) and predicted (BBp) bud break in trees of cv. Stella. Predictions were made using the chill unit model shown in Figure 2A (cv. Stella shoots). The solid line (y = x) represents perfect agreement between observed and predicted values. Closed symbols show response of trees stored at – 1.2, 3.8 and 6.8°C and open symbols at 9.4°C.

In sour cherry, 5.5°C is believed to be the optimum for chill accumulation (Anderson *et al*., 1986). According to the chill-unit models presented here, temperatures above approximately 12°C and below approximately –4.5°C were ineffective in breaking bud dormancy of cvs Stella, Summit and Sunburst. This was found to be true in the experiment where shoots stored at 11.9 and 15.4°C failed to develop suggesting that these temperatures were too high to be effective in breaking dormancy. A decrease in chilling efficiency with decreasing temperature to –6°C was suggested by Sudakevitch (1962) for various stone fruits. This supports the conclusion that temperatures near 3°C break dormancy more effectively than higher or lower temperatures and is consistent with the general suggestion of Chandler *et al.* (1937) that dormancy is broken most rapidly at temperatures between 0°C and 7°C.

The effects of chilling temperature on bud break in a number of other species are similar to those reported here for cherry. For example, Gilreath and Buchanan (1981) found temperatures in the range 0–7°C to be most effective at breaking dormancy in rabbiteye blueberry, and Erez and Lavee (1971) found 3–8°C to be most effective in peach. A chill unit model has been developed for the strawberry cv. Elsanta using an approach similar to that described here (Battey *et al*., 1998). In this case 2°C was the optimum temperature for chilling and approximately 1340 chill units were required to satisfy the chilling requirement of this cultivar. This suggests that the chilling requirements for cherry cultivars are slightly less than that of strawberry cv. Elsanta, and the temperature optima slightly higher. It would be interesting in future work to investigate the chilling requirements of sweet cherry cultivars with more diverse ripening times than those used in this study.

Tehranifar *et al.* (1998) provided evidence that field and controlled chilling differ in their effectiveness, and this possibility needs to be studied for cherry. Research of this kind would, in addition, provide important validation for the chill unit models derived in the current work under controlled environment conditions. Our results indicated that the response to chilling temperature of cut shoots is slightly different from that of whole plants of cv. Stella, especially at higher temperatures. This is contrary to the findings of Felker and Robitaille (1985) who found no difference, and it suggests that our chill unit models may need to be adapted for use on whole plants.

Chilling temperatures are frequently interrupted by unseasonably high temperatures both briefly and for extended periods of time. It is therefore necessary to understand how cherries respond to such environmental fluctuations so that their effects can be incorporated into chill models. Deciduous fruit species are generally of temperate-zone origin. When they are grown under subtropical conditions climatic requirements may not be fulfilled and their growth and yield potential will therefore be reduced (Chandler *et al*., 1937).

Chill unit models of the kind described here should be useful in selecting cultivars which would be adapted to particular temperature conditions. By analysing historical temperature data, cultivars which seem likely to receive sufficient chilling for their chill requirements to be satisfied could be chosen before planting. Predictions of spring bud break could also be made based on the actual amount of chilling accumulated. This would be especially important for polytunnel or glasshouse production and in warmer climates where chill unit accumulation is likely to be marginal. The chill unit models can therefore be used as planting tools for both growers and researchers as well as for scheduling out-of-season cherry production.

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