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Improved models of the effects of winter chilling on blackcurrant (*Ribes nigrum* L.) show cultivar specific sensitivity to warm winters

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A Abstract

Sufficient chilling in winter is essential for many perennial crops to start growing in spring and to produce good yields. Using blackcurrants as an example we have developed improved models which can help identify varieties resilient to the variable winters expected as the climate warms. Controlled temperature experiments were used to calibrate 3 proposed models of chilling accumulation requirements for a number of commercial blackcurrant cultivars. The first model assumed a linear relationship between bud break and chilling accumulation, the second a quadratic relationship which allows for the possibility of over-chilling and the third, an asymmetric quadratic relationship in which the maximum achievable effectiveness is temperature dependent. The models were then applied to data on selected cultivars gathered from blackcurrant growers across the United Kingdom and the third model was found to provide the best fit for the data, suggesting that long warm winters do not have the same effect as short cold winters in terms of the satisfaction of chilling requirement. Further, the degree to which temperature affects maximum bud break varies by cultivar. We discuss the potential effects of differing timing of chill on the applicability of the models presented.

Key Words: *Ribes*, winter chilling, bud break, Dormancy, chill models, climate change

B Introduction

Adequate winter chilling is required for the satisfaction of the chilling requirement that is needed for optimal bud break and flowering of many temperate fruit crops including blackcurrant (*Ribes nigrum* L.). The potential reduction of winter chill with climate change is of particular concern to growers of many woody fruit crops in the UK (Atkinson *et al.*, 2004, 2013) and elsewhere (Snelling and Langford, 2002; Oukabli *et al.*, 2003; Andersen *et al.*, 2017) as it can cause erratic bud burst and increase the spread of flowering, thus leading to reduced crop yields and quality. Quantification of the amount of winter chilling has been the subject of much research on a range of crops with widely differing requirements both for cold during the dormant period and for warming to facilitate the actual bud break once chilling has been satisfied. Since the early work of Weinberger (1950) a wide range of chilling functions have been proposed to quantify the chill experienced by different crops (reviewed by Dennis, 2003; Atkinson *et al.*, 2013; Sunley *et al.*, 2006). The most widely used chilling models either weight all temperatures below 7.2°C or all temperatures between 0°C and 7.2°C equally, though it has been recognised that different temperatures can have a different effect on chilling satisfaction leading to the development of more specialised chilling units for specific species including the 'Utah' units that have been derived for peach (Richardson *et al.*, 1974).

For blackcurrant, there is good evidence that the impact of chilling increases approximately exponentially as temperature decreases (Bidabe, 1967; Lantin, 1973; 1977; Jones *et al.*, 2013). Nevertheless, various studies have shown that the chilling requirement differs substantially between cultivars adapted for different climates (Atwood, 2003; Jones *et al.*, 2013; Lantin, 1977). Furthermore, Jones *et al.* (2013) found evidence that excessive chilling could even inhibit the chilling response in some cultivars and proposed a model in which bud break can be modelled as a quadratic response to temperature related chilling accumulation. This allows for supra- as well as the more usual sub-optimal chilling, but the effects are symmetrical and the maximum achievable bud break is independent of temperature. The implication would be that 100% bud break would be achievable if fairly warm

temperatures were applied for long enough. It therefore makes sense also to consider the possibility of generalizing the Jones models to one that allows an asymmetric response and where maximum achievable bud break depends on the temperature history.

Previous model fits have used either regression or non-linear fits assuming normal residuals (Jones et al., 2013). This is a reasonable approximation when moderate levels of bud break are achieved.

However, field experiments can lead to very high or very low levels of bud break and here we refine the fitting methods to take account of the binomial distribution in the data, which is particularly important when there has been either very high or very low bud break.

We used controlled temperature data to calibrate three models (Lantin, Jones and generalized Jones) for various cultivars, assessing the degree to which the response to temperature is cultivar specific. We then validated the models against field data from around the country.

We found that the parameters were cultivar specific and the generalized Jones model had a better fit suggesting that cultivars have an optimal chilling range; that a long warm winter will have a different impact on bud break than a short cold one; and that these effects are cultivar specific. Thus it is both possible to characterise the chilling requirements of a cultivar and important to select cultivars suitable for the conditions in which they will be cultivated. Expressing climates of the different regions where blackcurrants are cultivated in terms of chilling hours below 7.2°C, these can vary from less than 1000 h in the warmest areas such as some in New Zealand to approaching 5000 h over a winter in more Continental climates. Even at any one site (such as Dundee, Scotland) the value can vary by 25% between years (Jones et al., 2014). The lowest levels of chilling in the UK are to be found in Kent and the West Midlands especially Herefordshire (Atkinson et al., 2004), which are the areas where the most serious budbreak problems have been reported in blackcurrant. Any transition from the endodormancy phase to ecodormancy requires the full chilling requirement to be satisfied, so that the timing of endodormancy is determined by environmental conditions.

C Methods

C.1 Bud break experiments

C.1.1 *Experiment 1: model calibration*

Controlled temperature experiments for model calibration were performed at the Scottish Crop Research Institute (now the James Hutton Institute) in the winter of 2007/2008 in which different combinations of cultivar, temperature and chilling time were considered. For full details of the experiments see Jones et al. (2013). In short, four equivalent 12-bud cuttings were taken in mid-October 2007 from 4-5 year old bushes in the field of each of 20 cultivars from a wide range of geographical provenances where blackcurrants are cultivated and subsequently transferred at random to controlled environment rooms and kept at a constant temperature (either -5°C, 0°C, 5°C or 10°C) for periods of 35, 63, 91, 119 or 147 days.

After chilling, the cuttings were transferred to a glasshouse maintained at 20°C for 6 weeks, which provided an environment conducive to budbreak, and records of bud burst taken at weekly intervals; recording ceased after 6 weeks as no further budburst was seen after this period. Dead buds were excluded from the analysis and any bud which showed initial signs of bud swelling or further progression was considered to have broken.

C.1.2 *Experiment 2: model validation*

C.1.2.1 Plant material

Six commercially important UK cultivars were selected from those studied in Experiment 1. Cuttings were sampled in the field every 2 weeks from 07/10/2015 until 22/03/2016 by five growers from three key blackcurrant-growing regions of the UK (1 in Scotland, 2 in Herefordshire and 2 in Kent) and these samples sent to the James Hutton Institute for monitoring of bud burst. Cuttings were maintained at 20°C and after 21 days the top 13 buds were examined. Dead buds were excluded from the analysis and any buds that had broken to leaf or flower were considered to have broken. Each sample

consisted of 2 cuttings each from 3 bushes of each cultivar, though not all cultivars were available at all grower sites (see Table A1 in Appendix AA for a table of the number of cuttings by cultivar and grower and Table A2 for the dates on which the cuttings were received by cultivar.).

C.1.2.2 Temperature data

Hourly data from the UK Meteorological Office stations at NIAB-EMR (East Malling), Fittenden and Manston in Kent, Pershore in Herefordshire, Leuchars in Fife, together with data from East Adamson Farm and The James Hutton Institute in Angus, were obtained for 1 October 2015 through to 22 March 2016. For each region (Kent, Herefordshire and Eastern Scotland) the mean average hourly temperature over all stations was taken. Dundee tended to have lower temperatures whilst Herefordshire and Kent had similar average temperatures though Herefordshire was somewhat more variable than Kent (See Figure 1 for the temperatures from 01/12/2015-31/01/2016).

Figure 1 Averaged temperature data (see text for details) from 01/12/2015 until 31/01/2016 for Dundee, Herefordshire and Kent.

C.2 Model formulation

Effectiveness (E) is defined as the proportion of buds breaking. There are many factors which influence Effectiveness and chilling is an important one so we consider 3 different models of the relationship

between temperature and the Effectiveness due to chilling (E_c). The 3 functions described below were fitted to the controlled temperature data from Experiment 1 using day as the unit of time using general non-linear modelling implemented in the gnm package (Turner and Firth 2015) in R (R Core Team 2107). We are using proportions so we work with the logit of effectiveness due to chilling (E_c):

$$\text{logit}(E_c) = \log\left(\frac{E_c}{1 - E_c}\right).$$

This accounts for the fact that proportions are bounded at zero and 1 and is approximately linear when E takes intermediate values. Logit(E) increases with the proportion of buds broken being zero when $E=0.5$. Negative values indicate that fewer than half the buds have broken and positive values indicated that more than half the buds have broken.

C.2.1 Lantini model:

The Lantini model assumes that the chilling contribution from any time is a negative exponential of the temperature at that time. The total chilling accumulation then sums the contributions from all times, t , so at temperature, T , (which may vary with time, t) chilling accumulation C is:

$$C = \int_0^t e^{-aT} dt$$

The logit of Effectiveness due to chilling is a linear function of chilling time:

$$\text{logit}(E_c) = b_0 + b_1 C$$

C.2.2 Jones model:

The same model is used for chilling accumulation, C and a quadratic term is introduced to allow for supra-optimal chilling so effectiveness E_c is:

$$\text{logit}(E_c) = b_0 + b_1 C + b_2 C^2$$

The construction of this function means that the optimum chilling time (the chilling time which will lead to the largest proportion of buds breaking) increases as temperature increases and the maximum achievable effectiveness is independent of temperature. Therefore, whilst increasing the temperature increases the chilling time necessary to attain maximum effectiveness, keeping a cutting plant even at 20°C for long enough would, theoretically, still achieve maximum effectiveness according to this model, which may be unrealistic at extreme temperatures.

C.2.3 Generalized Jones model:

The Jones model is generalized so that the maximum effectiveness due to chilling becomes dependent on temperature T. Consider

$$\text{logit}(E_c) = b_0 + b_1 \int_0^t e^{-aT} dt + b_2 \left(\int_0^t e^{-(k+1)aT} dt \right)^2$$

If $k=0$, this reduces to the Jones model. It is a quadratic function of chilling accumulation where the temperature weighting for the quadratic term is allowed to differ from that of the linear term.

Assuming $b_2 < 0$ and $a > 0$ then the effect of increasing temperature, T depends on k as follows (table 1.):

Table 1 The effect of k have on the optimum chilling time and maximum achievable effectiveness

	Optimum Chilling Time	Maximum Effectiveness max(E)
$k < -0.5$	Decreases	Decreases
$k = -0.5$	Independent	Decreases
$-0.5 < k < 0$	Increases	Decreases
$k = 0$	Increases	Independent
$k > 0$	Increases	Increases

C.3 Parameter estimation, model fitting and selection.

The models are highly non-linear, therefore it is not possible to compare model fit using standard methods such as AIC or likelihood ratio tests which compare the numbers of parameters in the model to the deviance explained. Therefore the models are calibrated to controlled environment data and the residuals assessed for bias which would indicate poor formulation of the model. The calibrated

models are then applied to independent data as an offset and the quality of the fit compared for the three models. No temperature related parameters are estimated during the second stage which allows the addresses the possibility of over-fitting to the initial, controlled temperature data-set. The models were fitted within a generalised mixed modelling framework to the 2007/2008 controlled temperature data from Experiment 1 to obtain parameters that minimized the residual deviance. The AICs of the different models were considered and residuals assessed for bias. The parameters from these experiments were then applied to the temperature data described in section 3.1.2 to calculate for each proposed chilling model (parameterised as described above using data from Experiment 1), the predicted contribution of chilling accumulation to effectiveness $\text{logit}(E_c)$, for each cultivar, location and sampling date in the field data collected in 2015/16 for Experiment 2. The samples used in Experiment 2 were collected from across the United Kingdom and chilling accumulation is one of a number of factors such as soil type and moisture(for which Location is a proxy); and cultivation practices (for which Grower is a proxy) that may influence effectiveness and the influence may vary by cultivar. Therefore, a binomial generalized linear mixed model was fitted to the 2015/16 field data using the predicted $\text{logit}(E_c)$ as an offset and including cultivar and location effects together with their interaction; and grower as a random effect as follows,

$$\text{logit}(\text{Effectiveness}) = \text{Cultivar} + \text{Location} + \text{Cultivar}:\text{Location} + (\text{Grower}) + \text{offset}(\text{logit}(E_c))$$

Where E_c is the predicted contribution from the chilling model (see section 3.2) being tested. This allows us to compare between the models because the fitting of the chilling accumulation models for the offsets was performed on data from Experiment 1 and the structure of the model of overall effectiveness model fitted to data from Experiment 2 does not depend on which model of chilling accumulation is being tested.

The fact that different cultivars are grown in different parts of the country means that the data is very unbalanced and it is not possible to achieve convergence in the mixed model framework. Therefore in

order to consider sampling date as a covariate, it is necessary to treat grower as a fixed factor and fit an unbalanced binomial generalized linear model (Faraday 2005).

$\text{logit}(\text{Effectiveness}) = \text{Cultivar} + \text{Location} + \text{Cultivar}:\text{Location} + \text{Location}:\text{Grower} + \text{Sampling_Date} + \text{offset}(\text{logit}(E_c))$.

The level of imbalance with respect to cultivar and grower in the second model means that the first (mixed effects) model must be used to assess the significance of Cultivar and Location, but the second model can be used to assess whether the inclusion of sampling date improves the model fit. This is because no cultivar is planted in every location but sampling date is treated as a covariate and each location is measured on every sampling date.

D Results

When fitted to the 2007/2008 data as discussed in section C3 all three models showed significant differences in parameter estimates between cultivars ($p < 0.05$). There is considerable variation in the proportion of buds breaking within each treatment combination which suggests that chilling accumulation is not the only influence on the proportion of buds breaking (see Appendix B.1-B.3). In addition, the nature of binomially distributed data is that greater variation is to be expected where bud-break is expected to be close to 50% than when it is close to 0% or 1%. However, the removal of structure from the residuals would indicate that the model is accounting for the contribution of chilling accumulation to budbreak. The Lantini model shows considerable structure in the residuals which is removed by the Jones and generalized Jones models (see Appendix B.4). The generalized Jones model has k significantly different from 0 ($p < 0.05$) for 7 of the cultivars suggesting that the maximum effectiveness of these cultivars is particularly sensitive to temperature (Table 22). Table 33 shows the parameters obtained from the controlled temperature experiment, Experiment 1, which will be used to calculate the offset for cultivars submitted by growers in the 2015/2016 field experiment, Experiment 2. Full model details of the fitted values are in Appendix B and pictures in supplementary information.

Table 2 Estimated values of k for the Generalized Jones model. cultivars with a * have a value significantly different from 0 at the 95% confidence level

Cultivar	k	s.e(k)
Ben Starav	-6.06	3.933
Ben Klibreck*	-2.18	0.814
Ben Avon*	-1.96	0.416
Ben Gairn*	-0.69	0.108
Ben Lomond*	-0.36	0.029
Ben Baldwin*	-0.35	0.031
9521-2*	-0.34	0.048
Ben Brodtporp*	-0.27	0.067
Ben Andega*	-0.23	0.041
Ben Dorain	-0.09	0.115
Ben Tirran	-0.04	0.098
9137-2	-0.04	0.087
Amos Black	0.22	0.113
Pilot Mamkin	0.22	0.239
Ben Hope	0.32	0.381
B1834	0.35	0.299
Ben Hedda	0.62	0.668
9134-7	0.70	0.482
9559-6	1.21	1.579
Ben Vane	2.26	2.460

For the 2015/2016 data, using the generalized Jones model gave the lowest deviance, had the lowest AIC (table 4) and showed the lowest bias in the residuals (Figure 22). Temperatures over that winter were fairly warm (so plants were not subjected to over-chilling) suggesting that the improvement in fit of the Generalized Jones model relative to the Jones model was related to the temperature dependence of the maximum rather than asymmetric effects of over- and under-chilling.

Table 3 parameters for the Generalized Jones model from the controlled temperature data for cultivars submitted by growers in 2015/2016. There were significant differences in parameter estimates between cultivars ($p < 0.05$) for all 4 parameters.

Cultivar	b_1	b_2	a	k (s.e)
Ben Dorain	7.92e-02 (1.320e-02)	2.29e-04 (7.789e-05)	1.03e-01 (1.219e-02)	-9.14e-02 (1.146e-01)
Ben Gairn	8.76e-02 (1.296e-02)	-3.72e-04 (7.429e-05)	-5.26e-02 (9.436e-03)	-6.94e-01 (1.075e-01)
Ben Hope	3.35e-02 (6.298e-03)	-4.96e-05 (4.117e-05)	-1.47e-01 (1.811e-02)	3.17e-01 (3.814e-01)

Ben Klibreck	3.90e-02 (8.978e-03)	-2.40e-05 (4.408e-05)	-6.14e-02 (2.176e-02)	-2.18e+00 (8.144e-01)
Ben Starav	3.55e-02 (4.812e-03)	-3.16e-06 (1.347e-05)	-3.25e-02 (1.582e-02)	-6.06e+00 (3.933e+00)
Ben Tirran	7.77e-02 (1.194e-02)	-2.18e-04 (7.041e-05)	-1.29e-01 (1.293e-02)	-3.90e-02 (9.814e-02)

211

212 Table 4 Residual deviance and AIC for the 3 models.

Model	Res. Deviance	Res. d.f.	AIC
Lantin	6594.8	1382	6622.8
Jones	6066.3	1382	6094.3
Gen. Jones	5885.7	1382	5913.7

213

Figure 2. Binned residuals from the three models fitted to data from 03 November 2015 onwards. The points are the average residuals for each fitted value and the grey lines the boundaries in which 95% of values would be expected to lie if the model is appropriate.

Cultivar, Location and the interaction between them (Cultivar:Location) were all significant suggesting that different cultivars do better in different locations (table 5). There as a fairly large difference between the two Kent growers. However, the temperature data were taken from the nearest meteorological office station rather than on the farm and it is likely that this may account for the differences. Also, the two sites had differences in topography.

Table 5 Fixed effects and their significance for the 3 models of chilling accumulation

		Lantin		Jones		generalized Jones	
	Df	Chisq	Pr(>Chisq)	Chisq	Pr(>Chisq)	Chisq	Pr(>Chisq)
Cultivar	5	1490.2	<2.20E-06	3424.4	<2.20E-06	3424.4	<2.20E-06
Location	2	25.6	2.76E-06	58.1	2.42E-13	58.1	2.42E-13
Cultivar:Location	5	61.1	7.27E-12	67.5	3.47E-13	67.5	3.47E-13

There is considerable residual deviance in the model which remains somewhat overdispersed (see Table 4). However, the inclusion of sampling date in the generalized linear model of the 2015/16 data was significant (Chi-sq(1)=77.59, $p < 0.00001$) and somewhat reduced the bias in the residuals (Figure 2). This suggests that the time at which chilling occurs may be important or that photo-period may have an influence on bud break. Figure 3 shows the model fit for the generalized Jones model using date as covariate the model fit against the raw data is shown in figure C1 in the appendix. The bud break later in the season in Dundee is somewhat underestimated, particularly for Ben Klibreck, but estimates for Kent and Herefordshire are rather better. In general, in the case of Ben Tirran, Dundee has greater bud break than Herefordshire or Kent towards the end of the season and for Ben Gairn Herefordshire has lower bud break than Dundee or Kent. For Ben Starav and Ben Hope there is little difference between the three locations.

Figure 2 Binned residuals for the generalized Jones model when grower is a random factor(top) and when date is included as a covariate (bottom). The points are the average residuals for each fitted value and the grey lines the boundaries in which 95% of values would be expected to lie if the model is appropriate.

Figure 3 The fit for the Generalized Jones Model when date is included as a covariate. Points are the mean observed proportion open, red circles and solid lines are from Dundee, blue triangles and dotted lines are from Herefordshire and green squares and dashed lines are from Kent.

246

247 **E Discussion**

248

249 The majority of studies on bud break in winter dormant woody crops have been solely concerned with
250 the date of bud break or flowering (often expressed at the date of 50% achievement of the
251 appropriate phenological stage (Weinberger, 1950; Lantin 1977; Richardson et al 1974; Sunley et al
252 2006). Here we consider the progress of dormancy release during the season as chill accumulates
253 expressed in terms of the final proportion of bud burst after saturating exposure of blackcurrant
254 cuttings to a permissive temperature that allows optimal bud break. Previous work has shown that a
255 chill function that weights lower temperatures more heavily than warmer temperatures (such as
256 Lantin's (1977) or other exponential functions (Jones et al 2014) provides the best fit to bud burst data
257 in blackcurrant. Earlier work indicated that in some cultivars excessive chill accumulation can even act
258 to inhibit bud burst (Jones et al. 2013). A similar effect of excess chilling in blackcurrant has also been
259 reported by Sønsteby and Heide (2014a; 2016), a process that they termed secondary bud-dormancy
260 as this is a term that has been well established for seeds. The model of chill effectiveness that was
261 used to account for this effect by Jones et al. (2013) was a symmetric quadratic function of chill
262 accumulation. Here we demonstrate that an asymmetric function in which maximum achievable
263 proportion of budbreak as well as the actual proportion realised was related to temperature, the
264 generalized Jones model, gave an even better fit to the data. These results confirmed that some
265 cultivars have an optimum chilling range, meaning that it is possible to have supra- as well as sub-
266 optimal chilling and that maximum bud break is related to temperatures experienced as well as overall
267 chilling accumulation.

268 The significance of the difference between the effect of chilling accumulation (b_1 in the models)
269 between cultivars suggests that some cultivars will be more suited to climates where overall chilling
270 across the winter is higher or lower, confirming that there is scope for breeders to select

appropriately-adapted future cultivars on that basis. The difference between the k 's - temperature weightings in the quadratic term which control the relationship between maximum achievable effectiveness and temperature - suggests that some cultivars will be more affected by warm temperatures, failing to achieve full bud break in warmer winters, whilst others are more resilient to variable winters being better able to trade off between longer chilling times and warmer temperatures. In the field data, the only cultivar planted in more than one location that had a significant k was Ben Gairn. The winter in 2015/2016 was relatively warm and Ben Gairn did better in Dundee and Kent, which had a colder winter than in Herefordshire, although Ben Gairn is regarded as having a lower chilling requirement compared to the other cultivars used in this work. It is an early-flowering and ripening cultivar, but this can leave it vulnerable to spring frost damage at flowering time. Conversely, at the time of its release in the late 1980s Ben Tirran was intended as a late-flowering and ripening cultivar to spread the harvest season and avoid the most damaging spring frosts, but the trend towards warmer winters in the UK has now rendered it highly vulnerable to chill-related problems. Overall, with the warm winter in this study, Ben Tirran and Ben Hope had low bud break compared to the other cultivars, which is related to the relatively small value of a – the primary temperature weighting in both the linear and quadratic terms of the chilling models. Ben Tirran in particular is regarded as having a high chilling requirement; it is the latest of all the UK commercial blackcurrant cultivars, in terms of bud break, flowering and harvest date. The emerging problems with lack of winter chilling in Ben Tirran and other cultivars evidenced in recent warm winters in the UK have led to growers looking to exogenously applied agents to enhance bud break, together with the growing of cultivars with lower chilling requirement (such as Ben Gairn).

It is notable that these experiments were based on studies of chill response of shoots excised from plants in early October. Although there is a possibility that such excised shoots may behave differently in their chill responses than whole plants, our unpublished data, and results from Sønsteby and Heide (2014b), confirm that excised shoots can be representative of whole rooted plants.

Whilst there remains considerable unexplained variation, the models explain the proportion of the variation related to chill accumulation. Lack of systematic patterns in the residuals validates the model form and it is clear that the quadratic forms of the models avoid these patterns in both the controlled environment and field data which the linear model did not. In the field data there remains some over-estimation of bud break at low chilling accumulations and an under-estimation at mid-levels. One complication that was not accounted for by the present models is the evidence that the timing of chill also affects its effectiveness at stimulating bud burst, with Jones et al. (2013) showing that earlier chill tended to be more effective than later chill at satisfying the chill requirement. Another possibility that the present model does not incorporate is possible negation of chill by warm periods, as in the dynamic chill models (Erez et al. 1979; Fishman et al., 1987). Further experiments will be needed to disentangle the influence of the timing of chill, sequences of warm and chill and possible photo-period effects.

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Appendix

A Summary of Cuttings from Growers

Table A1 The number of cuttings received from growers, classified by cultivar

	Ben Dorain	Ben Gairn	Ben Hope	Ben Klibreck	Ben Starav	Ben Tirran
Scotland	132	132	132	132	132	132
Herefordshire 1	0	78	78	0	0	78
Herefordshire 2	0	72	72	0	0	72
Kent 1	0	46	46	0	46	46
Kent 2	0	0	0	0	66	66

Table A2 The number of cuttings received classified by cultivar and date

	Ben Dorain	Ben Gairn	Ben Hope	Ben Klibreck	Ben Starav	Ben Tirran
07/10/2015	6	12	12	6	6	12
21/10/2015	6	24	24	6	18	30
03/11/2015	6	24	24	6	18	30
17/11/2015	6	24	24	6	18	30
01/12/2015	12	30	30	12	24	36
15/12/2015	12	33	33	12	24	39
29/12/2015	12	12	12	12	12	12
12/01/2016	12	28	28	12	22	34
26/01/2016	12	24	24	12	18	30
09/02/2016	12	28	28	12	22	34
23/02/2016	12	31	31	12	22	37
08/03/2016	12	27	27	12	18	33
22/03/2016	12	31	31	12	22	37

373 B Calibration Model Fits

374 B.1 Lantin model :

375 Call:

```
376 gnm(formula = cbind(Total_Buds, No_bud) ~ Genotype +  
377 eff.fnc.lantin.gnm(Days_Chilling,  
378 Temp, Genotype), family = binomial, data = dred, start = cbasered[1:54],  
379 tolerance = 1e-10, iterMax = 3e+05, ridge = 1)
```

380

381 Deviance Residuals:

382	Min	1Q	Median	3Q	Max
383	-6.9899	-1.4537	-0.2927	1.0565	5.4557

384

385 Coefficients:

386		Estimate	Std. Error	z value	Pr(> z)
387	(Intercept)	-2.658279	0.214480	-12.394	< 2e-16 ***
388	Genotype'9137-2'	0.052925	0.303996	0.174	0.861789
389	Genotype'9521-2'	0.464011	0.293662	1.580	0.114087
390	Genotype'9559-6'	0.421299	0.292464	1.441	0.149722
391	Genotype'Amos Black'	0.657068	0.301020	2.183	0.029050 *
392	Genotype'Andega'	1.022019	0.283364	3.607	0.000310 ***
393	Genotype'Avon'	-1.213590	0.352923	-3.439	0.000585 ***
394	Genotype'B1834'	-0.647887	0.331511	-1.954	0.050661 .
395	Genotype'Baldwin'	1.333217	0.271652	4.908	9.21e-07 ***
396	Genotype'Brodorp'	1.263135	0.279764	4.515	6.33e-06 ***
397	Genotype'Dorain'	-0.382999	0.316739	-1.209	0.226589
398	Genotype'Gairn'	1.067936	0.282244	3.784	0.000154 ***
399	Genotype'Hedda'	-0.300973	0.313853	-0.959	0.337578
400	Genotype'Hope'	1.280890	0.281761	4.546	5.47e-06 ***
401	Genotype'Lomond'	0.755916	0.283543	2.666	0.007677 **
402	Genotype'Pilot Mamkin'	0.921075	0.287118	3.208	0.001337 **
403	Genotype'Tirran'	-0.094219	0.306386	-0.308	0.758450

404	Genotype 'Vane'	0.735134	0.286243	2.568	0.010222	*
405	b1Genotype '9134-7'	0.028378	0.002498	11.359	< 2e-16	***
406	b1Genotype '9137-2'	0.023850	0.002349	10.155	< 2e-16	***
407	b1Genotype '9521-2'	0.028648	0.002474	11.581	< 2e-16	***
408	b1Genotype '9559-6'	0.021423	0.002258	9.489	< 2e-16	***
409	b1Genotype 'Amos Black'	0.010216	0.002064	4.950	7.41e-07	***
410	b1Genotype 'Andega'	0.011436	0.002016	5.674	1.39e-08	***
411	b1Genotype 'Avon'	0.047942	0.003568	13.437	< 2e-16	***
412	b1Genotype 'B1834'	0.025888	0.002591	9.993	< 2e-16	***
413	b1Genotype 'Baldwin'	0.006769	0.002108	3.211	0.001323	**
414	b1Genotype 'Brodtorp'	0.012451	0.002072	6.010	1.86e-09	***
415	b1Genotype 'Dorain'	0.038030	0.002916	13.042	< 2e-16	***
416	b1Genotype 'Gairn'	0.025852	0.002630	9.829	< 2e-16	***
417	b1Genotype 'Hedda'	0.029057	0.002650	10.964	< 2e-16	***
418	b1Genotype 'Hope'	0.017065	0.002241	7.615	2.63e-14	***
419	b1Genotype 'Lomond'	0.022306	0.002344	9.518	< 2e-16	***
420	b1Genotype 'Pilot Mamkin'	0.027889	0.002425	11.503	< 2e-16	***
421	b1Genotype 'Tirran'	0.029450	0.002567	11.472	< 2e-16	***
422	b1Genotype 'Vane'	0.022023	0.002032	10.838	< 2e-16	***
423	aGenotype '9134-7'	-0.099822	0.009855	-10.129	< 2e-16	***
424	aGenotype '9137-2'	-0.089705	0.010916	-8.218	< 2e-16	***
425	aGenotype '9521-2'	-0.094894	0.009522	-9.965	< 2e-16	***
426	aGenotype '9559-6'	-0.101968	0.012612	-8.085	< 2e-16	***
427	aGenotype 'Amos Black'	-0.040268	0.016844	-2.391	0.016818	*
428	aGenotype 'Andega'	-0.091001	0.020977	-4.338	1.44e-05	***
429	aGenotype 'Avon'	-0.107842	0.007329	-14.715	< 2e-16	***
430	aGenotype 'B1834'	-0.086230	0.010676	-8.077	< 2e-16	***
431	aGenotype 'Baldwin'	-0.151461	0.047451	-3.192	0.001413	**
432	aGenotype 'Brodtorp'	-0.105318	0.021678	-4.858	1.18e-06	***
433	aGenotype 'Dorain'	-0.099069	0.007857	-12.610	< 2e-16	***
434	aGenotype 'Gairn'	-0.146594	0.014927	-9.821	< 2e-16	***


```

435 aGenotype'Hedda'      -0.110363    0.010689 -10.325 < 2e-16 ***
436 aGenotype'Hope'       -0.101704    0.016428  -6.191 5.98e-10 ***
437 aGenotype'Lomond'     -0.127844    0.014309  -8.934 < 2e-16 ***
438 aGenotype'Pilot Mamkin' -0.082963    0.009093  -9.124 < 2e-16 ***
439 aGenotype'Tirran'     -0.103266    0.009854 -10.480 < 2e-16 ***
440 aGenotype'Vane'       -0.047806    0.007748  -6.170 6.83e-10 ***

```

```
441 ---
```

```
442 Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
443
```

```
444 (Dispersion parameter for binomial family taken to be 1)
```

```
445
```

```
446 Residual deviance: 4779 on 1367 degrees of freedom
```

```
447 AIC: 7542
```

```
448
```

449 **B.2 Jones model:**

```
450
```

```
451 Call:
```

```

452 gnm(formula = cbind(Total_Buds, No_bud) ~ Genotype +
453 eff.fnc.gnm(Days_Chilling,      Temp, Genotype), family = binomial, data =
454 dred, start = cbasered,
455     tolerance = 1e-10, iterMax = 3e+05, ridge = 1)

```

```
456
```

```
457 Deviance Residuals:
```

```

458      Min      1Q   Median      3Q      Max
459 -5.4990 -1.1126 -0.1699  1.0544  5.0970

```

```
460
```

```
461 Coefficients:
```

```

462              Estimate Std. Error z value Pr(>|z|)
463 (Intercept)    -4.664e+00  3.909e-01 -11.934 < 2e-16 ***

```

464	Genotype '9137-2'	7.924e-02	5.589e-01	0.142	0.887260	
465	Genotype '9521-2'	1.449e+00	4.967e-01	2.917	0.003536	**
466	Genotype '9559-6'	1.184e+00	5.041e-01	2.349	0.018806	*
467	Genotype 'Amos Black'	4.406e-01	5.945e-01	0.741	0.458591	
468	Genotype 'Andega'	1.659e+00	5.014e-01	3.309	0.000936	***
469	Genotype 'Avon'	-8.942e-02	5.640e-01	-0.159	0.874035	
470	Genotype 'B1834'	-1.639e-01	5.928e-01	-0.276	0.782226	
471	Genotype 'Baldwin'	2.404e+00	4.637e-01	5.184	2.17e-07	***
472	Genotype 'Brodtorp'	2.551e+00	4.708e-01	5.418	6.01e-08	***
473	Genotype 'Dorain'	4.326e-01	5.334e-01	0.811	0.417319	
474	Genotype 'Gairn'	2.838e+00	4.483e-01	6.331	2.44e-10	***
475	Genotype 'Hedda'	8.104e-01	5.215e-01	1.554	0.120218	
476	Genotype 'Hope'	2.535e+00	4.727e-01	5.363	8.18e-08	***
477	Genotype 'Lomond'	1.842e+00	4.746e-01	3.880	0.000104	***
478	Genotype 'Pilot Mamkin'	1.789e+00	4.893e-01	3.656	0.000256	***
479	Genotype 'Tirran'	1.475e-01	5.455e-01	0.270	0.786875	
480	Genotype 'Vane'	1.129e+00	5.168e-01	2.184	0.028948	*
481	b1Genotype '9134-7'	7.863e-02	7.206e-03	10.912	< 2e-16	***
482	b1Genotype '9137-2'	7.154e-02	7.204e-03	9.932	< 2e-16	***
483	b1Genotype '9521-2'	5.917e-02	6.005e-03	9.853	< 2e-16	***
484	b1Genotype '9559-6'	5.450e-02	5.895e-03	9.245	< 2e-16	***
485	b1Genotype 'Amos Black'	6.981e-02	9.318e-03	7.493	6.76e-14	***
486	b1Genotype 'Andega'	4.605e-02	6.042e-03	7.620	2.53e-14	***
487	b1Genotype 'Avon'	7.556e-02	7.782e-03	9.710	< 2e-16	***
488	b1Genotype 'B1834'	6.097e-02	7.538e-03	8.088	< 2e-16	***
489	b1Genotype 'Baldwin'	2.969e-02	4.982e-03	5.959	2.54e-09	***
490	b1Genotype 'Brodtorp'	3.257e-02	5.056e-03	6.442	1.18e-10	***
491	b1Genotype 'Dorain'	7.201e-02	6.944e-03	10.370	< 2e-16	***
492	b1Genotype 'Gairn'	3.746e-02	4.475e-03	8.370	< 2e-16	***
493	b1Genotype 'Hedda'	5.291e-02	6.178e-03	8.563	< 2e-16	***
494	b1Genotype 'Hope'	4.089e-02	5.414e-03	7.553	4.26e-14	***

495	b1Genotype'Lomond'	5.003e-02	5.241e-03	9.545	< 2e-16	***
496	b1Genotype'Pilot Mamkin'	6.598e-02	6.121e-03	10.778	< 2e-16	***
497	b1Genotype'Tirran'	7.445e-02	6.967e-03	10.686	< 2e-16	***
498	b1Genotype'Vane'	6.895e-02	6.706e-03	10.283	< 2e-16	***
499	b2Genotype'9134-7'	-2.137e-04	2.638e-05	-8.100	< 2e-16	***
500	b2Genotype'9137-2'	-2.010e-04	2.714e-05	-7.405	1.31e-13	***
501	b2Genotype'9521-2'	-1.556e-04	2.346e-05	-6.633	3.28e-11	***
502	b2Genotype'9559-6'	-1.397e-04	2.164e-05	-6.456	1.07e-10	***
503	b2Genotype'Amos Black'	-2.664e-04	4.437e-05	-6.004	1.93e-09	***
504	b2Genotype'Andega'	-1.377e-04	2.488e-05	-5.534	3.13e-08	***
505	b2Genotype'Avon'	-1.661e-04	3.118e-05	-5.327	1.00e-07	***
506	b2Genotype'B1834'	-1.537e-04	2.707e-05	-5.677	1.37e-08	***
507	b2Genotype'Baldwin'	-7.018e-05	1.882e-05	-3.728	0.000193	***
508	b2Genotype'Brodorp'	-8.264e-05	1.911e-05	-4.324	1.53e-05	***
509	b2Genotype'Dorain'	-1.810e-04	2.699e-05	-6.708	1.97e-11	***
510	b2Genotype'Gairn'	-6.794e-05	1.465e-05	-4.638	3.52e-06	***
511	b2Genotype'Hedda'	-1.136e-04	2.180e-05	-5.210	1.89e-07	***
512	b2Genotype'Hope'	-1.066e-04	2.082e-05	-5.120	3.05e-07	***
513	b2Genotype'Lomond'	-1.139e-04	1.818e-05	-6.262	3.80e-10	***
514	b2Genotype'Pilot Mamkin'	-1.915e-04	2.431e-05	-7.878	< 2e-16	***
515	b2Genotype'Tirran'	-1.947e-04	2.503e-05	-7.778	< 2e-16	***
516	b2Genotype'Vane'	-2.346e-04	2.893e-05	-8.111	< 2e-16	***
517	aGenotype'9134-7'	-1.270e-01	8.390e-03	-15.136	< 2e-16	***
518	aGenotype'9137-2'	-1.164e-01	8.921e-03	-13.046	< 2e-16	***
519	aGenotype'9521-2'	-1.116e-01	9.029e-03	-12.363	< 2e-16	***
520	aGenotype'9559-6'	-1.392e-01	1.183e-02	-11.769	< 2e-16	***
521	aGenotype'Amos Black'	-1.127e-01	1.082e-02	-10.420	< 2e-16	***
522	aGenotype'Andega'	-1.258e-01	1.377e-02	-9.130	< 2e-16	***
523	aGenotype'Avon'	-1.189e-01	7.632e-03	-15.578	< 2e-16	***
524	aGenotype'B1834'	-1.112e-01	1.057e-02	-10.522	< 2e-16	***
525	aGenotype'Baldwin'	-1.848e-01	2.528e-02	-7.310	2.68e-13	***

```

526 aGenotype'Brodtorp'      -1.355e-01  1.873e-02  -7.235  4.66e-13  ***
527 aGenotype'Dorain'        -1.098e-01  7.512e-03 -14.614  < 2e-16  ***
528 aGenotype'Gairn'         -1.745e-01  1.721e-02 -10.141  < 2e-16  ***
529 aGenotype'Hedda'         -1.245e-01  1.060e-02 -11.749  < 2e-16  ***
530 aGenotype'Hope'          -1.319e-01  1.499e-02  -8.798  < 2e-16  ***
531 aGenotype'Lomond'        -1.685e-01  1.402e-02 -12.012  < 2e-16  ***
532 aGenotype'Pilot Mamkin'  -1.135e-01  8.663e-03 -13.099  < 2e-16  ***
533 aGenotype'Tirran'        -1.322e-01  8.908e-03 -14.839  < 2e-16  ***
534 aGenotype'Vane'          -8.570e-02  7.351e-03 -11.658  < 2e-16  ***

```

```
535 ---
```

```
536 Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
537
```

```
538 (Dispersion parameter for binomial family taken to be 1)
```

```
539
```

```
540 Residual deviance: 3392.9 on 1349 degrees of freedom
```

```
541 AIC: 6191.9
```

```
542
```

```
543
```

544 **B.3 Generalized Jones model:**

```
545
```

```
546 call:
```

```

547 gnm(formula = cbind(Total_Buds, No_bud) ~ Cultivar +
548 eff.fnc.all.gnm(Days_Chilling,
549   Temp, Cultivar), family = binomial, data = d8, start = cba1,
550   tolerance = 1e-10, iterMax = 30000, ridge = 1e-04)

```

```
551
```

```
552 Deviance Residuals:
```

```

553      Min       1Q   Median       3Q      Max
554 -5.5811 -1.1396 -0.1421  0.9623  4.5230

```

```
555
```

```
556 Coefficients:
```

	Estimate	Std. Error	z value	Pr(> z)	
557					
558	(Intercept)	-3.998e+00	3.494e-01	-11.442	< 2e-16 ***
559	Cultivar'9137-2'	-7.055e-01	6.213e-01	-1.136	0.256117
560	Cultivar'9521-2'	-8.417e-01	6.376e-01	-1.320	0.186813
561	Cultivar'9559-6'	1.088e+00	4.445e-01	2.447	0.014400 *
562	Cultivar'Amos Black'	1.819e-01	5.369e-01	0.339	0.734717
563	Cultivar'Andega'	1.102e-01	5.835e-01	0.189	0.850241
564	Cultivar'Avon'	-6.182e-01	6.782e-01	-0.912	0.362007
565	Cultivar'B1834'	-3.440e-01	5.774e-01	-0.596	0.551323
566	Cultivar'Baldwin'	3.789e-01	5.979e-01	0.634	0.526243
567	Cultivar'Brodorp'	1.313e+00	5.499e-01	2.388	0.016931 *
568	Cultivar'Dorain'	-4.781e-01	6.353e-01	-0.752	0.451754
569	Cultivar'Gairn'	6.146e-01	5.845e-01	1.051	0.293055
570	Cultivar'Hedda'	5.678e-01	4.875e-01	1.165	0.244110
571	Cultivar'Hope'	2.104e+00	4.400e-01	4.782	1.74e-06 ***
572	Cultivar'Klibreck'	1.782e+00	5.058e-01	3.524	0.000426 ***
573	Cultivar'Lomond'	-1.022e+00	6.436e-01	-1.588	0.112199
574	Cultivar'Pilot Mamkin'	1.339e+00	4.750e-01	2.818	0.004829 **
575	Cultivar'Starav'	1.069e+00	4.500e-01	2.375	0.017565 *
576	Cultivar'Tirran'	-6.222e-01	6.137e-01	-1.014	0.310586
577	Cultivar'Vane'	1.260e+00	4.311e-01	2.923	0.003470 **
578	b1Cultivar'9134-7'	5.872e-02	6.707e-03	8.755	< 2e-16 ***
579	b1Cultivar'9137-2'	7.504e-02	1.164e-02	6.447	1.14e-10 ***
580	b1Cultivar'9521-2'	1.065e-01	1.348e-02	7.895	< 2e-16 ***
581	b1Cultivar'9559-6'	3.783e-02	5.224e-03	7.242	4.43e-13 ***
582	b1Cultivar'Amos Black'	5.553e-02	8.753e-03	6.344	2.24e-10 ***
583	b1Cultivar'Andega'	7.374e-02	1.148e-02	6.424	1.33e-10 ***
584	b1Cultivar'Avon'	7.737e-02	1.383e-02	5.594	2.22e-08 ***
585	b1Cultivar'B1834'	4.804e-02	8.718e-03	5.510	3.60e-08 ***
586	b1Cultivar'Baldwin'	7.778e-02	1.251e-02	6.220	4.98e-10 ***
587	b1Cultivar'Brodorp'	5.154e-02	1.111e-02	4.641	3.47e-06 ***
588	b1Cultivar'Dorain'	7.918e-02	1.320e-02	6.001	1.96e-09 ***
589	b1Cultivar'Gairn'	8.763e-02	1.296e-02	6.761	1.37e-11 ***
590	b1Cultivar'Hedda'	4.127e-02	6.624e-03	6.231	4.65e-10 ***
591	b1Cultivar'Hope'	3.346e-02	6.298e-03	5.313	1.08e-07 ***

592	b1Cultivar'Klibreck'	3.898e-02	8.978e-03	4.341	1.42e-05	***
593	b1Cultivar'Lomond'	1.176e-01	1.404e-02	8.379	< 2e-16	***
594	b1Cultivar'Pilot Mamkin'	5.787e-02	8.206e-03	7.052	1.77e-12	***
595	b1Cultivar'Starav'	3.551e-02	4.812e-03	7.380	1.59e-13	***
596	b1Cultivar'Tirran'	7.765e-02	1.194e-02	6.504	7.84e-11	***
597	b1Cultivar'Vane'	4.347e-02	4.667e-03	9.314	< 2e-16	***
598	b2Cultivar'9134-7'	-5.090e-05	4.358e-05	-1.168	0.242817	
599	b2Cultivar'9137-2'	-2.245e-04	6.539e-05	-3.434	0.000595	***
600	b2Cultivar'9521-2'	-4.478e-04	7.263e-05	-6.165	7.05e-10	***
601	b2Cultivar'9559-6'	-1.091e-05	3.133e-05	-0.348	0.727510	
602	b2Cultivar'Amos Black'	-1.571e-04	4.902e-05	-3.205	0.001349	**
603	b2Cultivar'Andega'	-3.221e-04	6.417e-05	-5.019	5.20e-07	***
604	b2Cultivar'Avon'	-1.538e-04	7.378e-05	-2.084	0.037155	*
605	b2Cultivar'B1834'	-6.871e-05	4.541e-05	-1.513	0.130271	
606	b2Cultivar'Baldwin'	-3.976e-04	6.972e-05	-5.703	1.18e-08	***
607	b2Cultivar'Brodthorp'	-2.113e-04	6.390e-05	-3.306	0.000945	***
608	b2Cultivar'Dorain'	-2.292e-04	7.789e-05	-2.943	0.003247	**
609	b2Cultivar'Gairn'	-3.721e-04	7.429e-05	-5.009	5.48e-07	***
610	b2Cultivar'Hedda'	-3.129e-05	3.818e-05	-0.820	0.412475	
611	b2Cultivar'Hope'	-4.957e-05	4.117e-05	-1.204	0.228499	
612	b2Cultivar'Klibreck'	-2.403e-05	4.408e-05	-0.545	0.585681	
613	b2Cultivar'Lomond'	-5.409e-04	7.593e-05	-7.124	1.05e-12	***
614	b2Cultivar'Pilot Mamkin'	-1.226e-04	5.775e-05	-2.123	0.033775	*
615	b2Cultivar'Starav'	-3.160e-06	1.347e-05	-0.235	0.814470	
616	b2Cultivar'Tirran'	-2.175e-04	7.041e-05	-3.089	0.002011	**
617	b2Cultivar'Vane'	-1.302e-05	3.333e-05	-0.391	0.696004	
618	aCultivar'9134-7'	-1.460e-01	9.191e-03	-15.883	< 2e-16	***
619	aCultivar'9137-2'	-1.133e-01	1.201e-02	-9.430	< 2e-16	***
620	aCultivar'9521-2'	-6.292e-02	8.837e-03	-7.120	1.08e-12	***
621	aCultivar'9559-6'	-1.663e-01	1.410e-02	-11.793	< 2e-16	***
622	aCultivar'Amos Black'	-1.207e-01	1.110e-02	-10.872	< 2e-16	***
623	aCultivar'Andega'	-8.895e-02	1.311e-02	-6.783	1.17e-11	***
624	aCultivar'Avon'	-4.106e-02	1.105e-02	-3.715	0.000203	***
625	aCultivar'B1834'	-1.272e-01	1.399e-02	-9.091	< 2e-16	***
626	aCultivar'Baldwin'	-8.934e-02	1.602e-02	-5.577	2.45e-08	***

```

627 aCultivar'Brodtorp' -9.737e-02 2.103e-02 -4.629 3.68e-06 ***
628 aCultivar'Dorain' -1.031e-01 1.219e-02 -8.459 < 2e-16 ***
629 aCultivar'Gairn' -5.258e-02 9.436e-03 -5.572 2.52e-08 ***
630 aCultivar'Hedda' -1.410e-01 1.296e-02 -10.884 < 2e-16 ***
631 aCultivar'Hope' -1.474e-01 1.811e-02 -8.136 < 2e-16 ***
632 aCultivar'Klibreck' -6.136e-02 2.176e-02 -2.820 0.004807 **
633 aCultivar'Lomond' -8.060e-02 9.662e-03 -8.342 < 2e-16 ***
634 aCultivar'Pilot Mamkin' -1.200e-01 9.925e-03 -12.087 < 2e-16 ***
635 aCultivar'Starav' -3.249e-02 1.582e-02 -2.053 0.040040 *
636 aCultivar'Tirran' -1.292e-01 1.293e-02 -9.992 < 2e-16 ***
637 aCultivar'Vane' -1.014e-01 7.722e-03 -13.126 < 2e-16 ***
638 kCultivar'9134-7' 6.979e-01 4.817e-01 1.449 0.147326
639 kCultivar'9137-2' -3.894e-02 8.653e-02 -0.450 0.652682
640 kCultivar'9521-2' -3.413e-01 4.775e-02 -7.148 8.83e-13 ***
641 kCultivar'9559-6' 1.210e+00 1.579e+00 0.766 0.443402
642 kCultivar'Amos Black' 2.163e-01 1.126e-01 1.921 0.054672 .
643 kCultivar'Andega' -2.247e-01 4.061e-02 -5.532 3.17e-08 ***
644 kCultivar'Avon' -1.957e+00 4.163e-01 -4.700 2.60e-06 ***
645 kCultivar'B1834' 3.487e-01 2.994e-01 1.165 0.244173
646 kCultivar'Baldwin' -3.447e-01 3.062e-02 -11.257 < 2e-16 ***
647 kCultivar'Brodtorp' -2.681e-01 6.746e-02 -3.975 7.05e-05 ***
648 kCultivar'Dorain' -9.142e-02 1.146e-01 -0.797 0.425177
649 kCultivar'Gairn' -6.939e-01 1.075e-01 -6.453 1.10e-10 ***
650 kCultivar'Hedda' 6.218e-01 6.680e-01 0.931 0.351905
651 kCultivar'Hope' 3.166e-01 3.814e-01 0.830 0.406358
652 kCultivar'Klibreck' -2.175e+00 8.144e-01 -2.671 0.007567 **
653 kCultivar'Lomond' -3.550e-01 2.868e-02 -12.378 < 2e-16 ***
654 kCultivar'Pilot Mamkin' 2.211e-01 2.390e-01 0.925 0.354930
655 kCultivar'Starav' -6.061e+00 3.933e+00 -1.541 0.123235
656 kCultivar'Tirran' -3.896e-02 9.814e-02 -0.397 0.691366
657 kCultivar'Vane' 2.264e+00 2.460e+00 0.921 0.357293
658 ---
659 signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
660
661 (Dispersion parameter for binomial family taken to be 1)

```

662

663 Residual deviance: 3660.9 on 1481 degrees of freedom

664 AIC: 6822.1

665

B.4 Model Residuals

Figure B7 Residual deviances from the three models fitted to the calibration data. Column 1 shows deviances for the Lantini model, column 2 for the Jones model and column 3 for the Generalized Jones model. Row 1 shows residuals for observations at -5 °C, row 2 at 0 °C, row 3 at 5 °C and the bottom row at 10 °C. The number of days chilling (35,63,91 and 119) is shown on the horizontal axes.

Figure B8 Residual deviances from the three models fitted to the calibration data. Column 1 shows deviances for the Lantini model, column 2 for the Jones model and column 3 for the Generalized Jones model. Row 1 shows residuals for observations for 35 days chilling, row 2 for 63 days, row 3 for 91 days and the bottom row for 147 days chilling. The temperature (-5°C , 0°C , 5°C and 10°C) is shown on the horizontal axes.

679 C 2015/2016 Model fits

680 C.1 Generalized Linear Mixed Model including Grower Effect

681 C.1.1 Lantini model

682 Generalized linear mixed model fit by maximum likelihood (Laplace

683 Approximation) [glmerMod]

684 Family: binomial (logit)

685 Formula: cbind(open, not.open) ~ Cultivar * location + (1 | Grower)

686 Data: b

687 offset: offset.1

688

689 AIC BIC logLik deviance df.resid

690 6622.8 6696.2 -3297.4 6594.8 1382

691

692 Scaled residuals:

693 Min 1Q Median 3Q Max

694 -3.4788 -1.2724 -0.6689 0.8857 8.8395

695

696 Random effects:

697 Groups Name Variance Std.Dev.

698 Grower (Intercept) 0.01971 0.1404

699 Number of obs: 1396, groups: Grower, 5

700

701 Fixed effects:

702		Estimate	Std. Error	z value	Pr(> z)
703	(Intercept)	-3.40206	0.15623	-21.776	< 2e-16 ***
704	CultivarBen Gairn	2.17796	0.08688	25.069	< 2e-16 ***
705	CultivarBen Hope	1.35345	0.09239	14.649	< 2e-16 ***
706	CultivarBen Klibreck	0.47293	0.09382	5.041	4.63e-07 ***
707	CultivarBen Starav	0.53045	0.08988	5.901	3.60e-09 ***
708	CultivarBen Tirran	0.20347	0.10078	2.019	0.043484 *
709	locationher	-0.93044	0.21207	-4.387	1.15e-05 ***
710	locationkent	-0.27794	0.20135	-1.380	0.167459
711	CultivarBen Gairn:locationher	-0.57616	0.21498	-2.680	0.007362 **
712	CultivarBen Hope:locationher	0.82789	0.20694	4.001	6.32e-05 ***
713	CultivarBen Starav:locationher	0.16096	0.15138	1.063	0.287647

```

714 CultivarBen Gairn:locationkent -0.07477    0.12871  -0.581 0.561302
715 CultivarBen Hope:locationkent   0.45303    0.13402   3.380 0.000724 ***
716 ---
717 signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
718
719 Correlation of Fixed Effects:
720      (Intr) CltvBG CltvBH CltvBK CltvBS CltvBT lctnhr lctnkn
721 CltvrBnGrn:lctnh
722 CultvrBnGrn      -0.346
723 CultivrBnHp      -0.326  0.586
724 CltvrBnKlbr      -0.321  0.577  0.542
725 CltvrBnStrv      -0.335  0.602  0.566  0.558
726 CltvrBnTrrn      -0.299  0.537  0.505  0.497  0.519
727 locationher      -0.595  0.000  0.000  0.000  0.000 -0.255
728 locationknt      -0.626  0.000  0.000  0.000  0.000 -0.269  0.589
729 CltvrBnGrn:lctnh  0.000 -0.152  0.000  0.000  0.000  0.252 -0.390 -0.125
730 CltvrBnHp:lctnh  0.000  0.000 -0.201  0.000  0.000  0.262 -0.405 -0.130
731 0.574
732 CltvrBStrv:      0.000  0.000  0.000  0.000 -0.248  0.357 -0.453 -0.179
733 0.461
734 CltvrBnGrn:lctnk  0.000 -0.255  0.000  0.000  0.000  0.420 -0.200 -0.423
735 0.300
736 CltvrBnHp:lctnk  0.000  0.000 -0.310  0.000  0.000  0.404 -0.192 -0.407
737 0.189
738      CltvrBnHp:lctnh CltBS: CltvrBnGrn:lctnk
739 CultvrBnGrn
740 CultivrBnHp
741 CltvrBnKlbr
742 CltvrBnStrv
743 CltvrBnTrrn
744 locationher
745 locationknt
746 CltvrBnGrn:lctnh
747 CltvrBnHp:lctnh
748 CltvrBStrv:      0.479

```

```

749 CltvrBnGrn:lctnk 0.205          0.280
750 CltvrBnHp:lctnk 0.335          0.269 0.636
751 fit warnings:
752 fixed-effect model matrix is rank deficient so dropping 5 columns /
753 coefficients
754
755 C.1.2 Jones Model
756 Generalized linear mixed model fit by maximum likelihood (Laplace
757 Approximation) [glmerMod]
758 Family: binomial ( logit )
759 Formula: cbind(open, not.open) ~ Cultivar * location + (1 | Grower)
760 Data: b
761 offset: offset.j
762
763      AIC      BIC   logLik deviance df.resid
764  6094.3  6167.7 -3033.1  6066.3    1382
765
766 scaled residuals:
767      Min      1Q  Median      3Q      Max
768 -3.6223 -1.2059 -0.5241  0.8521  7.8641
769
770 Random effects:
771 Groups Name      Variance Std.Dev.
772 Grower (Intercept) 0.01403  0.1184
773 Number of obs: 1396, groups: Grower, 5
774
775 Fixed effects:
776
777      Estimate Std. Error z value Pr(>|z|)
778 (Intercept)      -4.47329    0.13812  -32.39 < 2e-16 ***
779 CultivarBen Gairn      3.13833    0.08907   35.24 < 2e-16 ***
780 CultivarBen Hope      1.83870    0.09502   19.35 < 2e-16 ***
781 CultivarBen Klibreck    0.93760    0.09657    9.71 < 2e-16 ***
782 CultivarBen Starav      0.69754    0.09297    7.50 6.25e-14 ***
783 CultivarBen Tirran     -0.02136    0.10479   -0.20 0.838515

```

```

783 locationher -1.46914 0.19463 -7.55 4.41e-14 ***
784 locationkent -0.43657 0.18154 -2.40 0.016180 *
785 CultivarBen Gairn:locationher -0.17613 0.22279 -0.79 0.429210
786 CultivarBen Hope:locationher 1.18381 0.21684 5.46 4.78e-08 ***
787 CultivarBen Starav:locationher 0.54109 0.15684 3.45 0.000561 ***
788 CultivarBen Gairn:locationkent 0.04905 0.13259 0.37 0.711454
789 CultivarBen Hope:locationkent 0.56499 0.13856 4.08 4.55e-05 ***
790 ---
791 signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
792
793 Correlation of Fixed Effects:
794 (Intr) CltvBG CltvBH CltvBK CltvBS CltvBT lctnhr lctnkn
795 CltvrBnGrn:lctnh
796 CltvrBnGrn -0.410
797 CltvrBnHp -0.384 0.596
798 CltvrBnKlbr -0.378 0.587 0.550
799 CltvrBnStrv -0.393 0.609 0.571 0.562
800 CltvrBnTrrn -0.349 0.541 0.507 0.499 0.518
801 locationher -0.522 0.000 0.000 0.000 0.000 -0.291
802 locationknt -0.560 0.000 0.000 0.000 0.000 -0.312 0.564
803 CltvrBnGrn:lctnh 0.000 -0.145 0.000 0.000 0.000 0.254 -0.452 -0.145
804 CltvrBnHp:lctnh 0.000 0.000 -0.193 0.000 0.000 0.261 -0.465 -0.149
805 0.591
806 CltvrBStrv: 0.000 0.000 0.000 0.000 -0.247 0.361 -0.519 -0.208
807 0.469
808 CltvrBnGrn:lctnk 0.000 -0.244 0.000 0.000 0.000 0.427 -0.230 -0.494
809 0.298
810 CltvrBnHp:lctnk 0.000 0.000 -0.303 0.000 0.000 0.409 -0.220 -0.473
811 0.192
812 CltvrBnHp:lctnh CltvBS: CltvrBnGrn:lctnk
813 CltvrBnGrn
814 CltvrBnHp
815 CltvrBnKlbr
816 CltvrBnStrv
817 CltvrBnTrrn

```

```

818 locationher
819 locationknt
820 CltvrBnGrn:lctnh
821 CltvrBnHp:lctnh
822 CltvrBStrv:      0.482
823 CltvrBnGrn:lctnk 0.206      0.285
824 CltvrBnHp:lctnk  0.330      0.273  0.648
825 fit warnings:
826 fixed-effect model matrix is rank deficient so dropping 5 columns /
827 coefficients
828
829 C.1.3 Generalized Jones Model
830 Generalized linear mixed model fit by maximum likelihood (Laplace
831 Approximation) [glmerMod]
832 Family: binomial ( logit )
833 Formula: cbind(open, not.open) ~ Cultivar * location + (1 | Grower)
834 Data: b
835 Offset: offset.jg
836
837      AIC      BIC   logLik deviance df.resid
838  5913.7   5987.1 -2942.9   5885.7    1382
839
840 Scaled residuals:
841      Min      1Q   Median      3Q      Max
842 -5.0276 -0.9991 -0.1993  0.8708 28.2248
843
844 Random effects:
845 Groups Name      Variance Std.Dev.
846 Grower (Intercept) 0.02146  0.1465
847 Number of obs: 1396, groups:  Grower, 5
848
849 Fixed effects:
850
851      Estimate Std. Error z value Pr(>|z|)
(Intercept)      -10.6445    0.1680  -63.35  < 2e-16 ***

```

```

852 CultivarBen Gairn          4.5056      0.1001    45.01 < 2e-16 ***
853 CultivarBen Hope           5.5846      0.1069    52.25 < 2e-16 ***
854 CultivarBen Klibreck       6.4124      0.1044    61.44 < 2e-16 ***
855 CultivarBen Starav         7.4100      0.1003    73.90 < 2e-16 ***
856 CultivarBen Tirran        -0.5731      0.1208    -4.75 2.08e-06 ***
857 locationher                0.1905      0.2288      0.83 0.404985
858 locationkent              -0.3443      0.2173    -1.58 0.113056
859 CultivarBen Gairn:locationher -0.6945      0.2294    -3.03 0.002470 **
860 CultivarBen Hope:locationher  0.3298      0.2297      1.44 0.151017
861 CultivarBen Starav:locationher -1.4193      0.1665    -8.52 < 2e-16 ***
862 CultivarBen Gairn:locationkent  0.1726      0.1463      1.18 0.238121
863 CultivarBen Hope:locationkent  0.5769      0.1537      3.75 0.000174 ***
864 ---
865 Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
866
867 Correlation of Fixed Effects:
868      (Intr) CltvBG CltvBH CltvBK CltvBS CltvBT lctnhr lctnkn
869 CltvrBnGrn:lctnh
870 CltvrBnGrn      -0.403
871 CltvrBnHp       -0.377  0.633
872 CltvrBnKlbr     -0.386  0.649  0.607
873 CltvrBnStrv     -0.402  0.675  0.632  0.647
874 CltvrBnTrrn     -0.334  0.561  0.525  0.538  0.560
875 locationher     -0.558  0.000  0.000  0.000  0.000 -0.283
876 locationknt     -0.588  0.000  0.000  0.000  0.000 -0.298  0.588
877 CltvrBnGrn:lctnh  0.000 -0.141  0.000  0.000  0.000  0.282 -0.432 -0.155
878 CltvrBnHp:lctnh  0.000  0.000 -0.189  0.000  0.000  0.281 -0.432 -0.155
879 0.583
880 CltvrBStrv:      0.000  0.000  0.000  0.000 -0.196  0.388 -0.505 -0.216
881 0.517
882 CltvrBnGrn:lctnk  0.000 -0.222  0.000  0.000  0.000  0.442 -0.233 -0.472
883 0.329
884 CltvrBnHp:lctnk  0.000  0.000 -0.283  0.000  0.000  0.421 -0.222 -0.449
885 0.221
886      CltvrBnHp:lctnh CltBS: CltvrBnGrn:lctnk

```



```

887 CultvrBnGrn
888 CultivrBnHp
889 CltvrBnKlbr
890 CltvrBnStrv
891 CltvrBnTrrn
892 locationher
893 locationknt
894 CltvrBnGrn:lctnh
895 CltvrBnHp:lctnh
896 CltvrBStrv:      0.516
897 CltvrBnGrn:lctnk 0.232      0.320
898 CltvrBnHp:lctnk  0.352      0.305  0.667
899 fit warnings:
900 fixed-effect model matrix is rank deficient so dropping 5 columns /
901 coefficients
902

```

903 C.2 Generalized Linear Model including date

904 C.2.1 Lantini Model

905 Call:

```

906 glm(formula = cbind(open, not.open) ~ Cultivar * location + date,
907      family = binomial, data = b, offset = offset.l)

```

908

909 Deviance Residuals:

910	Min	1Q	Median	3Q	Max
911	-5.3115	-1.1949	-0.5813	0.6866	6.4825

912

913 Coefficients: (5 not defined because of singularities)

914		Estimate	Std. Error	z value	Pr(> z)
915	(Intercept)	-3.084e+02	1.039e+01	-29.677	< 2e-16 ***
916	CultivarBen Gairn	2.545e+00	9.727e-02	26.161	< 2e-16 ***
917	CultivarBen Hope	1.536e+00	1.009e-01	15.229	< 2e-16 ***
918	CultivarBen Klibreck	5.458e-01	1.034e-01	5.280	1.29e-07 ***

```

919 CultivarBen Starav          7.517e-01  1.008e-01   7.456 8.89e-14 ***
920 CultivarBen Tirran          2.127e-01  1.092e-01   1.947 0.051491 .
921 locationher                 -9.338e-01  1.281e-01  -7.289 3.13e-13 ***
922 locationkent                -3.838e-01  1.118e-01  -3.433 0.000598 ***
923 date                        1.810e-02  6.167e-04  29.359 < 2e-16 ***
924 CultivarBen Gairn:locationher -8.507e-01  2.063e-01  -4.123 3.74e-05 ***
925 CultivarBen Hope:locationher  8.697e-01  1.958e-01   4.442 8.90e-06 ***
926 CultivarBen Klibreck:locationher      NA          NA          NA          NA
927 CultivarBen Starav:locationher  1.727e-01  1.661e-01   1.040 0.298439
928 CultivarBen Tirran:locationher      NA          NA          NA          NA
929 CultivarBen Gairn:locationkent -7.622e-02  1.402e-01  -0.544 0.586575
930 CultivarBen Hope:locationkent  5.510e-01  1.443e-01   3.819 0.000134 ***
931 CultivarBen Klibreck:locationkent      NA          NA          NA          NA
932 CultivarBen Starav:locationkent      NA          NA          NA          NA
933 CultivarBen Tirran:locationkent      NA          NA          NA          NA
934 ---
935 Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
936
937 (Dispersion parameter for binomial family taken to be 1)
938
939 Null deviance: 6537.9 on 1395 degrees of freedom
940 Residual deviance: 3337.5 on 1382 degrees of freedom
941 AIC: 5534.9
942
943 Number of Fisher Scoring iterations: 5
944
945 C.2.2 Jones Model
946 Call:
947 glm(formula = cbind(open, not.open) ~ Cultivar * location + date,
948     family = binomial, data = b, offset = offset.j)
949

```

```

950 Deviance Residuals:
951      Min       1Q   Median       3Q      Max
952 -5.1656  -1.1983  -0.4803   0.7834   6.4030
953
954 Coefficients: (5 not defined because of singularities)
955
956              Estimate Std. Error z value Pr(>|z|)
957 (Intercept)      -2.286e+02  1.045e+01 -21.870 < 2e-16 ***
958 CultivarBen Gairn      3.456e+00  9.729e-02  35.520 < 2e-16 ***
959 CultivarBen Hope      1.983e+00  1.018e-01  19.475 < 2e-16 ***
960 CultivarBen Klibreck  1.015e+00  1.038e-01   9.773 < 2e-16 ***
961 CultivarBen Starav    8.832e-01  1.013e-01   8.716 < 2e-16 ***
962 CultivarBen Tirran   -5.789e-02  1.115e-01  -0.519  0.60371
963 locationher      -1.475e+00  1.311e-01 -11.255 < 2e-16 ***
964 locationkent     -5.259e-01  1.147e-01  -4.583 4.57e-06 ***
965 date              1.331e-02  6.204e-04  21.447 < 2e-16 ***
966 CultivarBen Gairn:locationher -3.887e-01  2.053e-01  -1.893  0.05832 .
967 CultivarBen Hope:locationher  1.177e+00  1.989e-01   5.915 3.32e-09 ***
968 CultivarBen Klibreck:locationher      NA          NA      NA      NA
969 CultivarBen Starav:locationher  5.470e-01  1.674e-01   3.268  0.00108 **
970 CultivarBen Tirran:locationher      NA          NA      NA      NA
971 CultivarBen Gairn:locationkent  5.970e-02  1.413e-01   0.422  0.67267
972 CultivarBen Hope:locationkent  6.407e-01  1.470e-01   4.359 1.30e-05 ***
973 CultivarBen Klibreck:locationkent      NA          NA      NA      NA
974 CultivarBen Starav:locationkent      NA          NA      NA      NA
975 CultivarBen Tirran:locationkent      NA          NA      NA      NA
976 ---
977
978 Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
979
980 (Dispersion parameter for binomial family taken to be 1)
981
982 Null deviance: 8475.1  on 1395  degrees of freedom

```

981 Residual deviance: 3354.9 on 1382 degrees of freedom

982 AIC: 5552.3

983

984 Number of Fisher Scoring iterations: 5

985

986 *C.2.3 Generalized Jones model*

987 Call:

988 glm(formula = cbind(open, not.open) ~ Cultivar * location + date,

989 family = binomial, data = b, offset = offset.jg)

990

991 Deviance Residuals:

992	Min	1Q	Median	3Q	Max
-----	-----	----	--------	----	-----

993	-5.0747	-1.1681	-0.2494	0.8817	6.5527
-----	---------	---------	---------	--------	--------

994

995 Coefficients: (5 not defined because of singularities)

996		Estimate	Std. Error	z value	Pr(> z)
-----	--	----------	------------	---------	----------

997	(Intercept)	-1.049e+02	1.108e+01	-9.472	< 2e-16 ***
-----	-------------	------------	-----------	--------	-------------

998	CultivarBen Gairn	4.651e+00	1.042e-01	44.625	< 2e-16 ***
-----	-------------------	-----------	-----------	--------	-------------

999	CultivarBen Hope	5.656e+00	1.102e-01	51.321	< 2e-16 ***
-----	------------------	-----------	-----------	--------	-------------

1000	CultivarBen Klibreck	6.520e+00	1.078e-01	60.509	< 2e-16 ***
------	----------------------	-----------	-----------	--------	-------------

1001	CultivarBen Starav	7.565e+00	1.048e-01	72.174	< 2e-16 ***
------	--------------------	-----------	-----------	--------	-------------

1002	CultivarBen Tirran	-5.973e-01	1.237e-01	-4.829	1.37e-06 ***
------	--------------------	------------	-----------	--------	--------------

1003	locationher	2.659e-01	1.406e-01	1.892	0.058541 .
------	-------------	-----------	-----------	-------	------------

1004	locationkent	-3.840e-01	1.248e-01	-3.077	0.002092 **
------	--------------	------------	-----------	--------	-------------

1005	date	5.594e-03	6.572e-04	8.512	< 2e-16 ***
------	------	-----------	-----------	-------	-------------

1006	CultivarBen Gairn:locationher	-9.508e-01	2.063e-01	-4.608	4.06e-06 ***
------	-------------------------------	------------	-----------	--------	--------------

1007	CultivarBen Hope:locationher	1.231e-01	2.095e-01	0.588	0.556690
------	------------------------------	-----------	-----------	-------	----------

1008	CultivarBen Klibreck:locationher	NA	NA	NA	NA
------	----------------------------------	----	----	----	----

1009	CultivarBen Starav:locationher	-1.455e+00	1.706e-01	-8.528	< 2e-16 ***
------	--------------------------------	------------	-----------	--------	-------------

1010	CultivarBen Tirran:locationher	NA	NA	NA	NA
------	--------------------------------	----	----	----	----

1011	CultivarBen Gairn:locationkent	1.634e-01	1.495e-01	1.093	0.274506
------	--------------------------------	-----------	-----------	-------	----------

1012 CultivarBen Hope:locationkent 5.983e-01 1.574e-01 3.800 0.000145 ***

1013 CultivarBen Klibreck:locationkent NA NA NA NA

1014 CultivarBen Starav:locationkent NA NA NA NA

1015 CultivarBen Tirran:locationkent NA NA NA NA

1016 ---

1017 Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

1018

1019 (Dispersion parameter for binomial family taken to be 1)

1020

1021 Null deviance: 20732.8 on 1395 degrees of freedom

1022 Residual deviance: 3647.1 on 1382 degrees of freedom

1023 AIC: 5844.4

1024

1025 Number of Fisher Scoring iterations: 5

Figure C1 The fit for the Generalized Jones Model when date is included as a covariate. Points are the observed proportion open for each sample, red circles and solid lines are from Dundee, blue triangles and dotted lines are from Herefordshire and green squares and dashed

Table 1

	Optimum Chilling Time	Maximum Effectiveness max(E)
$k < -0.5$	Decreases	Decreases
$k = -0.5$	Independent	Decreases
$-0.5 < k < 0$	Increases	Decreases
$k = 0$	Increases	Independent
$k > 0$	Increases	Increases

Table 1 The effect of k have on the optimum chilling time and maximum achievable effectiveness

Table 2

Cultivar	k	s.e(k)
Ben Starav	-6.06	3.933
Ben Klibreck*	-2.18	0.814
Ben Avon*	-1.96	0.416
Ben Gairn*	-0.69	0.108
Ben Lomond*	-0.36	0.029
Ben Baldwin*	-0.35	0.031
9521-2*	-0.34	0.048
Ben Brodthorp*	-0.27	0.067
Ben Andega*	-0.23	0.041
Ben Dorain	-0.09	0.115
Ben Tirran	-0.04	0.098
9137-2	-0.04	0.087
Amos Black	0.22	0.113
Pilot Mamkin	0.22	0.239
Ben Hope	0.32	0.381
B1834	0.35	0.299
Ben Hedda	0.62	0.668
9134-7	0.70	0.482
9559-6	1.21	1.579
Ben Vane	2.26	2.460

Table 1 Estimated values of k for the Generalized Jones model. cultivars with a * have a value significantly different from 0 at the 95% confidence level

Table 3

Cultivar	b ₁	b ₂	a	k (s.e)
Ben Dorain	7.92e-02 (1.320e-02)	-2.29e-04 (7.789e-05)	-1.03e-01 (1.219e-02)	-9.14e-02 (1.146e-01)
Ben Gairn	8.76e-02 (1.296e-02)	-3.72e-04 (7.429e-05)	-5.26e-02 (9.436e-03)	-6.94e-01 (1.075e-01)
Ben Hope	3.35e-02 (6.298e-03)	-4.96e-05 (4.117e-05)	-1.47e-01 (1.811e-02)	3.17e-01 (3.814e-01)
Ben Klibreck	3.90e-02 (8.978e-03)	-2.40e-05 (4.408e-05)	-6.14e-02 (2.176e-02)	-2.18e+00 (8.144e-01)
Ben Starav	3.55e-02 (4.812e-03)	-3.16e-06 (1.347e-05)	-3.25e-02 (1.582e-02)	-6.06e+00 (3.933e+00)
Ben Tirran	7.77e-02 (1.194e-02)	-2.18e-04 (7.041e-05)	-1.29e-01 (1.293e-02)	-3.90e-02 (9.814e-02)

Table 1 parameters for the Generalized Jones model from the controlled temperature data for cultivars submitted by growers in 2015/2016

Table 4

Model	Res. Deviance	Res. d.f.	AIC
Lantin	6594.8	1382	6622.8
Jones	6066.3	1382	6094.3
Gen. Jones	5885.7	1382	5913.7

Table 1 Residual deviance and AIC for the 3 models.

Table 5

	Df	Lantin		Jones		generalized Jones	
		Chisq	Pr(>Chisq)	Chisq	Pr(>Chisq)	Chisq	Pr(>Chisq)
Cultivar	5	1490.2	<2.20E-06	3424.4	<2.20E-06	3424.4	<2.20E-06
Location	2	25.6	2.76E-06	58.1	2.42E-13	58.1	2.42E-13
Cultivar:Location	5	61.1	7.27E-12	67.5	3.47E-13	67.5	3.47E-13

Table 1 Fixed effects and their significance for the 3 models of chilling accumulation

Figure 1

Figure 1gray

Figure 2

Figure 3

Figure 4

Figure 4gray

Figure C1 :Appendix [part of manuscript]

Figure C1 grayscale: Appendix [part of manuscript]

S Calibration Model Fits

S.1 Lantin model :

Figure S1 Proportion of buds broken at the end of the controlled data experiment. Lines represent predictions from the Lantin model and points represent observed data. Black shows outcomes at -5 °C, red 0 °C, green 5 °C and blue 10 °C.

Figure S2 Logit transform of the proportion of buds broken at the end of the controlled data experiment. Lines represent predictions from the Lantin model and points represent observed data. Black shows outcomes at 5 °C, red 0 °C, green 5 °C and blue 10 °C.

S.2 Jones model:

Figure S3 Proportion of buds broken at the end of the controlled data experiment. Lines represent predictions from the Jones model and points represent observed data. Black shows outcomes at -5 °C, red 0 °C, green 5 °C and blue 10 °C.

Figure S4 Logit transform of the proportion of buds broken at the end of the controlled data experiment. Lines represent predictions from the Lantin model and points represent observed data. Black shows outcomes at -5 °C, red 0 °C, green 5 °C and blue 10 °C.

S.3 Generalized Jones model:

Figure S5 Proportion of buds broken at the end of the controlled data experiment. Lines represent predictions from the Generalized Jones model and points represent observed data. Black shows outcomes at -5 °C, red 0 °C, green 5 °C and blue 10 °C.

Figure S6 Logit of the proportion of buds broken at the end of the controlled data experiment. Lines represent predictions from the Generalized Jones model and points represent observed data. Black shows outcomes at -5 °C, red 0 °C, green 5 °C and blue 10 °C.