Modelling the Dormancy and Chilling Requirements in Raspberry

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Introduction

The Raspberry Breeding Consortium (RBC) at James Hutton Limited (JHL) is breeding a number of new floricane and primocane raspberry varieties. Recent releases include Glen Dee and Glen Carron with more varieties in the pipeline. The global trend in raspberry production is for cold stored, long cane material produced in pots of substrate. This approach minimises costs and pest and disease problems. However, this technique relies on a good understanding of the dormancy and chilling requirements of each variety.

To help the industry successfully utilise the new RBC varieties, we have established their dormancy and chilling requirements. This information will enable growers and propagators to:

- Match varieties to specific commercial needs, such as long cane production and use in cold or warm climates
- Optimise cold storage for long cane production by variety
- Manipulate crop timings to programme production
- Maximise yields by ensuring complete bud break
- Understand the resilience of varieties in different climatic conditions
- Harvest long cane plants at the optimum time to ensure successful cold storage and bud break

This grower report builds on AHDB Grower Report 'A Review of Dormancy and Chilling Requirements in Raspberries' published in November 2015, where we detailed a new model to describe the dormancy of raspberry. The model showed significant promise. However, experimental verification with different varieties under a range of climate conditions and seasons was required to calibrate the model. Following three years of experiments at JHL, this work has now been completed.

This report summarises the chilling responses and requirements of four different RBC varieties: Glen Dee, Glen Carron, RBC16F6 and Glen Ample. RBC16F6 is a large fruited, early, root rot resistant floricane variety, developed from a floricane x primocane cross, that is currently being bulked up for commercialisation by the RBC in 2020.

Definitions of terms used in the report

A number of terms used about dormancy in this report are defined below:

- **Endo-dormancy** - is dormancy controlled within an individual bud *per se*. Typically a period of cold (c. 1 to 4^{O}C) temperature is required to break this process.

- **Eco-dormancy -** occurs once the bud has been chilled. Effectively the bud is primed but now needs improved environmental conditions, typically warm temperatures, in order to grow and for the leaves to burst.

- **Chilling** - is the biological process whereby the accumulation of cold temperatures promotes the breaking of dormancy. Buds burst after plants have received a cumulated number of 'chilling hours'.

- **Chilling hours -** often considered to be a fixed number of hours at a standard temperature, often 4°C. However, the number of chilling hours required by plants can vary with temperature and between varieties.

- **Thermal time** - Many other plant developmental responses are also a function of temperature. Plants are considered to measure time by accumulating a set amount of thermal time. This is the temperature summed between one phenological event to another (e.g. sowing of a seed to flowering). Thus development progresses at a faster rate at higher temperatures compared to lower ones.

The model

The raspberry dormancy model detailed in AHDB Grower Report 'A Review of Dormancy and Chilling Requirements in Raspberries' predicted the date of first bud break for a number of new and existing raspberry floricane varieties. The model developed was a two-step model. The first step of the model predicted when the plant had been sufficiently chilled to break endo-dormancy. The second step (eco-dormancy) then predicted the date of bud burst assuming that it was a function of warm temperatures starting from the end of the chilling phase. The key temperature responses are illustrated in Figure 1.

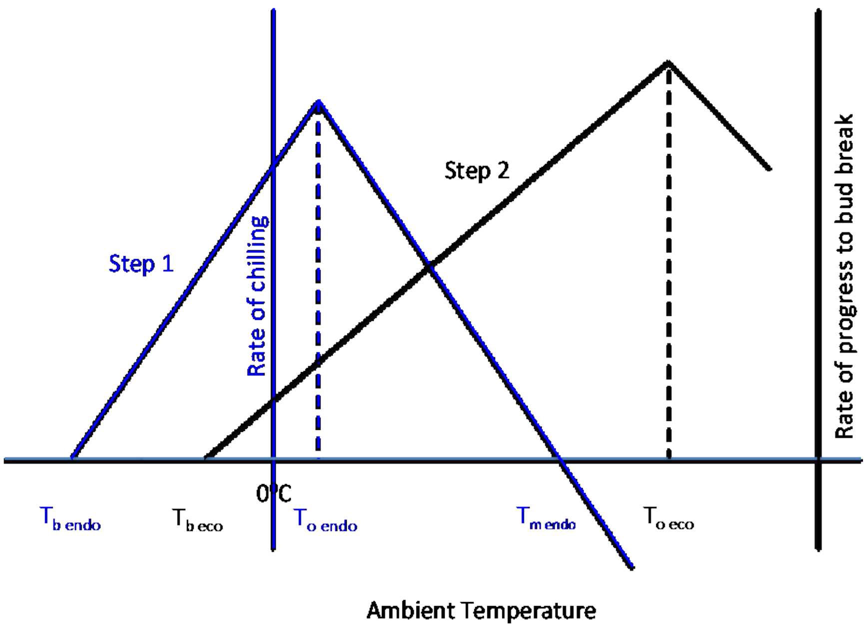


Figure 1. The two indicative temperature responses used in the floricane raspberry dormancy model. Step 1 represents the chilling response (endo-dormancy) and Step 2 is the warmer temperature response (eco-dormancy) required to break buds post chilling. Base temperature for chilling °C = $T_{b\ endo}$; Optimum chilling temperature °C = $T_{o\ endo}$; Maximum temperature for chilling °C = $T_{m\ endo}$; Base temperature post chilling = $T_{b\ eco}$; Optimum chilling temperature °C = $T_{o\ eco}$.

The model assumed the chilling response to temperature (endo-dormancy, Step 1, Figure 1) was triangular with optimum rate of chilling occurring at $T_{o\ endo}$. Based on the raspberry literature, the optimum temperature to break endo-dormancy was anticipated to be around 3 to 8°C. The model quantified the impact of temperatures above or below the optimum ($T_{o\ endo}$) on the rate of chilling. The higher temperature response (eco-dormancy, Step 2; Figure 1) began once chilling was completed. The post chilling temperature response was also assumed to be triangular. Actual bud break occurred after the plant had received a set number of degree days (thermal time) post chilling.

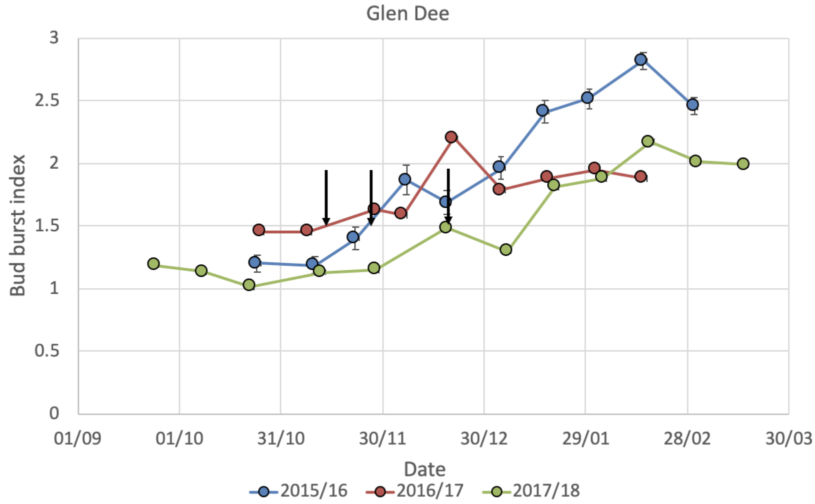
The model was run using hourly temperature data from 1st November. The model was solved for each variety by adjusting the chilling and post chilling day degrees, optimum and base temperatures until the model accurately predicted the date of first bud break of raspberry canes. This calibration data was gathered at JHL for canes grown between 2009 and 2018. Therefore, each variety could have up to nine years of data. A powerful evolutionary algorithm was used to search for optimal chilling hours, post chilling hours and optimal / base temperatures.

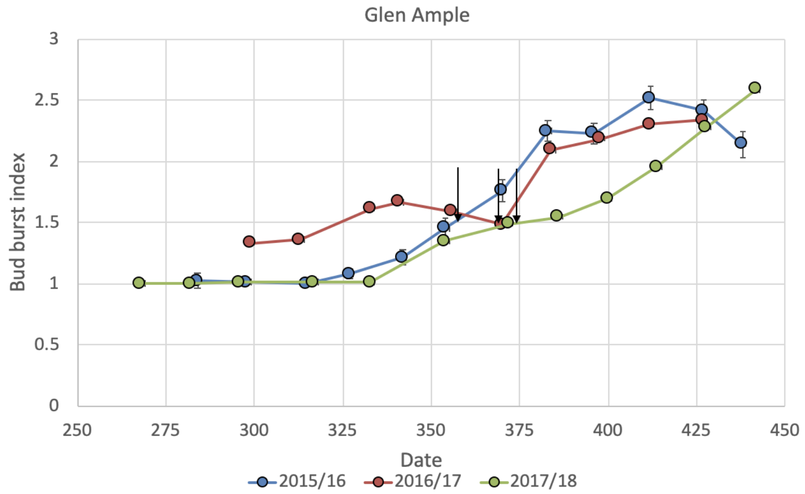
Dormancy transfer experiments

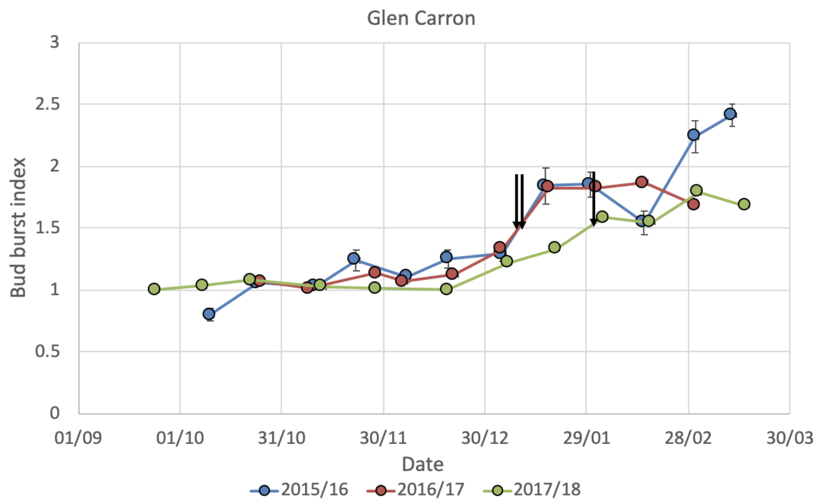
In addition, for three years (2015 to 2017) we conducted detailed experiments to determine the end of chilling for each of the four varieties: Glen Dee, Glen Ample, Glen Carron and RBC16F6. The approach was to transfer five canes of outdoor grown batches of each variety into a warm (>18°C) glasshouse at around two weekly intervals from mid-October onwards. After three weeks in the warm temperatures, the growth stage of the first 25 buds on each transferred cane were assessed. The transfer approach enabled a clear understanding of when canes had been fully chilled by outdoor temperatures. The growth stage of each bud (after three weeks of warm temperatures) was classified as tight bud (B), bud burst in leaf (BB), flowering (FL) or dead (D). To index the rate of progress of the cane through endo dormancy, the bud stages were enumerated as B=1, BB=2, FL= 3, D=4.

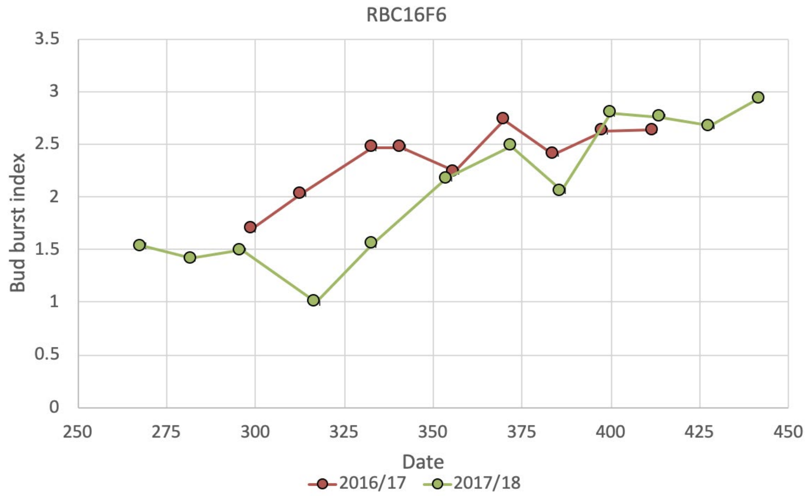
Results of transfer experiments

Figures 2A, B, C and D (overleaf) show the mean bud stage index three weeks after the canes of each variety were transferred from outside into a warm glasshouse. A low index means that the buds did not develop on warming, post transfer from outdoors. Effectively, given the scoring mechanism, a bud burst index of 1.5 means at least 50% of buds on a cane had burst after three weeks post transfer to a warm glasshouse. Figures 2A (Glen Dee), B (Glen Ample) and C (Glen Carron) all show that buds on canes transferred early in the winter did not develop on transfer (bud burst index was below 1.5). With later transfers the buds developed rapidly on warming (index > 1.5). For the analysis, we interpolated the date of chilling completion as the time when buds achieved a bud burst index of 1.5 post transfer. These dates are marked on Figures 2A, B and C with black downwards arrows. There were striking differences in the varietal responses. Glen Dee ended its outdoor chilling phase consistently earlier than Glen Ample and Glen Carron. However, for RBC16F6 (Figure 2D) the buds grew rapidly on transfer to the warm irrespective of transfer date. This data suggests that RBC16F6 has no specific chilling requirement.


Glen Dee
Bud burst index
3
2.5
2
1.5
1
0.5
0
01/09
01/10
31/10
30/11
30/12
29/01
28/02
30/03
Date
2015/16
2016/17
2017/18


Glen Ample
Bud burst index
3
2.5
2
1.5
1
0.5
0
250
275
300
325
350
375
400
425
450
Date
2015/16
2016/17
2017/18


Glen Carron
Bud burst index
3
2.5
2
1.5
1
0.5
0
01/09
01/10
31/10
30/11
30/12
29/01
28/02
30/03
Date
2015/16
2016/17
2017/18



Figures 2A, 2B, 2C and 2D. The bud burst index of Glen Dee (A), Glen Ample (B), Glen Carron (C) and RBC16F6 (D; only two years data available) measured three weeks after canes were transferred from outside to a warm glasshouse. Date is the day of transfer from outside into the warm glasshouse. The black arrows show the interpolated date of endo-dormancy cessation, taken as the date an index of 1.5 was achieved by the canes except for RBC16F6 where there was no consistent evidence of a chilling response.

For the varieties showing a chilling response, on average, for all three years:

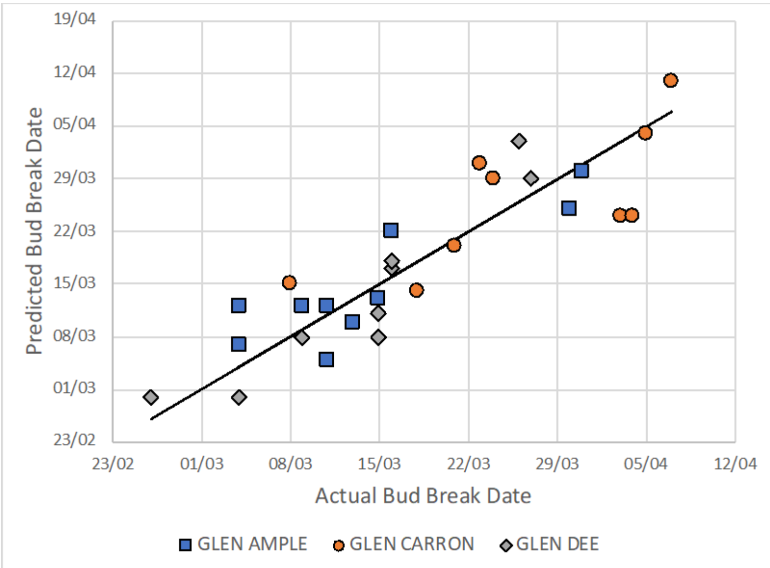
- **Glen Dee** had completed dormancy on **2 December** (30 November, 2015; 14 November, 2016; 21 December, 2017)
- **Glen Ample** had a mean date one month later on **2 January** (23 December, 2015, 5 January, 2016 and 9 January, 2017)
- **Glen Carron** had a mean date of **17 January** (9 January 2015, 10 January 2016 and 1 February, 2017).

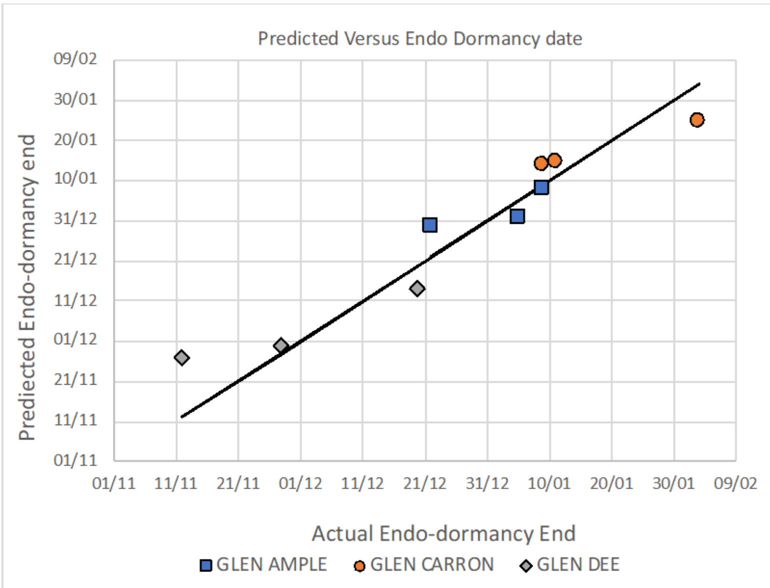
The differences between these three varieties (Glen Dee, Glen Ample and Glen Carron) were analysed by non-parametric ANOVA. This showed highly significant differences between varietal response ($P<0.01$) and indicates a very strong genetic component to the dormancy process in raspberry.

Quantification of the dormancy phase in raspberry

The model was re-run with the additional data from the transfer experiment. This provided a more robust calculation of the chilling hours for the three varieties that showed a dormancy response, namely Glen Dee, Glen Ample and Glen Carron. Figure 3A shows the predicted versus actual date of bud break for these three varieties. Figure 3B shows the predicted versus actual date when endo-dormancy ceased for each of the three years in the transfer experiment.

Figure 3A shows an excellent fit to the model. The overall coefficient of determination (r^2) for all varieties was 0.68 with a forecast error of +/- 5.2 days. For Glen Dee, Glen Ample and Glen Carron the r^2 and errors were; 0.78 and +/-4.3 days; 0.76 and +/- 4.6 days; 0.52 and +/- 8.0 days, respectively. The model accurately forecast the end of chilling (endo-dormancy) (see Figure 3B), the overall r^2 was 0.87 with a forecast error of +/- 7.2 days.





Figures 3A and B. The predicted versus actual date for first bud break (endo and eco dormancy cessation) [A] and endo dormancy cessation [B] of three raspberry varieties recorded between 2008 and 2018 at JHL.

The parameter values determined by the model are shown in Table 1. The evolutionary algorithm used to fit the model showed small differences in optimum chilling temperatures between varieties. Glen Dee had an optimum chilling temperature of 4.2ºC compared to

Glen Ample and Glen Carron at 4.8°C and 4.1°C, respectively. The optimum temperatures to promote bud break post chilling were much higher at 29, 34 and 35°C for Glen Dee, Glen Ample and Glen Carron, respectively. Genetic algorithms are deterministic and do not provide parameter error values, although these optima are well within the ranges expected for dormancy processes of woody species.

Table 1. Key parameter values for different varieties determined by the model and the derived number of chilling hours, at a standard 4°C, required to break dormancy.

Parameters	**Glen Dee**	**Glen Ample**	**Glen Carron**
Optimum chilling temperature ($T_{o\ endo}$) °C	4.2	4.8	4.1
Base temperature for chilling ($T_{b\ endo}$) °C	-0.54	-9.1	-7.1
Thermal time to bud break for chilling (Θ_{endo}) day degrees	49.3	646	758
Optimum temperature for bud break post chilling ($T_{o\ eco}$) °C	29.2	34.6	35
Base temperature post chilling ($T_{b\ eco}$) °C	-14.8	-9.3	-7.6
Thermal time to bud break post chilling (Θ_{eco}) day degrees	1820	897	758
r^2	78%	76%	52%
Chilling Units (hours at 4°C required to break chilling of 50% the buds)	**236**	**1049**	**1268**
Predicted Total Chilling Units (hours at 4°C required to break chilling of all buds)*	**750**	**1500**	**1750**

* Cold storage duration trials are required to confirm total chilling units.

For ease of comparison and validation with previous experimental data in the literature, Table 1 also shows the predicted number of chilling hours at a set 4°C which are required to break dormancy of 50% of the buds for each of the varieties. It showed some important differences. Glen Dee was predicted to require just 236 hours at 4°C, Glen Ample 1,049 hours at 4°C to break dormancy compared to 1,268 hours at 4°C for Glen Carron. These number of chilling hours only determine the number of degree days for 50% of the buds to burst on a stem. We estimate an additional 500 hours per variety are required for full completion of chilling. The cold store (4°C) duration for a cane to break chilling for each variety (rounded to nearest 250 hours) is predicted to be 750 hours for Glen Dee, 1500 hours for Glen Ample and 1750 hours for Glen Carron.

Although further definitive cold storage duration trials are required to confirm these total chilling hour estimates, the derived chilling hours for each variety were broadly consistent with known data. White (1999) demonstrated by using cold stores that Glen Moy required 951 chilling units at 4°C for 50% bud break. Similarly, Mazzitelli et al. (2007) showed Glen Ample required c. 1300 chilling units at 4°C for 50% of the buds to break.

Summary

The new model determines the optimum chilling temperature and the number of hours to break dormancy for Glen Dee, Glen Ample and Glen Carron. This has shown that there are low chill, medium chill and high chill varieties. It can easily be updated each year as new data becomes available for both existing and new RBC varieties.

The model shows that effective variety selection can help match and optimise varieties for different locations. Clearly cooler growing regions may need varieties that require higher chilling hours (to minimise mid-winter bud break and manage frost damage risk). Conversely warmer climates may require lower chill varieties.

The model also provides an excellent framework for decision support, in terms of varietal selection for different growing regions and managing the time of harvest, duration and temperature of cold storage to ensure maximum bud break.

Moreover, the model can be deployed in other ways:

- To optimise harvesting date for long cane production by propagators
- To predict date of bud break on grower sites.

Guidance for growers and propagators

Table 2 (overleaf) shows potential uses for the new RBC varieties based on their chilling requirements. It is important to note that as RBC16F6 is a new variety being released in 2020 and has not yet been trialled extensively in a range of different climatic environments. Thus potential usage may change over time as more information becomes available.

Table 2. Potential uses for the new RBC varieties based on their chilling requirements

	Potential Use*					
Variety	**Long cane**	**UK**	**Colder Climates**	**Warmer Climates**	**Notes for Growers**	**Notes for Propagators**
Glen Dee	✓	✓	✓	✓	• Performs well in Scotland • Of interest to warmer areas as has a low chilling requirement	Harvest early in the autumn before plants have received 750 chilling units in the field to ensure plants remain dormant in cold storage
Glen Ample	✓	✓	✓		• Programmed cold stored long cane to fulfil chilling requirement • Cold climates where chilling hours will be naturally fulfilled	
Glen Carron	✓	✓	✓		• Mid to late season programmed cold stored long cane as has a high chilling requirement • Cold climates where chilling hours will be naturally fulfilled	
RBC16F6	✓	✓	Not yet trialled	Not yet trialled	• Floricane x primocane cross • This variety does not appear to require chilling	

*Potential uses may change over time as more data becomes available.

References

Mazzitelli, L., Hancock, R.D., Haupt, S., Walker, P.G., Pont, S.D.A., McNicol, R.J., Cardle, L., Morris, J., Viola, R., Brennan, R., Heldey, P.E. and Taylor, M.A. (2007). Co-ordinated gene expression during phases of dormancy release in raspberry (*Rubus idaeus* L.) buds. *Journal of Experimental Botany*, 58, 1035-1045.

White, J.M. (1999). Factors influencing the control of dormancy and bud break in raspberry (*Rubus idaeus* L.). PhD Thesis, University of Essex, UK.