A model to predict the beginning of the pollen season

Toldam-Andersen, Torben Bo

Published in:
Grana

DOI:
10.1080/00173139109427810

Publication date:
1991

Document Version
Publisher's PDF, also known as Version of record

Grana
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/sgra20

A model to predict the beginning of the pollen season

Torben B. Andersen [a]

[a] Institute of Agricultural Sciences, Section of Horticulture , Royal Veterinary and Agricultural University , Bülowsvej 13, DK-1870, Frederiksberg C, Denmark

Published online: 01 Sep 2009.

To cite this article: Torben B. Andersen (1991) A model to predict the beginning of the pollen season, Grana, 30:1, 269-275, DOI: 10.1080/00173139109427810

To link to this article: http://dx.doi.org/10.1080/00173139109427810

Grana 30: 269–275, 1991

A model to predict the beginning of the pollen season

TORBEN B. ANDERSEN

Andersen, T. B. 1991. A model to predict the beginning of the pollen season. – Grana 30: 269–275. 1991. Odense, September 1991. ISSN 0017-3134.

In order to predict the beginning of the pollen season, a model comprising the Utah phenoclimatography Chill Unit (CU) and ASYMCUR-Growing Degree Hour (GDH) submodels were used to predict the first bloom in *Alnus*, *Ulmus* and *Betula*. The model relates environmental temperatures to rest completion and bud development. As phenologic parameter 14 years of pollen counts were used. The observed dates for the beginning of the pollen seasons were defined from the pollen counts and compared with the model prediction. The CU and GDH submodels were used as:
1. A fixed day model, using only the GDH model with 1st January as fixed initiation point.
2. A CU/GDH model, with a fixed sum of Chill Unit requirement as initiation point for the subsequent GDH accumulation.
3. A dynamic CU/GDH model, based on a dynamic relationship between CU and GDH.

It is concluded that the CU and GDH relationships defined for fruit trees are generally applicable, and give a reasonable description of the growth processes of other trees. This type of model can therefore be of value in predicting the start of the pollen season. The predicted dates were generally within 3-5 days of the observed.
Finally the possibility of frost damage is discussed in relation to the great variation in the total pollen counts observed from one year to the other.

Torben Bo Andersen, Institute of Agricultural Sciences, Section of Horticulture, Royal Veterinary and Agricultural University, Bülowsvej 13, DK-1870 Frederiksberg C, Denmark.

Flowering is a phenological event, which is a result of a long period of development. The buds are initiated and differentiated into flower and vegetative buds during the summer. The falling temperatures of late summer causes a gradually change into a phase of winter rest with little or no growth activity. After a period, which in lenght apparently depends on the climate and the plant species, the plant gradually goes back to a phase of active growth in the spring. The longer photoperiods and favorable temperatures finally causes the buds to break and flowers to emerge (Perry 1971, Vegis 1964).

The observed dates of first bloom, and thereby the beginning of the pollen season and pollen counts, are found to deviate profoundly from one year to another. In a 14 year period (1977 to 1990), the beginning of the pollen season in Denmark deviates within the following periods: *Alnus* – from the 30th December to the 1st April, *Ulmus* – from the 21th February to the 2nd May, and *Betula* – from 2nd April to the 9th May.

The determination of the end of rest and prediction of flowering has been the issue of several previous studies. In regard to fruit trees Ashcroft et al. (1977), Richardson et al. (1974), Richardson & Anderson (1986) and Anderson & Richardson (1986), have developed a phenoclimatography model which relates environmental temperatures to rest completion and bud development. Furthermore Winter (1986) correlated the phenologic development during the dormancy period with the evolution of frost resistance and simulated frost damage in apple trees. This strong correlation between the evolution of frost hardness and bud dormancy status has recently been verified by Colombo (1990).

Especially the buds and flowers are damaged by the frost which may reduce the fruit setting in fruit trees dramatically. Apparently the damage to the flowers affects both the amount of pollen despersed and the pollen germination. As both the time of season and the amount of pollen dispersed are of great interest in relation to pollen allergy, it would be very valuable if models similar to those proposed for fruittrees could be adapted to other trees.

 4th Int. Conf. Aerobiol./Stockholm/1990: Session 3, Poster

Table I. *Betula Growing Degree Hours (GDH) accumulation from estimated end of rest to begin of flowering (2.5% of total pollen count) for 7 estimates of Chill Unit (CU) requirement.*

Minimum standard deviation (SD) obtained at CU estimate 1900 giving an average of 2446 GDH.

	CU						
Year	1700	1750	1800	1850	1900	1950	2000
1977	2635	2568	2503	2364	2238	2167	1985
1978	2762	2754	2736	2717	2694	2630	2571
1979	2227	2167	2119	2043	1953	1720	1195
1980	3155	3144	3053	2980	2932	2740	2649
1981	2283	2277	2165	2095	2062	1828	1745
1982	3074	2881	2490	2389	2023	1632	1424
1983	2588	2538	2442	2377	2267	2215	2199
1984	2594	2570	2555	2544	2459	2427	2216
1985	2682	2670	2668	2646	2612	2543	2269
1986	1394	1291	1216	1124	1043	979	900
1987	2606	2576	2563	2550	2545	2536	2522
1988	2276	2198	2145	2111	2078	2062	2052
1989	3544	3449	3398	3356	3204	3119	3034
1990	4637	4509	4425	4292	4136	3993	3922
SD	712	699	696	691	682	697	741
Avg. GDH	2747	2685	2606	2542	2446	2328	2192

The aim of the present study was to test these phenoclimatographic models on the allergenic trees *Alnus, Ulmus* and *Betula* in order to provide a method to predict the beginning of the pollen season.

METHODS

Pollen counts have been practised in Denmark since 1977 with a Burkard Volumetric Spore Trap, placed 15 metres above ground, on the roof of the Danish Meteorological Institute in Copenhagen (Goldberg et al. 1988). As phenologic parameter in the model 14 years of pollen data from the trap were used. The start of pollen season was defind to be a fixed procent (2.5%) of total counts. Furthermore hourly temperatures were estimated by the method of Linvill (1990), from 24-hours daily maximun and minimum temperatures, measured at Frederiksberg, Copenhagen.

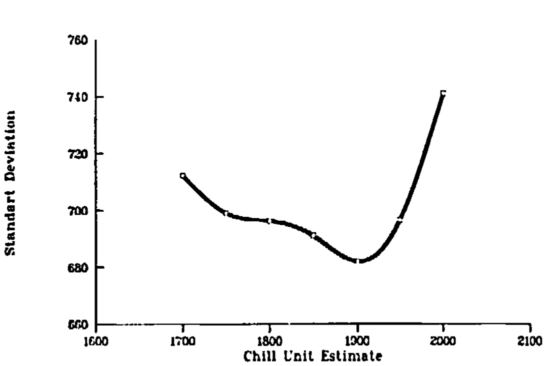

Fig. 1. Betula: Statistical estimation of Chill Unit (CU) and Growing Degree Hours (GDH) in the CU/GDH-model. Curve values (□) based on Table I. Minimum standard deviation obtained at CU estimate 1900.

Richardson et al. (1974), expressed the chilling requirement of fruit trees by Chill Units (CU). One CU defined as one hour at 6°C, which was found to be the optimum Chill Unit temperature for fruit trees. This definition was applied in the present study.

The ordinary CU-model (Richardson et al. 1974) means the relation between the measured temperatures and the "Effective Bud Temperature". In order to simplify the calculations a sine function was used, as proposed by Linvill (1990). The initiation point for beginning of the CU calculations and accumulation was (as used by Richardson et al. 1974) determined to be the first day giving positive chilling values. The experimentally determined temperatures for the Growing Degree Hour (GDH) function (the base temperature = 4°C, the optimum temperature = 25°C and the critical temperature = 36°C (Richardson & Anderson 1986)) were used in this study for *Alnus, Ulmus* and *Betula,* except the base temperature which was changed to 2°C, giving a slightly better correlation.

The chilling requirement and dates of rest completion were estimated with the statistical method developed by Ashcroft et al. (1977), minimizing the standard deviation of

Table II. *Total pollen counts, and observed dates of beginning of pollen season for Alnus, Ulmus and Betula.* Start defined as 2.5% and 5% of total. Modelpredictions and deviation () in days from day nr. observed (Start def: 2.5%).

Year	Total counts	Observed 2.5%	Observed 5.0%	Predictions & deviation Fix. day		CU/GDH		Dyn-CU/GDH	
ALNUS									
1977	–	–	–	69	(–)	67	(–)	64	(–)
1978	723	70	71	71	(1)	70	(0)	65	(– 5)
1979	390	85	85	91	(6)	89	(4)	86	(1)
1980	210	89	91	97	(8)	93	(4)	90	(1)
1981	58	68	68	67	(– 6)	68	(0)	68	(0)
1982	595	80	80	74	(– 6)	84	(4)	83	(3)
1983	261	18	21	10	(– 8)	13	(– 5)	22	(4)
1984	513	77	89	68	(– 9)	90	(13)	68	(– 9)
1985	312	84	84	92	(8)	92	(8)	86	(2)
1986	498	79	81	86	(7)	87	(8)	80	(1)
1987	465	85	86	93	(8)	78	(– 7)	86	(1)
1988	100	–1	–1	4	(6)	–1	(0)	–2	(– 1)
1989	936	17	25	13	(– 4)	16	(– 1)	17	(0)
1990	382	18	24	16	(– 2)	29	(11)	22	(4)
ULMUS									
1977	218	110	113	97	(–13)	96	(–14)	84	(–26)
1978	709	100	102	95	(– 5)	91	(– 9)	92	(– 8)
1979	534	121	122	105	(–16)	105	(–16)	104	(–17)
1980	489	100	101	107	(6)	106	(6)	104	(4)
1981	722	96	97	91	(– 5)	91	(– 5)	91	(– 5)
1982	531	93	94	92	(– 1)	97	(4)	95	(2)
1983	808	71	72	69	(– 2)	79	(8)	81	(10)
1984	1072	96	102	106	(10)	105	(9)	105	(9)
1985	607	93	100	108	(15)	102	(9)	99	(6)
1986	1402	88	99	112	(24)	114	(26)	110	(22)
1987	956	86	96	110	(24)	106	(20)	105	(19)
1988	328	96	98	93	(– 3)	93	(– 3)	98	(2)
1989	1089	50	54	37	(–13)	43	(– 7)	51	(1)
1990	879	52	53	36	(–16)	52	(0)	51	(– 1)
BETULA									
1977	921	121	124	123	(2)	123	(2)	121	(0)
1978	3221	122	124	123	(1)	117	(– 5)	120	(– 2)
1979	1110	129	129	133	(4)	133	(4)	133	(4)
1980	4054	125	126	124	(– 1)	121	(– 4)	121	(– 4)
1981	58	103	116	107	(4)	106	(3)	106	(3)
1982	3492	115	115	112	(– 3)	118	(3)	118	(3)
1983	1427	112	119	112	(0)	114	(2)	113	(1)
1984	6146	116	117	117	(1)	116	(0)	117	(1)
1985	2128	128	131	130	(2)	128	(0)	128	(0)
1986	3743	117	117	123	(6)	124	(7)	124	(7)
1987	4046	119	119	121	(2)	119	(0)	119	(0)
1988	691	111	123	115	(4)	113	(2)	116	(5)
1989	7837	101	102	85	(–16)	88	(–13)	103	(2)
1990	5188	92	92	70	(–22)	78	(–14)	81	(–11)

Growing Degree Hours (GDH) over a range of CU estimates. Exemplified in Table I, and Fig. 1 for *Betula*.

The ordinary (CU/GDH) model proposed by Richardson et al. (1974) comprising the Chill Unit (CU) and the Growing Degree Hour (GDH) submodels, was compared to a simpler technique, a (Fix. day) model using only the

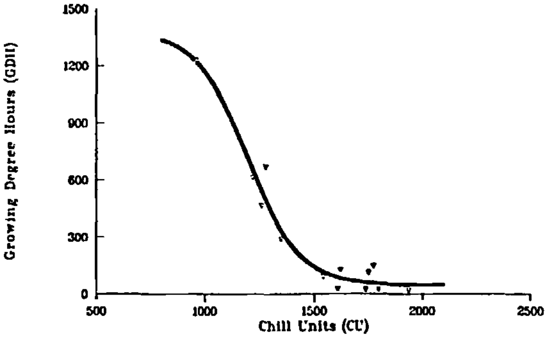

Fig. 2. The Growing Degree Hour requirement for *Alnus* as a function of the accumulated amount of Chill Units. Values (∇) and estimated curve based on Table III.

GDH submodel. 1st January was used as fixed initiation point.

A more complicated model involving the dynamic character of the dormancy growth fases was proposed. In this (Dyn-CU/GDH) model Chill Units were calculated and accumulated continuously during the winter. GDH-calculation was initiated every time the temperature rose above 2°C. Every time the temperature fell below this level for more than 24 hours the GDH accumulation was reset to zero.

Winther (1986) expressed the frost hardness by a LT50 value defined as the temperature where 50% of the generative organs are killed. Based on the LT50 values experimentally determined by Winter, the LT50 value at budbreak was estimated for the present trees to be −3°C, and the "heighest" LT50 value reached in the dormant phase, corresponding the heighest level of dormancy, to be −35°C. A transformation of the dynamic CU/GDH function was used to estimate the frost hardness of the trees.

RESULTS AND DISCUSSION

The starting day depends on the definition chosen (Table II). Usually the starting dates obtained by different start definitions deviates 2-3 days, and in some years even 8-10 days. This uncertainty must be kept in mind when prediction models are compared.

The average Growing Degree Hours (GDH) accumulated from the 1st January to the defined starting dates were: *Alnus:* 258 *Ulmus:* 1090 and *Betula:* 3000. The predicted dates are shown in Table II ("Fix. day" model).

In the ordinary Chill Unit and Growing Degree Hour model the CU and GDH requirement of the trees were statistically estimated to: *Alnus:* CU = 1550, GDH = 200, *Ulmus:* CU = 1850, GDH = 700 and *Betula:* CU = 1900, GDH = 2446. Using these parameters, the predicted dates for the beginning of the season were determined, (Table II, "CU/GDH" model.

In the dynamic model the corresponding CU and GDH values until the start of the season were determined by the procedure described. Using this method neither the CU nor the GDH was fixed, but the necessary GDH to budbreak was adjusted according to the amount of Chill Units obtained. As can be seen in Table III the Chill Units and Growing Degree Hours obtained deviated from one year to the other according to the different temperature regimes observed. The relationship between CU and GDH was proposed to follow a not-lineary function, with shape of an s-curve as illustrated in Fig. 2. for *Alnus:*

$$GDH = C + (D-C) / 1 + EXP((CU - CU_0)/A) \qquad (1)$$

GDH: Growing Degree Hour requirement to flowering.
C: Minimum number of GDH's required.
D: Maximum number of GDH's required.
CU: Chill Units obtained.
CU_0: The inflexion point, (at which the fall in GDH requirement are fastest.
A: The slope of the curve at the inflexion point.

The parameters were estimated by non-linear regression (NLIN) using SAS/PC (Statistical Analysis System for Personal Computers), (Table III). Finally the dates were predicted (Table II "Dyn-CU/GDH" model).

When compared with the observed dates the predictions made by the simple "Fix-day" model are within 4-8 days for *Alnus,* more than 10 days for *Ulmus* and *Betula* 5-7 days. Using the CU/GDH model the predictions are about the same for *Alnus*

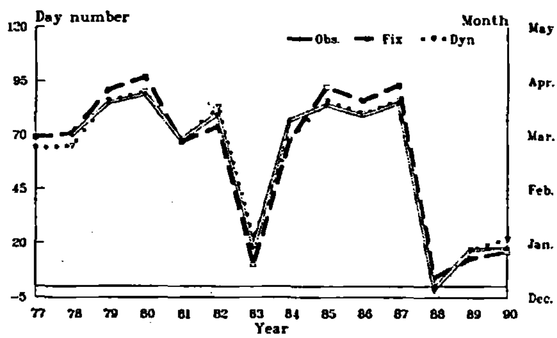

Fig. 3. Observed dates for beginning of the *Alnus* pollen season compared with model predictions. Based on Table II (Day nr 1 = > 1/1, nr 0 = > 31/12 and nr −5 = > 26/12).

Table III. *Chill Units (CU) and correspondin Growing Degree Hours (GDH) determined by the dynamic model, and estimated model parameters in the function:*

$GDH = C + (D-C)/1 + \exp((CU-CU_0)/A)$

GDH : Growing Degree Hour requirement to flowering.
C : Minimum number of GDH's required.
D : Maximum number of GDH's required.
CU : Chill Units obtained.
CU_0: The inflexion point, (at which the fall in GDH requirement are fastest).
A : The slope of the curve at the inflexion point.

Year	*ALNUS*		*ULMUS*		*BETULA*	
	CU	GDH	CU	GDH	CU	GDH
1977	–	–	1695	1361	1695	2641
1978	1776	146	2106	1094	2106	2465
1979	1608	27	1608	1882	1608	2351
1980	1740	21	1740	427	1740	3148
1981	1754	111	1858	1121	1858	2090
1982	1352	291	1352	1232	1352	3388
1983	1219	612	2030	296	2030	2193
1984	1622	127	1622	301	1622	2685
1985	1800	23	1800	294	1800	2668
1986	1541	91	1541	308	1541	1599
1987	1938	18	1938	58	1938	2540
1988	1279	669	2511	470	2511	1759
1989	959	1228	959	2317	959	4820
1990	1260	464	1260	1882	1260	5440
C :		46		565		2262
D :		1384		2590		5473
CU_0:		1198		1292		1332
A :		120		166		179

and *Ulmus* but slightly improved to be within 4-6 days for *Betula*.

Compared to these two models the predictions are improved to be within 2-4 days for *Alnus*, 8-10 days for *Ulmus* and 3-5 days for *Betula* in "the Dynamic-CU/GDH model" (Table II and Fig. 3).

A deviation of this size must be regarded as acceptable compared both to the very large deviation in time form one year to the other (about 4 months for *Alnus*), and the uncertainity in the definition of starting dates. Though it must be a question of priority between a simple model with predictions within a reasonable deviation or a more complicated model, and a slightly better prediction.

If the predictions are to be further improved a photoperiodic parameter apparently has to be included, especially in regard to *Ulmus* and *Betula*. From 1st March to 1st May the daylength in Denmark increases about five hours, from about ten hours to fifteen hours. This marked increase obviously plays a role in relation to the budbreak.

The buds of *Betula* detect the day length directly, apparently the bud scales themselves respond, or enough light penetrates to bring about the respons within the primordial leaf tissues inside the bud (Salisbury & Ross 1985).

The involvement of a dynamic relationship complicates the model a little, but tends to improve the simulation of the gradual changes during dormancy and budbreak. The s-formed relationship shown in Fig. 2 for *Alnus* is consistent with the descriptions of several authors (Perry 1971, Vegis 1964). According to Perry (1971) and Vegis (1964) the level of dormancy changes very much during winter giving it a normal distribution or "bellshaped" character.

The level of dormancy and heat required to break dormancy gradually increases during autumn, and then the process is reversed in spring. The same results were found by Swartz & Powell (1981), Borkowska (1981) and Crabbé (1981): long chilling treatment increased the growthability and lowered the heat requirement.

The relationship found by the "dynamic model" also fits very well with the chilling requirement estimated by the ordinary Chill Unit and Growing Degree Hour model: at 1550 Chill Units (CU requirements for *Alnus*) the fall in heat (GDH) requirement is no longer significant.

By using the LT50 submodel, days where frost

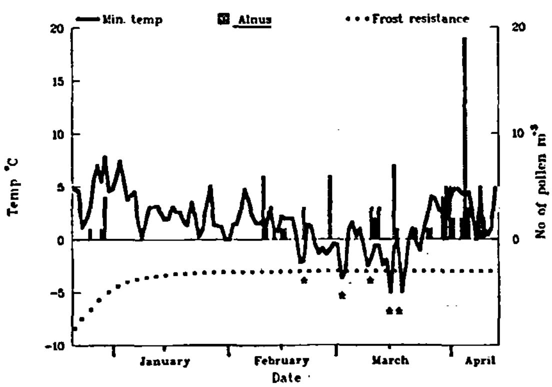

Fig. 4. The climate in the spring 1988, and the *Alnus* pollen season. The pollen counts were not started before the 8. February but as the model predicted it to start before new year control counts were made and *Alnus* pollen were found! Later on lethal temperatures (*) caused severe damage.

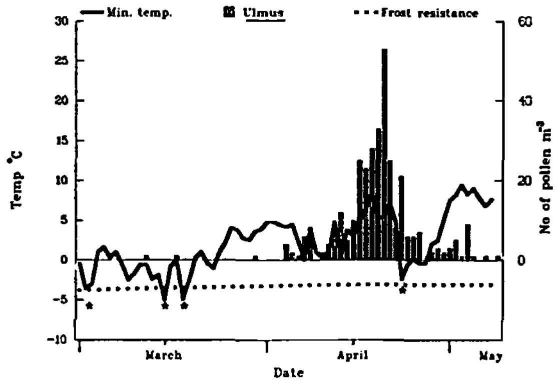

Fig. 5. The climate in the spring 1988, and the *Ulmus* pollen season. Frost damage apparently occured both before and in the season (*).

damaged might have occured were detected, especially in 1981 and 1988 (Figs. 4 and 5) – though the exact level of the LT50 values have to be confirmed by experiments with *Alnus, Ulmus* and *Betula.* These damages give a reasonable answer to the question why so few pollen grains were found in 1981 and 1988 (Table II). If the hormonal regulation mechanisms, known to control alternate bearing in apples (Lavee 1989), are applied to the present trees it can explain the biennial tendency observed in the pollen seasons.

In apple trees the developing fruits produces hormones, mainly gibberellines and auxins, which reduces the flower bud development the following year, i.e., years with a great pollination and fruit-development give a high hormonal production giving few flowers and pollen grains next year, – and years with poor pollination and fruiting, give many pollen grains in the following year.

Very often it is an environmental factor which induces this cycle. Severe frost damage (or drought) could be the one. The potential production of pollen apparently depends on the climate during bud development and differentiation in the summer, but the actual amount dispersed and observed is very much dependent on the weather during budbreak and flowering. In other words frost damage might affect both total pollen counts in the actual year and the potential pollen amount the following year. This makes predictions of the total counts very difficult.

CONCLUSION

The predictions obtained by the models must be regarded as acceptabel in relation to the many uncertainties involved with weather prediction, pollen dispersal and pollen monitoring. *Alnus* tends to be completely regulated by the temperature while other parameters like the photoperiod apparently has to be involved in relation to *Ulmus* and *Betula* if predictions are to be further improved.

The CU and GDH relationships defined for fruit trees are generally applicable, giving a reasonable description of the growth processes for other trees. This type of model can therefore be of value in predicting the start of the pollen season. Furthermore the results indicate that frost damage might be an important factor which can strongly affect the total pollen counts.

REFERENCES

Anderson, J. L. & Richardson, E. A. 1986. Validation of Chill Unit and flowerbud phenology models for "Montmorency" sour cherry. – Acta Hortic. 184. [Modelling in Fruit Research.]: 71–78.

Ashcroft, G. L., Richardson, E. A. & Seeley, Schuyler D. 1977. A statistical method of determining chill unit and growing degree hour requirements for deciduous fruit trees. – Hortic. Sci. 12: 347–348.

Borkowska, B. 1981. Dormancy and development of apple axillary buds investigated in vitro. – Acta Hortic. 120 [Growth regulators in Fruit Production]: 161–166.

Colombo, S. J. 1990. Bud dormancy status, frost hardiness, shoot moisture content, and readiness of black spruce container seedlings for frozen storage. J. Am. Soc. Hortic. Sci. 115: 302–307.

Crabbé, J. J. 1981. The interference of bud dormancy in the morphogensis of trees and shrubs. – Acta Hortic. 120 [Growth regulators in Fruit Production]: 167–172.

Goldberg, C., Buch, H., Moseholm, L. & Weeke, E. R. 1988. Airborne pollen records in Denmark, 1977–1986. – Grana 27: 209–217.

Lavee, S. 1989. Involvement of plant growth regulators and endogenous growth substances in the control of alternate bearing. – Acta Hortic. 239. [Growth regulators in Fruit Production]: 311–322.

Linwill, D. E. 1990. Calculating Chilling Hours and Chill Units from Daily Maximum and Minimum Temperature Observations. – HortScience 25: 14–16.

Perry, T. O. 1971. Dormancy of trees in winter. – Science. 171: 29–36.

Richardson, E. A. & Anderson, J. L. 1986. The omnidata biophenometer (TA45-p): A Chill Unit and Growing Degree Hour Accumulator. Acta Hortic. 184 [Modelling in Fruit Research.]: 95–99.

Richardson, E. A., Seeley, Schuyler D. & Walker, D. R.

1974. A model for estimating the completion of Rest for "Redhaven" and "Elberta" Peach Trees. – HortScience. 9: 331–332.
Salisbury, F. B. & Ross, C. W. 1985. Plant physiology, 3rd ed. – Wattsworld Publ. Co., Bellmond, California.
Swartz, H. J. & Powell, L. E. Jr. 1981. The effekt of long chillingrequirement on time of bud break in apple. Acta Hortic. 120. [Growth regulators in fruit production.]: 173–178.
Vegis, A. 1964. Dormancy in higher plants. – Ann. Rev. Plant Physiol. 15: 185–224.
Winter, F. 1986. A simulation model of phenology and corresponding frost resistance of "Golden Delicious" apple. – Acta Hortic. 184 [Modelling in Fruit Research]: 103–108.