



Grana

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/sgra20>

The influence of air temperature on the starting date of *Quercus* pollination in the South of Europe

F. Javier Rodríguez-RaJo^a, Giuseppe Frenguelli^b & Victoria Jato^a

^a Department of Plant Biology and Soil Sciences, University of Vigo, Campus As Lagoas, E-32004 Ourense, Spain

^b Department of Plant Biology, University of Perugia, Borgo XX Giugno 74, 06121 Perugia, Italy E-mail: javirajo@uvigo.es

Available online: 06 Oct 2011

To cite this article: F. Javier Rodríguez-RaJo, Giuseppe Frenguelli & Victoria Jato (2003): The influence of air temperature on the starting date of *Quercus* pollination in the South of Europe, Grana, 42:3, 145-152

To link to this article: <http://dx.doi.org/10.1080/00173130310016130>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.tandfonline.com/page/terms-and-conditions>

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

The influence of air temperature on the starting date of *Quercus* pollination in the South of Europe

F. JAVIER RODRÍGUEZ-RAJO, GIUSEPPE FRENGUELLI and VICTORIA JATO

Rodríguez-Rajo, F. J., Frenguelli, G. & Jato, V. 2003. The influence of air temperature on the starting date of *Quercus* pollination in the South of Europe. – Grana 42: 145–152. ISSN 0017-3134.

In temperate zones the air temperature influences many aspects of the plant growth and also the time of flowering is often correlated with this environmental parameter. It is a generally accepted idea that higher temperatures in the period preceding ripening of the flowers determine earlier pollination. To verify if a correlation between the air temperature and the date of onset of the pollination period of *Quercus* spp. exists, a comparative study was carried out over 7 years (1995–2001) in two South-European towns: Vigo (Spain) and Perugia (Italy). *Quercus* pollen is released in the atmosphere of Perugia on average in the last two weeks of April while in the Spanish region the pollination occurs on average one month before.

In order to overcome the dormancy period Perugia requires 1110 Chilling Hours (CH)-884 Growth Degree-Days (GDD°C) and Vigo 709 CH-861 GDD°C. With the Ashcroft method Perugia needs 1075 CH-1000 GDD°C and Vigo 625 CH-1512 GDD°C. Heat accumulation from the end of winter dormancy to the onset of pollination, showed the highest significance when mean temperature in Perugia and maximum temperature in Vigo were used. Every year we have found that the colder station needed a lower heat accumulation: Perugia required a higher quantity of chilling and heat than Vigo. However, the correlation detected between temperature and flowering was, on average, less significant than those found in the same regions for other arboreal taxa that present winter pollination (e.g. *Corylus*, *Alnus*). This preliminary study suggests that there is an effect of air temperature on *Quercus* pollination, but other environmental factors, such as photoperiod, hours of light, rainfall, relative humidity, may be of great influence in determining the onset of pollination in plants with a spring flowering.

F. Javier Rodríguez-Rajo & Victoria Jato, Department of Plant Biology and Soil Sciences, University of Vigo, Campus As Lagoas, E-32004 Ourense, Spain. Giuseppe Frenguelli, Department of Plant Biology, University of Perugia, Borgo XX Giugno 74, 06121 Perugia, Italy. E-mail: javirajo@uvigo.es

(Manuscript received 8 April 2002; accepted 12 June 2003)

Most trees in temperate zones, after the active phase of growth in the spring-summer period, go through a phase of dormancy during the autumn months. Usually, the beginning of dormancy is determined both by a shortening of the photoperiod and a lowering of temperature; these environmental conditions are found between the end of the summer and the beginning of autumn. The plant then progressively loses its leaves, growth slows until it completely stops, and the plant enters the dormancy phase. Growth-arresting conditions are eliminated when buds are exposed to chilling temperatures for a certain period. The subsequent stage of dormancy is called “quiescence”, which is defined as the period in which the buds remain dormant due to unfavourable environmental conditions. Bud burst takes place when the buds are exposed to forcing temperatures for a prolonged period (Kramer 1994).

The chilling requirement for dormancy release is generally measured by the number of hours that the plant must go through at a low temperature and it is expressed as Chilling Units or Chilling Hours (Aron 1983). It is not easy to identify the moment when a plant completes dormancy and begins its successive heat accumulation. However, in some arboreal winter plants, changes in the pollen volume following dehydration takes place during the pollen grain development in the period of dormancy and it can be

considered as a marker of this period (Frenguelli 1997, Frenguelli et al. 1997). Heat units (degree-hours or degree-days) are a measure of the time duration of one phenological stage and are often used to define phenological development of the plants. One degree-hour is observed when the air temperature is one degree above a lower threshold temperature for 1 h.

During the last few years studies to determine chilling and heat requirements using aerobiological data have been conducted (Frenguelli & Bricchi 1998, García-Mozo et al. 2000, Jato et al. 2000, Rodríguez-Rajo 2000, Galán et al. 2001, Laaidi 2001). Predicting the start of pollen season is of particular importance for people allergic to certain pollen. One of the most important aims in aerobiological studies is to develop predictive models that allow us to predict both the onset and severity of the pollen season.

In order to forecast tree pollen seasons, at least some days in advance, a number of pheno-meteorological models can be used. They include the use of “heat sums”, “chill units”, or other phenological or meteorological parameters. Phenological models based on “marker species” also can be utilised. Marker species are able to indirectly measure the complexity of meteorological variables and they are more accurate, especially if combinations of markers rather than one single species are used. *Corylus* and *Taxus* seem to be

the most accurate markers to flowering of *Quercus* in England and they are able to give information of *Quercus* pollination well in advance (Norris-Hill 1998).

The beginning of pollination in arboreal plants with winter flowering is more closely related to the thermal time rather than calendar time (Frenguelli & Bricchi 1998, Jato et al. 2000). The aim of this study is to determine temperature requirements to trigger *Quercus* pollination in two different climatic regions that are located at the same latitude (Central Italy and Northwest of Spain). Also to demonstrate the hypothesis that there is a linear relation between temperature and the rate of growth of the inflorescences and therefore of the moment of pollination although other factors, such as photoperiod, could be recognised to interfere with this process.

MATERIAL AND METHODS

Data of airborne pollen concentrations from Perugia (Central Italy) and Vigo (Northwest Spain), from 1995 to 2001 were used to determine the start of the *Quercus* pollination period.

Perugia is placed approximately 90 km inland on the west-facing slopes of the Apennines, 493 m above sea level (12°23'32"E, 43°06'N), overlooking the valley of the Tiber River to the southwest and the Lake Trasimeno to the northwest (Fig. 1). The annual mean temperature is 13.2°C, the average maximum temperature 17.1°C and the minimum 9.2°C. The average annual precipitation is 875 mm.

In northwest Spain, the city of Vigo lies on the southern margin of the Vigo estuary (Fig. 1), 50 m. a.s.l. (8°43'W, 42°15'N). The valley that shapes the city has a small drainage system, principally in north-south and southwest-northeast directions. The annual mean temperature is 14.9°C, with the average maximum temperature of 18.8°C and the minimum of 11°C. The average annual precipitation is 1412 mm.

Pollen of *Quercus robur*, *Q. suber*, *Q. ilex* and *Q. pyrenaica* represent the oak pollen type in Vigo, while in central Italy the most common source of airborne oak pollen is *Quercus robur*, *Q. pubescens* and *Q. ilex*.

Seven-day volumetric pollen traps Lanzoni VPPS 2000, developed from the Hirst pollen trap (Hirst 1952) were used. In Perugia it was placed on the roof of the Faculty of Agricultural Science, while

in Vigo on the terrace of the town hall. The Institute of Ecology of the Faculty of Agricultural Science in Perugia and The National Institute of Meteorology in Vigo recorded the meteorological data.

Melinex coated with silicon 2% solution was used as a pollen-trapping surface. The exposed tape was cut into seven pieces, which were mounted in separate glass slides. Daily values were represented as the number of pollen grains per cubic metre of air.

Two methods to determine the pollen season (Anderssen 1991, Mullenders 1974) were tested and the minor standard deviation was used to select the most accurate. As a minor standard deviation coefficient (C.S.%) was used the pollen period that includes 95% of the annual total pollen, removing the initial period until the 5 day running mean exceeded 2.5% (Table I).

Several methods have been used by different authors to measure the duration of chilling and to find the best starting date in spring to accumulate day-degrees (Aron 1983, Ashcroft et al. 1977, Faust 1989, Felker et al. 1983, Richardson et al. 1974, Rickman et al. 1983). Also different methods to determine the most accurate basic temperature for growth and flowering were utilised (Galán et al. 2001, García-Mozo et al. 2000, Jato et al 2000, Kramer 1994, Rodríguez-Rajo et al. 2000). Most of these methods make use of fixed calendar days, such as 1st November or 1st January to start chilling and heat accumulation respectively. In the present work to determine chilling requirement we have chosen a thermal time using the model proposed by Aron (1983). In this method the accumulation of chilling hours between 0° and 7.2°C is calculated considering the maximum and minimum temperatures and the length of the chilling period: $N = 801 + 0.2523B + 7.57B^2 \times 10^{-4} - 6.51B^4 \times 10^{-10} - 11.44T_{i\min} - 3.32T_{i\max}$. N=number of Chilling Hours during the period. B=24 D[(7.2-T_{min})/(T_{max}-T_{min})].

Where T_{imin} and T_{imax} are respectively the average of minimum and maximum temperatures during the period considered, and D is the number of the days of the same period. In both cities the mean temperature usually decreases below 10°C at the beginning of November and the day when this happened was considered as the start of the accumulation of chilling hours (CH).

The heat accumulation to induce pollination was expressed as growth degree-days (GDD°C) and it was obtained by different methods. Firstly, by the summation of daily mean and maximum temperatures, then by the sum of the difference between the maximum and minimum temperatures, and also calculated according to the equation proposed by Rickman et al. (1983): $T_n = \sum [(T_{i\max} + T_{i\min}) \times 0.5] - Tb$

Where T_n is the sum of °C for n days. T_i_{max} and T_i_{min} are daily maximum and minimum temperature °C of day i. Tb is the base temperature. Heat sums with different base temperatures (4, 4.5, 5, 5.5, 6 and 6.5°C) were used to estimate the most accurate base

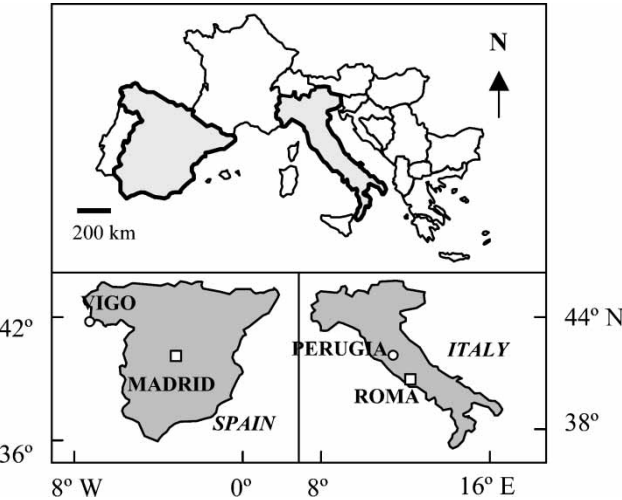


Fig. 1. Location of the studied zones.

Table I. Onset of *Quercus* pollen season calculated according 2.5% (Andersen 1991) and 1% methods (Mullenders 1971).

PERUGIA			VIGO			
2,50%	1%	2,50%		2,50%	1%	2,50%
30-apr	112	122	1994-95	80	78	21-mar
30-apr	114	123	1995-96	72	61	13-mar
25-apr	100	117	1996-97	65	63	06-mar
27-apr	111	119	1997-98	59	53	28-feb
28-apr	110	120	1998-99	73	71	14-mar
25-apr	111	118	1099-00	62	63	03-mar
25-apr	100	117	2000-01	76	57	17-mar
	5.79	2.37	S.D.	7.72	8.42	
	5.35	1.98	C. S. %	11.10	13.22	

Table II. Chilling hours (C.H.) calculated by using the Aron (1983) method.

Start	End	Length	PERUGIA	VIGO	Length	End	Start
23-nov	10-jan	49	1138	1994–95	669	15-jan	12-nov
18-nov	18-jan	62	1124	1995–96	674	11-jan	21-nov
17-nov	19-jan	64	1046	1996–97	655	08-jan	01-nov
12-nov	28-jan	78	1128	1997–98	680	05-jan	19-nov
07-nov	30-jan	85	1014	1998–99	808	01-jan	03-nov
15-nov	27-jan	74	1162	1999–00	722	01-jan	01-nov
16-nov	14-jan	60	1160	1900–01	755	08-jan	01-nov
		67	1110	Mean	709	61	
		49	1014	Min	655	48	
		85	1162	Max	808	69	
		12.25	57.47	S.D.	55.78	8.12	
		18.16	5.18	C.S. %	7.87	13.37	

temperature. The beginning of the period considered was the first day when the mean temperature reached the minimum values of the year and it starts to follow a positive trend (on average at the end of January or beginning of February).

The phenoclimatology model of Ashcroft et al. (1977) has been used. Different CH values, calculated according Aron method, were tested (from 950 to 1150 in Perugia and from 600 to 725 in Vigo). From the moment that the value was hardened up, GDD was calculated. In this model, Chill Units are calculated by means the Aron method (1983).

In the statistical approach, the heat accumulation is calculated from different experimental data sets, and the amount of the variation is calculated as Standard Deviation Coefficient (S.D.) and Standard Deviation Coefficient as percentage (C.S. %). We apply the Scheffé test with the aim of checking the differences between the temperatures recorded during the years under study. Finally to demonstrate a correlation between the different phenological phases studied (length of chilling, length of period of forcing temperatures, number of GDD, chilling hours and start of pollen season), we applied Spearman's Correlation Test.

RESULTS

Quercus pollen is released in the atmosphere of Perugia in the last two weeks of April. Vigo has an earlier start to pollination every year and it occurs, on average, fifty days before Perugia (Table I). Chilling requirement is lower in Vigo than Perugia, and chilling hours accumulation was on average 709 and 1110 respectively. Both Vigo and Perugia show a very low coefficient of standard deviation (Table II). In Vigo and Perugia the start of chilling happens during the first fortnight of November and finishes in January.

Heat accumulation from January until the start of flowering was calculated using two methods and expressed as GDD°C (Table III). The sum of medium temperature in Perugia and the sum of maximum temperature in Vigo were the parameters that showed a minor coefficient of variation (6.30% and 8.85% respectively). We tested different threshold temperatures but the result were not improved. The mean of heat requirement was very similar in both localities, and Perugia needs 884 GDD°C to trigger flowering and 867 GDD°C is required in Vigo.

The results obtained applying the Ashcroft method (Ashcroft et al. 1977) were also similar (Table IV). Coefficients of standard deviation obtained in Perugia were independent of the number of the chilling units

considered. However the best result (C.S.=4.81%) was obtained when 1075 CH was considered enough to break the period of dormancy. In that case 1000 GDD°C are on average necessary to trigger pollination. In contrast in Vigo the oscillation of the coefficients of standard deviation was large, and the lowest was founded when 625 CH was used as chilling requirement (C.S.=7.78%). In this case 1512 GDD°C was the heat requirement obtained. Medium temperature in Perugia and maximum temperature in Vigo showed the lowest coefficient of variation. The results obtained in Perugia using the Ashcroft method are satisfactory, and every year the amount of GDD°C is similar (between 956 to 1094), independent of the number of the CH considered. However the behaviour in Vigo is different, with the number of GDD°C calculated from the different CH showed a very high variability.

We apply the Scheffé test (Table V) with the aim of checking differences between the temperatures recorded during the years under study. There are two groups of the years that show different temperature behaviour, 1995–1998 and 1999 to 2001. In the same table the differences between maximum, minimum and medium temperatures in the two groups of years are given. Finally, Spearman's Correlation Test (Table VI) shows significant positive correlation between the pollen season start date, and the amount of GDD°C or the length of heat period in Vigo. The correlation was negative between the length of the chilling and heat accumulation period in Perugia (Table VI).

Depending on chilling requirement during dormancy, linear regression models (Fig. 2) enable us to predict necessary GDD°C values to complete heat requirements and trigger pollination. The model takes account of the data of Vigo (Fig. 2a), Perugia (Fig. 2b) and the two localities together (Fig. 2c), explaining in most cases high percentage of heat requirement variability.

DISCUSSION

Different authors have pointed out the influence of temperature on pollination (Frenguelli et al. 1991, Richardson et al. 1974, Spieksma et al. 1989). Studies focusing on *Quercus* and *Alnus* were carried out in the same area (Rodríguez-Rajo et al. 2000, Jato et al. 2000), where a

Table III. Values of GDD°C calculated by using different parameters and base temperatures.

	T. Max.	T. Mean	T. Max. – Min.	Rickman 5.5°C	T. Mean 4°C	T. Mean 4.5°C	T. Mean 5°C	T. Mean 5.5°C	T. Mean 6°C	T. Mean 6.5°C
PERUGIA										
94–95	1301	929	745	361	507	457	408	361	317	275
95–96	1149	821	653	325	443	401	362	325	290	256
96–97	1225	860	732	330	472	424	377	330	286	242
97–98	1171	829	673	368	478	438	399	362	326	292
98–99	1477	860	1330	373	529	490	452	416	382	349
99–00	1603	917	1425	404	560	517	473	431	389	348
00–01	1573	970	1200	505	587	541	497	454	413	374
Average	1357	884	965	381	511	467	424	383	343	305
S.D.	191.29	55.72	337.97	60.85	51.10	50.94	50.91	50.92	51.19	51.54
C.S. %	14.09	6.30	35.01	15.98	10.00	10.91	12.01	13.30	14.92	16.91
VIGO										
94–95	966	753	387	410	702	669	636	603	570	537
95–96	856	639	435	295	603	571	540	508	477	445
96–97	887	701	373	397	677	648	619	590	561	532
97–98	854	669	372	367	635	607	580	552	525	497
98–99	861	608	506	214	569	532	496	459	423	386
99–00	721	505	435	164	469	438	406	375	343	313
00–01	926	701	449	317	640	606	572	538	504	470
Average	867	654	422	309	614	582	550	518	486	454
S.D.	76.73	80.63	48.73	92.83	77.40	78.03	78.77	79.62	80.57	81.36
C.S. %	8.85	12.33	11.54	30.03	12.62	13.42	14.33	15.37	16.57	17.91

Table IV. Chill and Heat requirements by using the Ashcroft et al. (1977) method.

(T. Mean)	950	975	1000	1025	1050	1075	1100	1150
PERUGIA								
94–95	1044	1034	1034	1022	1010	999	989	978
95–96	1041	1024	955	947	941	932	861	837
96–97	1033	1028	1028	1024	1024	1020	992	959
97–98	1039	1018	997	977	968	950	934	920
98–99	1163	1160	1150	1132	1110	1049	1034	993
99–00	1226	1195	1129	1115	1084	1062	1045	1035
00–01	1111	1102	1082	1059	1022	992	986	973
Mean	1094	1080	1053	1040	1023	1000	977	956
S.D.	75.98	72.93	70.48	67.71	59.58	48.11	62.81	63.17
C.V. %	6.95	6.75	6.69	6.51	5.83	4.81	6.43	6.60
VIGO (T. Max.)								
94–95	1800	1626	1337	1116	911	911		
95–96	1729	1634	1375	1219	751	751		
96–97	1683	1560	826	540	423	423		
97–98	1644	1494	1276	1217	733	733		
98–99	1560	1560	1560	1560	1507	1459		
99–00	1521	1367	1367	1357	1279	1151		
00–01	1341	1341	1341	1341	1309	1026		
Mean	1611	1512	1297	1193	988	922		
S.D.	152.49	117.67	225.82	320.70	388.04	333.09		
C.V. %	9.46	7.78	17.41	26.88	39.29	36.13		

statistically significant correlation was found between the start of the pollination period and the addition of the mean temperatures registered during the days before flowering. These data are strong evidence to conclude that temperature exerts a great influence on the start of flowering in those trees. However, a more extensive knowledge about chilling and heat requirements is needed to predict the start of flowering in *Quercus*. In both areas where this work was

conducted, *Quercus* is represented by different species and the first to flower is *Quercus robur*. Because chilling and heat requirements are variable according to different species, the results obtained in this study are largely based on *Quercus robur*.

Every year *Quercus* flowering occurs earlier in Vigo, which is warmer than Perugia. Climatic differences between the two areas and different chilling and heat requirements are

Table V. Values of the coefficients of Scheffé's Test (* - 90%, ** - 95% and *** - 99,9% of significance) and temperature average during the dormancy period during the studied years in Vigo and Perugia.

	1995	1996	1997	1998	1999	2000	2001
PERUGIA	11.401	10.767	11.656	11.692	15.444	16.517	13.931
1995	-----	0.950	1.000	0.999	0.000***	0.000***	0.000***
1996	0.793	-----	0.788	0.751	0.000***	0.000***	0.000***
1997	0.833	1.000	-----	1.000	0.000***	0.000***	0.003***
1998	1.000	0.924	0.943	-----	0.000***	0.000***	0.003***
1999	0.000***	0.000***	0.000***	0.000***	-----	0.598	0.170
2000	0.000***	0.000***	0.000***	0.000***	1.000	-----	0.000***
2001	0.000***	0.000***	0.000***	0.000***	0.861	0.822	-----
VIGO	15.348	14.752	14.774	15.242	12.445	12.400	12.989

	PERUGIA			VIGO		
	T. MAX.	T. MIN.	T. MED.	T. MAX.	T. MIN.	T. MED.
1994-95	10.1	5.1	7.6	15.7	9.7	12.7
1995-96	10.2	5.3	7.7	15.2	9.7	12.5
1996-97	10.5	5.1	7.8	14.3	8.5	11.4
1997-98	10.2	5.5	7.8	14.8	9.8	12.3
1998-99	14.1	0.1	7.1	12.6	5.8	9.2
1999-00	15.0	1.0	8.0	12.5	5.6	9.0
1900-01	11.2	2.6	7.0	12.3	6.5	9.4
Average	11.6	3.5	7.6	13.9	7.9	10.9

Table VI. Coefficients of Spearman's test (* - 90%, ** - 95% and *** - 99,9% of significance).

Spearman Test	R ²
Start pollen season VIGO & G.D.D. (T. max)	0.857**
Start pollen season VIGO & Length Heat period	0.793*
Length Chilling PERUGIA & Length Heat period	-0.955**

genetically controlled in each zone and may explain the differences observed in the start date of pollination.

Two methods using different criteria to calculate the requirements to release dormancy, and thus trigger the onset of pollination, were utilised in this study. The aim was to determine which one is more accurate in each area according the pollen data recorded. In the first method, chilling was calculated from the day when mean temperature decreased under threshold temperature to the day (generally in the first half of January) when the minimum temperature was recorded and a change in temperature trend was observed (Aron 1983). The second method used in this study (Ashcroft et al. 1977) established the end of the chill period when several predetermined quantities of chilling were recorded. In both methods from the date when the amount of chilling considered is reached, the Growth Degree-Days (GDD°C) requirements were calculated. The lowest Coefficient of variation was used to select the most accurate quantity of chilling to overcome dormancy.

The chilling requirement was estimated taking into account the first method showed a small coefficient of variation (5.18% in Perugia and 7.87% in Vigo). Because in colder

areas the plants need protection against adverse environmental conditions for a longer time, chilling units and the length of the chilling period are greater (Richardson et al. 1974, Aron 1983, Landsberg 1974). This can be seen in our study, where the number of CH obtained was higher in Perugia (the locality with lower winter temperatures) than Vigo.

Heat requirements were calculated by different methods [summation of daily mean and maximum temperatures, the sum of the difference between maximum and minimum temperatures and according to the Rickman et al. (1983) method]. In each of them we looked for possible improvements by applying several threshold temperatures. Medium temperature in Perugia and maximum temperature in Vigo showed the lowest standard deviation. However the results obtained in Vigo by using medium temperature and the difference between maximum and minimum temperature were also low. The results did not improve when several threshold temperatures were utilised. Nevertheless, in previous studies 5.5°C in Vigo and 4.5°C in Ourense (locality near to Vigo) were used as threshold temperatures, they showed the lowest coefficient of standard deviation (Rodríguez-Rajo et al. 2000), and 11°C as in *Quercus* from the south of Spain Garcia-Mozo et al. (2000).

Despite both models showing low coefficients of variation in both localities, the Ashcroft method (Ashcroft et al. 1977) is very accurate for study the chilling and heat requirements in the different phenological phases of dormancy in Perugia. So there are few differences in heat requirement (number of GDD°C) independent of the chilling units considered. This does not occur in Vigo, where the differences in the coefficient of variation values with the Ashcroft method are

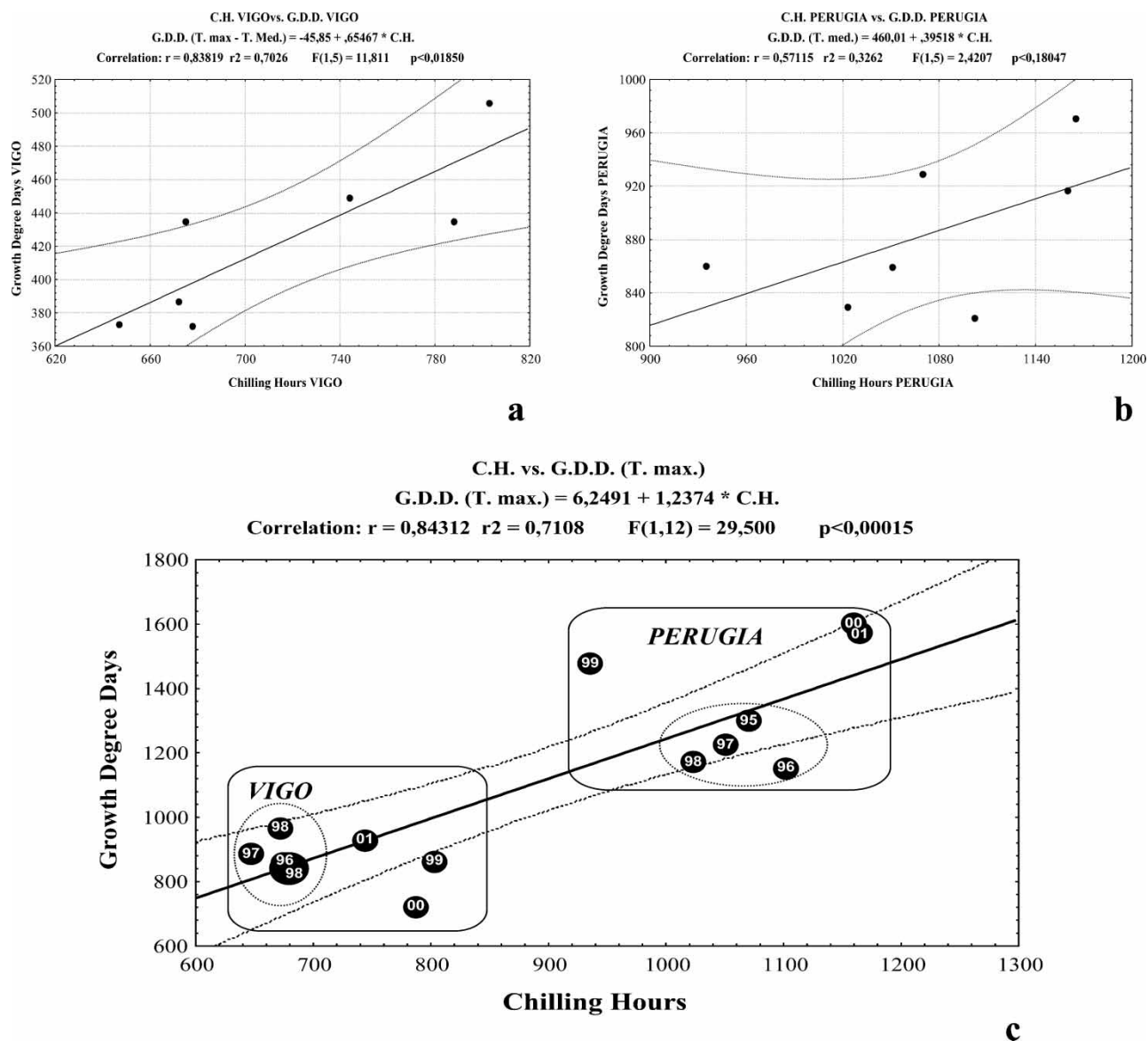


Fig. 2. Relationship between CH and GDD°C during dormancy and start of *Quercus* pollination (a - Vigo, b - Perugia, c - both). For 'c', the individual years are numbered.

greater. Therefore we consider the Aron method better suited to the environmental conditions of Vigo.

It is necessary to point out that differences in the meteorological conditions of the studied years can provoke certain deviations in the proposed models. More precisely, if the behaviour of the temperatures during dormancy and quiescence periods show large differences during any of the years studied, then the coefficient of standard deviation increases rendering prediction from the model difficult. For this reason we utilised the Scheffé test to demonstrate the existence of significant differences between the temperatures registered from November (onset of dormancy) to March (onset of pollination) in the years included in this study. Taking into account the results obtained (Table V) we observe that there are significant differences between the years (significant level 99.9%). The maximum temperatures were approximately 10°C in Perugia and 14–15°C in Vigo

during the years from 1995 to 1998. From 1999 to 2001 the behaviour of the temperature was different: in Perugia the thermal oscillation was higher and in Vigo temperatures were lower than in the previous years.

The correlation between the length of the periods of dormancy and heat requirements has been pointed out by different authors (Richardson et al. 1974, Aron 1983, Frenguelli 1997, Hänninen 1990). The results obtained by applying Spearman's correlation test (Table VI) demonstrates significant correlation between the length of the chilling and heat accumulation period. This implies the period of forcing temperatures are shorter when chilling accumulation is longer. Correlation was also significant and positive between heat accumulation and forcing temperature period and the onset of pollen season in Vigo. Finally correlation was significant but negative, between chilling hours and length of the chilling period. Previous

Table VII. Equations of the linear regression models obtained to predict heat requirement.

Quercus	R	r ²	Adj. r ²	F	g. I.	p	St. Err.
MODEL PROPOSED Without year 1999	0.882	0,779	0,759	38,727	1,11	0,0000	100,92
	G.D.D. (T. max)=6.933+1.209*C.H.						
Model Years 1995–96–97–98	0.942	0,888	0,869	47,62	1,600	0,0005	76,47
	G.D.D. (T. max)=356.65+0.803*C.H.						
Model Years 1999–00–01	0.910	0,828	0,785	19,304	1,40	0,0117	87,65
	G.D.D. (T. max)=−597.80+1.921*C.H.						

studies conducted in Perugia (Frenguelli & Bricchi 1997) demonstrated that when the temperature of the dormancy period was high, the heat requirement to begin the pollination is higher. In contrast if the temperature was low the heat requirement was minor. In the same way Myking (1997) in a study focused on *Betula* indicated a decrease of heat accumulation when the length of chilling period increased.

To predict flowering heat requirement as function of the accumulated chilling in the two localities linear regression models were developed (Fig. 2). When the data of each locality is considered independently, only the model of Vigo contains significant results ($r^2=0.702$). When both localities are considered together (Fig. 2b), the linear regression model obtained explains a high percentage of the heat requirement variability ($r^2=0.71$; 99.9% significant level). This graph reinforces the assertion that the areas with colder temperatures present a higher chilling and heat requirements that have been founded previously (Myking 1997, Chuine & Cour 1999, Jato et al. 2000). At an extreme of the regression line we have the points that correspond to the values reached during the years of study in Vigo, and at the other extreme those of Perugia.

The mean of the minimum temperatures were the lowest of the studied years, and so we consider the year 1999 anomalous (Table V). The model presented improved when this year was removed. The equation of this new linear regression model (Table VII) is used to predict the heat requirement to trigger flowering. In this case r^2 value increase to 0.779% (99.9% significant level).

The variable behaviour of the temperature every year make it possible to improve the result of the prediction, by applying different models according to the temperature registered every year. Taking into account that the Scheffé tests allows us to distinguish two groups in the studied years (Table V), we calculated different equations (Table VII). The first one includes the years from 1995 to 1998, and the second from 1999 to 2001. Both improve the r^2 value, however the number of the years included is low (four and three respectively) and the p value decreases with respect to the first equation. Therefore new studies with a higher number of years need to be conducted in order to reach better statistical significance.

CONCLUSIONS

Temperature in the periods preceding pollination play an important role in determining reproductive growth and anthesis. However correlations were not highly significant

and other factors probably influence this phenological phase. Heat requirement and the length of the chilling accumulation differs according of the climatic conditions of the areas where the plants live. So in colder areas these requirements are larger because the trees need protection for a longer period.

The Ashcroft model gave good results in Perugia. In this model heat requirement is calculated starting from a chilling requirement, independent of when it is reached. However the amount of chilling and heat requirement calculated starting from the date when minimum temperatures of the year are attained and a change in trend is observed, gives better results in the city of Vigo.

New studies with a higher number of years should be carried out with the aim of attaining greater statistical significance. The knowledge of chilling temperatures incidence on the pollination process of the winter-spring flowering in different areas are of particular interest in explaining the natural distribution of plants. This is particularly important given present day climatic changes in seasonal temperatures and how increased winter temperatures may affect the trees dormancy.

ACKNOWLEDGEMENTS

This work has been funded by the “Conselleria de Medio Ambiente de la Xunta de Galicia”. The authors thank the University of Vigo for the grant awarded.

REFERENCES

- Andersen, T. B. 1991. A model to predict the beginning of the pollen season. – *Grana* 30: 269–275.
- Aron, R. 1983. Availability of chilling temperatures in California. – *Agricult. Meteorol.* 28: 351–363.
- Ashcroft, G. L., Richardson, E. A. & Schuyler, D. S. 1977. A statistical method of determining chill unit and growing degree hour requirements for deciduous fruit trees. – *Hortoscience* 12: 347–348.
- Chuine, I. & Cour, P. 1999. Climatic determinants of budburst seasonality in four temperate-zone tree species. – *New Phytol.* 143: 339–349.
- Faust, M. 1989. Physiology of temperate zone fruit trees. – J. Wiley & Sons, Chichester/New York/Brisbane/Toronto/Singapore.
- Felker, F. C., Robitaille, H. A. & Hess, F. D. 1983. Morphological and ultrastructural development and starch accumulation during chilling of sour cherry flower buds. – *Am. J. Bot.* 70: 376–386.
- Frenguelli, G. 1997. Pollen volume change as a marker of the dormancy period in some arboreal plants. – *Allionia* 35: 181–187.
- Frenguelli, G. & Bricchi, E. 1998. The use of the pheno-climatic

- model for forecasting the pollination of some arboreal taxa. – *Aerobiologia* 14: 39–44.
- Frenguelli, G., Ferranti, F., Tedeschini, E. & Andreutti, R. 1997. Volume changes in pollen grain of *Corylus avellana* L. (Corylaceae) during development. – *Grana* 36: 289–292.
- Frenguelli, G., Spiekma, F. Th. M., Bricchi, E., Romano, B., Mincigrucci, G., Nikkels, A. H., Dankaa, W. & Ferranti, F. 1991. The influence of air temperature on the starting dates of the pollen season of *Alnus* and *Populus*. – *Grana* 30: 196–200.
- Galán, C., García-Mozo, H., Cariñanos, P., Alcázar, P. & Domínguez-Vilches, E. 2001. The role of temperature in the onset of the *Olea europaea* L. pollen season in south-western Spain. – *Int. J. Meteorol.* 45: 8–12.
- García-Mozo, H., Galán, C., Gómez-Casero, M. T. & Domínguez-Vilches, E. 2000. A comparative study of different temperature accumulation methods for predicting the start of the *Quercus* pollen season in Córdoba (South West Spain). – *Grana* 39: 194–199.
- Hänninen, H. 1990. Modelling bud dormancy release in trees from cool and temperature regions. – *Acta Forest. Fenn.* 213.
- Hirst, J. M. 1952. An automatic volumetric spore-trap. – *Ann. Appl. Biol.* 36: 257–265.
- Jato, V., Frenguelli, G., Rodríguez-Rajo, F. J. & Aira, M. J. 2000. Temperature requirements of *Alnus* pollen in Spain and Italy (1994–1998). – *Grana* 39: 240–245.
- Kramer, K. 1994. Selecting a model to predict the onset of growth of *Fagus sylvatica*. – *J. Appl. Ecol.* 31: 172–181.
- Laaidi, M. 2001. Forecasting the start of the pollen season of Poaceae: evaluation of some methods based on meteorological factors. – *Int. J. Biometeorol.* 45: 1–7.
- Landsberg, J. J. 1974. Apple fruit bud development and growth; analysis and an empirical model. – *Ann. Bot.* 38: 1013–1023.
- Mullenders, W. 1974. Aeropalynological research in Belgium. – In: *Atlas of European allergenic pollens* (ed. J. Charpin, R. Surinych & A.W. Frankland), pp: 95–102. – Sandoz, Paris.
- Myking, T. 1997. Dormancy, budburst and impacts of climatic warming in coastal-inland and altitudinal *Betula pendula* and *B. pubescens* ecotypes. – In: *Phenology in seasonal climates* (ed. H. Lieth & M.D. Schwartz), pp. 51–66. – Backhuys Publ., Leiden.
- Norris-Hill, J. 1998. A method to forecast the start of the *Betula*, *Platanus* and *Quercus* pollen seasons in North London. – *Aerobiologia* 14: 165–170.
- Richardson, E. A., Schuyler, D. S. & Walker, D. W. 1974. A model for estimating the completion of rest of “Redhaven” and “Elberta” peach trees. – *Hortoscience* 9(4): 331–332.
- Rickman, R. W., Klepper, B. L. & Peterson, C. M. 1983. Time distributions for describing appearance of specific culms of winter wheat. – *Agron. J.* 75: 551–556.
- Rodríguez-Rajo, F. J. 2000. El polen como fuente de contaminación ambiental en la ciudad de Vigo. – PhD. Thes. Dept. Plant Biol. Soil Sci., Univ. Vigo, Ourense.
- Rodríguez-Rajo, F. J., Méndez, J. & Jato, M. V. 2000. Influencia de la temperatura en la floración de *Quercus* en el sur de Galicia (Ourense y Vigo, 1994–98). – *Acta Bot. Malac.* 25: 153–163.
- Spiekma, F. Th. M., Frenguelli, G., Nikkels, A. H., Mincigrucci, G., Smithuis, L. O. M. J., Bricchi, E., Dankaa, W. & Romano, B. 1989. Comparative study of airborne pollen concentrations in central Italy and The Netherlands (1982–1985). – *Grana* 28: 25–36.