

Pollen allergy in the Bilbao area (European Atlantic seaboard climate): pollination forecasting methods

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Summary

Forecasting pollination can help the allergist to establish the appropriate treatment and advice for patients. Based on previous studies, we have related the climate variables with the grass pollen counts in the search for pollination predictors. By relating the meteorological data of the temperature recorded every 6 h and of the rainfall in hourly periods, together with the daily pollen counts obtained by the Hirst volumetric system, over a period of 3 years, we have tried to predict the start, duration and severity of the grass pollination, as well as the days of peak pollination. We have established a relationship by means of a polynomial regression originating from the mean cumulated temperature higher than 9°C [$R^2 = 0.927$ ($P = 0.0001$)], with the pollination season starting from 300°C and the maximum peak at 356°C, in the 3 years of the study. During the days of pollination, peaks higher than 50 grains/m³ coincide with average daily temperatures of 18.7 ± 3 and lower than 50 grains/m³ with temperatures of 16.8 ± 3 (significant to 95%). The duration of the pollination is influenced by the cumulated average temperatures (from 800 to 900°C) and especially by precipitation at the start of and during pollination. In order to forecast grass pollination, the cumulated average temperatures are useful, starting from a basal (9°C), pollination begins when this sum is greater than 300°C, whereas when 800°C is reached and depending on the rainfall during the season, pollination will end. The total severity of pollination seems to depend on the rainfall prior (in the same year) to the start. During pollination, the days with an average temperature of 18.7 ± 3 °C and an absence of rainfall between 4 and 12 h, will be the days with a presence of more than 50 grains/m³. Thus, it is possible to forecast and estimate risk factors in the long-term (by means of the rainfall prior to pollination) and in the short-term (for the following day, if a weather forecast is available) so as to offer it to those members of the population affected by pollinosis.

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Introduction

Forecasting pollination, both the start of pollen occurrences and their severity, can help the allergist to establish the appropriate treatment and advice to be dispensed to patients.

Several studies have been published based on different methods for forecasting the pollination of different pollen taxa [1–25], with the parameters to be forecast

differing according to their definition. Regarding the start of pollination, Stix [26] defined it as the day of the year on which 2% of the total of the pollens of the same taxon in the total counts for the last 35 years appear, at each count site [21–25], with a palinological criterion. But it can also be defined as the day on which each taxon reaches the level established as the threshold for causing symptoms in patients, thus being a clinical criterion.

The length of the pollination season is defined by Stix [26] as the time between the day pollination begins and the appearance of 98% of the total pollens of each taxon, being, like in the previous case, a value relative to each

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count site [17,18,21–25]. The start of the season, according to the study by Emberlin [25], begins at cumulated total pollen counts of 75/100 and the same criterion as Stix used to define the length of the season. It would be more useful for the allergist to use a clinical criterion, which would be the days of potential pollination above the symptom threshold. Regarding the method and constants to be used, there are different appreciation criteria for each author [10,11,19–22,25], depending on the weather, the type of taxon and its importance regarding the sensitization of patients in each specific area. The sensitivity of the forecasting might be for periods (10 days) or for days.

Driessen [24] applied a mathematical model with a simple regression formula whose main variable is the date (day of the year) when the birch pollen levels collected are 125, with which he obtains the date of appearance of 100 grass pollen grains with a standard deviation (SD) of 5.5 days, which is an estimable clinical approximation. In most studies the appearance of other taxa [13–20] is applied as an independent variable or crop estimate data is used, as in the case of Friis [8] or Subiza [23]. The most practical trend is to apply meteorological data or soil data in order to obtain forecasting formulas in the process of avoiding variables which might contain errors in themselves, as used in the case of Arobba [22] who, starting from purely climatic data, achieves a good correlation of the cumulated temperature with the start date of pollination of the *Urticaceae*, or Emberlin [25] who does the same with *Poaceae*.

Basing our studies on these backgrounds, we have tried to relate the climate variables with the pollen counts for *Poraceae*, always taking into account the levels of these that cause symptoms in our patients, in the search for pollination forecasters.

Materials and methods

The climate of Bilbao

The Bilbao area has a European Atlantic coastal climate, with mild temperatures and without great variations throughout the year ($13.4 \pm 4.2^\circ\text{C}$) nor interannually (1.3°C). Rainfall is high due to the prevailing north west winds and the accumulation of clouds in the mountains (1214 l/m^2), with an interannual variation lower than 30%.

Vegetation in the Bilbao area

Greater Bilbao has a surface area of 336 km^2 and a population of 900 000. Its orography is in the shape of a valley around a tidal river estuary, facing north west. The

neighbouring hilly and mountainous areas are covered with characteristic sub-Atlantic vegetation, with forests of Cantabrian holm oaks (*Quercus ilex*) and Gall oak groves of *Q. faginea*, *Q. pubescens* and *Q. robur*, on occasions in mixed forests with *Fraxinus excelsior*, *Acer campestre*, *Ulmus minor*, *Tilia cordata* and *Corylus avellana*. This autochthonous forest, which currently occupies less than 4% of the surface area, has been replaced, for industrial purposes, by the planting of large extensions of *Pinus radiata* (45 000 Ha in the Bilbao area—13.5% of its surface area). Heather, gorse and ferns have grown in areas where the forest has disappeared.

Meadows occupy 38% (127 680 ha) of its surface area and the majority are extensions of *Poa pratensis*, *Brachypodium pinnatum*, *Festuca rubra*, *Dactylis glomerata*, *Briza media*, *Holcus lannatus*, *Bromus tectorum*, *Holcus lanatus*, *Avena sativa*, and *Lolium perenne*.

Meteorological data

Data is obtained from the meteorological station at Sondica Airport (National Meteorological Institute), [Altitude 35 m Lat. $43^\circ 18' 16''$ long. $02^\circ 55' 46''$ W] situated 10 km from the Hospital de Basurto. The temperature figures were gathered each 6 h and rainfall data in hourly periods.

The average daily temperature values (the average of the four daily periods obtained) and the cumulated precipitations (accumulated in 24 h) will be used later, since the relative humidity is a data factor which is correlated with these variables.

Pollen count method

Recording was performed by the Hirst volumetric system [27] using a 7 day BURKARD Spore Trap (BURKARD Manufacturing Co Ltd), located on the roof terrace of the out-patients department at the Hospital de Basurto (at a height of 21 m of the ground). Morphological differentiation criteria were used to differentiate the pollens [28,29]. The pollen counts/ m^3/day are those used for the study.

Study of symptoms in the population

Monitoring of symptoms was carried out on a population of 43 patients allergic to grass pollens, 25 men and 18 women (age 26 ± 7 years), all inhabitants of Bilbao, during the months of May and June 1989. These patients carried out this monitoring by recording the following variables in specially prepared booklet: 0 = absence of symptoms; 1 = slight symptoms; 2 = moderate symptoms; 3 = severe symptoms.

Criteria of variables to be forecast

Start of pollination

We consider this to be the day of the year on which the level of grass pollens reached is sufficient to provoke symptoms in all patients (period of high risk pollination for all the population of sufferers from grass pollen allergy) in the population being studied, and therefore to define the pollination start date (ordinal number in the year) we shall use the prior data about the level of grass pollens at which 100% of the patients (in Bilbao) suffer from symptoms [30].

Duration and severity of pollination (total pollination)

The duration of pollination is another factor to be forecast (because it is clinically useful for controlling and treating patients as more days with symptoms can be observed). The variables we study in order to describe the duration of pollination are: the vegetation prior to pollination as a source of pollen emission [30]. In this case the vegetation of the Bilbao area, as described previously. The days with climatic factors favourable for this to take place [17]. The climate parameters that favour withering with the end of pollination [31,32].

The rainfall prior to the pollination period is an essential factor in order to calculate sources of pollen emission, its influence on ripening is notable, and it will especially favour the growth and pollination persistence due to the delay produced in withering or withering of plants, with rainfall also being able to influence in the same way during the season provided it does not alter the days favourable for pollination [23,31]. The total pollination severity in pollen grains/m³ of air, as it depends on similar parameters, will be sought with the same variables.

Days of severe pollination, high risk days

Starting from the days on which the threshold level of grass pollens is obtained, that cause symptoms in 100% of the patients, we shall relate the severity of the symptoms in the patients on these days and the meteorological variables that define and differentiate each population [31,32].

Statistical analysis

Description of variables

For qualitative variables we use percentages. For quantitative variables we use the average and the typical

deviation. The normal population distribution was checked by means of the Kolmogorow Smirnov test.

Comparison of variables

For comparison of a quantitative variable, of normal distribution, with another qualitative variable, Student's *t*-test for paired data is used. Differences were significant when the $P < 0.05$.

If the qualitative variable has *K* levels and the other is quantitative, an analysis of the variance is carried out.

The relationship between two quantitative variables is carried out by means of Pearson's *R*, seeking the best possible adjustment by linear or polynomial regression. A *P*-value below 0.01 was considered significant.

Results

Results of the climate in the 3 years of the study

In the 3 years of the study (1987, 1988 and 1989), the temperatures obtained ($13.2 \pm 4.6^\circ\text{C}$) and the rainfall (916.5 l/m²), fall within the interannual variation values, which means that they are representative of the climate endured (Fig. 1, Table 1).

Results of the monitoring of symptoms in patients with pollen allergy

The results of the monitoring of symptoms in the patients can be seen in Table 2. The threshold for the presence of

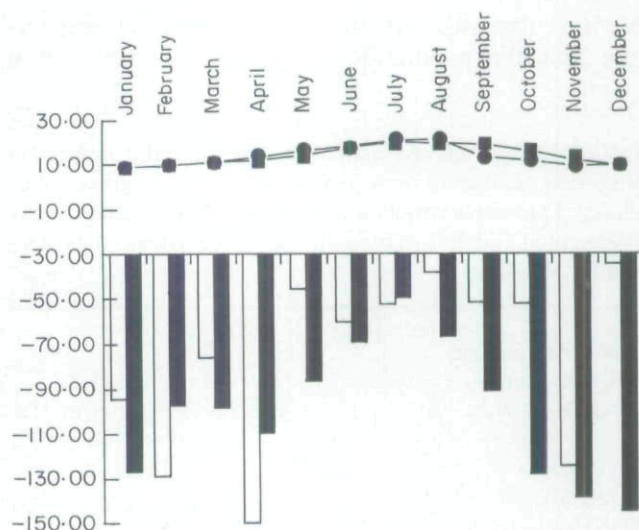


Fig. 1. Bilbao climate, in the 3 years of the study and the 40 years before. □. Rainfall — 3 study years. ■. Rainfall — 40 years before. —●—. Temperature — 3 study years. —■—. Temperature — 40 years before.

Table 1.

	Temperature °C		Rainfall l/m ²	
	3 Study years	40 Years before	3 Study years	40 Years before
January	8.92	8.6	95.22	127
February	9.77	9.6	129.25	98
March	11.37	10.9	75.81	99
April	13.22	11.9	154.40	110
May	16.01	14.3	46.00	87
June	18.35	17.7	61.14	70
July	20.52	19.7	52.43	50
August	21.11	19.7	38.80	67
September	13.32	18.6	52.17	92
October	11.68	16	52.20	129
November	9.53	11.8	124.77	140
December	9.59	9.5	34.30	145
Average	13.61	14.03	916.49	1214.00

moderate or severe symptoms (at which moderate or severe symptoms were present) in 100% of the patients was obtained on the day with 37 grains/m³ of grass pollen at our sampling station.

The simple correlation (Pearson's *R*) between the pollen count each day and the symptomatology of the patients produced a non-significant result.

Start of pollination

We have obtained a relationship between the temperature and the pollination of grasses by means of a

Table 2. Daily levels of grass pollen grains and the presence of symptoms (moderate or severe) in patients with grass pollen allergy. The simple correlation (Pearson's *R*) between the daily pollen count and the symptomatology of the patients gave non-significant results

Number of patients with symptoms (moderate-severe)	Grass pollen grains/m ³ /day
6 (15%)	3.5
38 (88%)	10
40 (93%)	16
42 (97.7%)	21
42 (97.7%)	27
43 (100%)	37

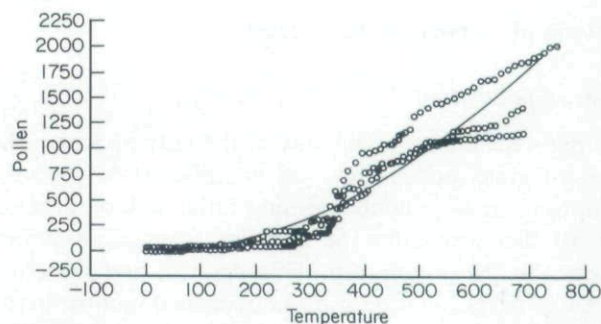


Fig. 2. Polynomial regression curve of the cumulated temperatures/cumulated pollen counts relation. Temperatures are the daily average higher than 9°C, from 1 March to 31 May (1987, 1988, 1989). Pollen counts are the daily *Graminae* gains collected in the spore trap, on the same dates. $R^2 = 0.927$. ($P = 0.0001$). $y = -36.246 + 0.163x + 3.503E - 3x^2$.

polynomial regression where an independent variable (*X*) was the value of the cumulated average temperatures from 1 March to 30 May, subtracting the value of 9 from each figure (as the best for adjusting the curve (Fig. 2). A statistical significance is obtained of the relation between both variables by means of a formula:

$$y = -36.246 + 0.163x + 3.503E - 3x^2$$

$$[(R^2 = 0.927) \text{ with a significant of } (P = 0.0001)]$$

In the 3 years recorded, the start of the season (day number of the year in which is reached the pollen thresholds or sensitivity of the Bilbao station for 100% of the patients in the Bilbao area — 37 grains/m³ — is given with average cumulated temperatures (>9°C) of $305 \pm 1.8^\circ\text{C}$ (Table 3), these cumulated temperature are obtained on days 133 ± 5 (Table 3).

As the average daily temperature in the month of May in Bilbao is 16.01°C ($> 9^\circ\text{C} = 7.01^\circ\text{C}$), we can therefore state that the start of the season on the day after a cumulated temperature of 300°C (average cumulated temperature above 9°C from March to May) is reached. And the possible error does not have an ordinal difference greater than ± 1 day. In the same way, the maximum pollen peak occurs when this temperature reaches 356°C , using the same data (Table 3).

Severity of daily pollination

From the pollen populations and climate variables we have been able to differentiate (Student's *t*-test) that during the 45 days after the start of pollination, pollen peaks higher than 50 grains/m³ are observed with daily temperatures of 18.7 ± 3 and lower with temperatures of 16.8 ± 3 , statistically differentiated by means of Student's *t*-test and significant to 95% (Table 4).

Table 3. Meteorological data results that influence the start, length and the end of the season, and total pollen counts (*Gramineae*).

Variables	1987	1988	1989
Start to peak days	13	9	5
Start day (day <i>n</i>)	129	132	139
Average cumulative temperature (start)	303.5°C	304.5°C	307.1°C
End day (day <i>n</i>)	191	197	189
Length of the season	62	67	50
Average cumulative temperature (end)	807°C	880°C	825°C
Rainfall 1/5	369 mm/m ²	529 mm/m ²	471 mm/m ²
Rainfall 10/7	510 mm/m ²	703 mm/m ²	553 mm/m ²
Total pollen counts	1457 pol/m ³	2200.9 pol/m ³	2180.1 pol/m ³

There are days with temperatures within these limits but on which the rainfall alters the conditions and there is no pollination, if the precipitation is before midday, whereas there might be days with abundant rainfall and the appropriate temperature when great amounts of pollen appear, when this precipitation does not occur between 08.00 and 14.00 h. Figure 3 shows the times of rainfall on those days, and we can observe that on the days with pollination, rainfall was either after 14.00 h or before 06.00 h, which are the normal pollination times for grasses and therefore the counts on these days are not affected; on the contrary, however, on days with favourable temperatures for pollination, when this does not occur, there was rainfall between 12.00 and 16.00 h.

Duration of the pollination

The duration of the pollination is influenced mainly by two variables, the cumulated temperature (from 800 to 900°C) (Table 3) which will give us the date of withering when it is reached, and especially the cumulated rainfall at the start of and during pollination (Table 3), which the greater the rainfall is, extends the season and delays

withering (Table 3). We can also observe that the speed in reaching the peak day from the start and the rapid increase in the cumulated temperature favour the severity of pollination, because of which the same total pollen level was reached in 1988 and 1989, although influenced by two different variables. In 1988, withering arrived late due to prior heavy rainfall (Table 3) and persistent rainfall during the season, with the pollination period being longer but less severe (Table 3). In 1989, it was favoured by prior rainfall and a very sharp increase in temperatures, causing days of severe pollination although for a shorter period than in 1988. In 1987, there was less prior rainfall, a longer time-span between the start and peak pollination and the temperatures did not cumulate as intensely as in 1989, causing less severity of pollination and earlier withering (Table 3).

Discussion

According to the results of this study the start date for grass pollination will coincide with the cumulated

Table 4. Meteorological parameters suitable for *Gramineae* pollination

Risk factor	Pollen/m ³	Average Temperature	Day numbers*	Rainfall
1	0–50/m ³	16.8 ± 3	161	No
2	51–100/m ³	18.7 ± 3	18	Variable

* All days in May and June (1987, 1988, 1989) have been taken into account ($P = 0.0037$) (significance 95%).

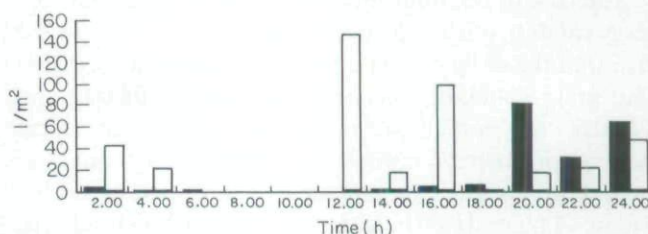


Fig. 3. On days with temperature suitable for pollination, the rainfall may appear in different periods. If the rainfall is between 16.00 and 24.00 h the pollination appears (■. Yes) whereas if the rainfall is in the first half of the day, pollination does not appear (□. No).

average temperatures ($>9^{\circ}\text{C}$) from March to May, when a value of $300\text{--}310^{\circ}\text{C}$ is reached, coinciding with days 129 to 149 of the year (9 May–29 May), provided that the grass vegetation, geography and climate are identical to ours [33].

In our study the duration of pollination is influenced by two main variables, the cumulated temperatures (from 800 to 900°C), which will give us the date of withering when reached, and the cumulated rainfall at the start of and during pollination, which will prolong the season and delay withering.

This same forecasting system, with the theoretical basis of application of thermal integral [8] was applied by Davies [17] and Emberlin [25], with similar results. Fairley [18] also obtained, with similar statistical methods, a forecasting approximation for pollination of *Fagaceae*. Since the fact of the cumulated temperatures is the datum most used with good results by different authors [19,21,22], it seems to have the greatest influence of the development and appearance of pollination.

The duration of pollination in our area, influenced mainly by two variables, the cumulated temperatures (from 800 to 900°C) and the cumulated rainfall at the start of and during pollination, will prolong the season and delay withering, according to Davies' [21] and Emberlin's [25] results.

We have also been able to observe that the speed in reaching the peak day from the start and the rapid increase in the cumulated temperatures favour severity of pollination. Davies [17,21] applies a similar formula, starting from the average temperatures for the 2 months prior to the appearance of pollination, in his case April and May, based on a hypothesis of cumulated temperatures but in the end uses the average of these temperatures (total amount/number of days) divided among the days in order to obtain it, i.e. there seems to be a connection not only with the cumulated temperature but also with the speed it is reached, giving the regression an integral and not linear form.

The lack of relationship of the severity of pollination/daily rainfall, during the pollination period, is due to the fact that the daily counts do not take into consideration that grass pollination occurs between 06.00/08.00 h and 14.00 h, so rainfall during these hours will affect pollination whereas rainfall at other hours will not, and pollination might even increase if precipitation occurs about 14.00 or 16.00 h, as a study by Pulsik [34] reflects. To this effect there are several publications with similar results that reflect that an increase in precipitation of more than 2 mm cleans pollen from the air and pollination stops with the plants being moist, if this happens during the day, in accordance with the data well

described previously by Spieksma [35]. However, nocturnal rain does not reduce pollination the following day unless it persists after 06.00 h [32,34,35], with references existing to confirm our results.

The best conditions for pollination are present on hot, dry, sunny days, as other authors mentioned [9,10,21,32,35], reflected in our study in the results for peak grass pollination days, which coincide with these weather characteristics.

To study the connection between the climate and the pollination, we have taken temperature and rainfall data because of the relationship that exists between the growth, development and ripening of the plants and the climatic variables, without excluding the photoperiod (hours of daylight and/or darkness) that each plant needs. The development of plants depends firstly on the activation of their enzymes, the speed of activation and the different activities to be developed by the plants until their ripening are thermosensitive and photosensitive [36,37].

The dependence on temperature is originated starting from a threshold temperature, above which the enzymes become activated; from this temperature up to an optimum temperature, their development is faster, especially if the temperature is higher and is maintained, with the daily variation cycles (more day-time and less night-time). On reaching a certain temperature the opposite occurs; the enzymatic processes slow down or stop, generating withering, with this development also depending on the amount of water and other nutrients available during the process, with development being shorter and smaller if these nutrients and water are more scarce [37].

The start date for pollination is conditioned by the appearance of 37 pol/m^3 of grass pollens in the collector, the pollen level that provokes symptoms in 100% of our patients, and which seems to us much more appropriate for this kind of study than others that define this date and the duration of pollination using purely quantitative and botanical parameters [5,21], with few applications in our daily work.

In his study on a continental climate (Madrid), Subiza [23] gives greater importance to winter rainfall, as a variable to be used in forecasting, justifying this as being the parameter of greatest variability in a climate with low rainfall and homogeneous interannual temperatures. Fairley [18] also finds a relationship between total pollination and rainfall, and it seems that this can be confirmed in our study (for lack of a greater number of years).

On studying the pollination forecast for pollens from tree families (*Quercus*), Fairley (18) relates the severity of pollination with cumulated rainfall in previous

months, a predictable observation since tree roots are deep and penetrate the phreatic mantle, meaning that they depend on climate alterations prior to their bursting dates [37]. This should not occur with *Poaceae*, which have short, superficial roots and are mostly evergreens (they grow from the previous rootball) and do not depend on much earlier climate variables [32,36,37]. This relationship would be present if the grasses observed in the count-taking depended on cultivated grasses, starting from their germination (seed), needing suitable humidity and temperatures for their germination (4–6 months before pollination), and later these variables would affect their growth (2–3 months before pollination), apart from the climatic variables for their ripening and flowering (1 month before pollination) [36,37]. For this reason, we consider that the study by Subiza [23], in which he relates total *Poaceae* pollination with rainfall 6 months prior to the start dates for pollination, cannot be extrapolated to a climate and vegetation like ours.

Publication in the mass media and to sanitary personnel of risk indices, for patients with pollen allergy, is taking place in some European countries [38], by means of low, moderate and high risk indices. The values by which each index is considered are arbitrary and are being revised. The appraisal of what value of atmospheric pollen causes symptoms in the population is a polemic matter and has no exact answer, and therefore the values found in this study, with two differentiated classes of risk days for pollination of *Gramineae* depending on the average temperature, might be useful in our environment, whereas its extrapolation to other areas is, at least, debatable. The best approach to the prevention of pollinosis is awareness of the calendar and pollinic map for each locality, not only for the resident population, since today people habitually travel, for work or leisure reasons, and patients with pollinosis should know the risk of symptoms if they travel, either to avoid travelling or to take the appropriate treatment. To this effect, the European Pollen Network has been formed, which sends easily understandable data to a database for publication in written media or for broadcasting via satellite television [39]. The forming of this database is more important for Central and North European countries, which benefit from the information from countries in the south, making it possible to forecast when pollination will be caused by bursting, due to the delay of 1–4 weeks (depending on the latitude) in relation to the countries in the south. Apart from this information, we should use each day's meteorological forecasts, in each climaticbotanical area, in order to establish the ranges or indices of pollination for the following day.

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