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ORIGINAL ARTICLE

Time linkages between pollination onsets of different *taxa* in Perugia, Central Italy – an update

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Abstract

Introduction and objective. In the last decades, increasing attention has been paid to pollinosis. Numerous studies have been carried out concerning the pollination timing of allergenic plant species and the possibility to forecast its beginning and intensity using several statistical methods and models. This study proposes a simple and fast method to identify in advance the time lapse in which the pollination of some allergenic *taxa* should start.

Materials and methods. The times of pollination of 14 *taxa* were recorded in the area of Perugia (Central Italy) by means of a 7-volumetric Hirst-Type pollen trap. For a 30-year period (1984–2013), annual starting dates were calculated for each *taxa*, using the 5% method (Lejoly-Gabriel). The time linkages between these starting dates were then estimated, considering them in pairs and calculating linear regression coefficients.

Results. For the significantly linked species, forecasting models were obtained by means of linear regression analysis. To apply these models to the ongoing pollen season, pollination beginning of the earlier species has to be calculated using a sum-based method. From this date, through the obtained equations, it is possible to predict the approximate period in which the pollination of the second linked *taxa* should start.

Conclusions. The possibility to predict the start of the pollen season of these *taxa* could be of great importance from the allergological point of view. In fact, an early or delayed flowering can have considerable effects in the prophylaxis programming and efficacy.

Key words

pollen, pollination, linear models, forecasting

INTRODUCTION

In the last decades, a dramatic rise in patients suffering from pollinosis and airway disease has been observed [1, 2, 3, 4, 5]. Studies of aerobiology with emphasis on allergenic pollens have become increasingly numerous and extensive. In fact, the possibility to predict the beginning of the pollen season for the most allergenic *taxa* is crucial for planning pollen avoidance and adequate pharmacological therapies; Scadding et al. have shown how starting the medication two weeks before the pollen season markedly improves the efficacy [6]. Many studies have been carried out concerning the pollination timing of allergenic species and the possibility to forecast its beginning and intensity by using several statistical models [7, 8, 9]. These models are sometimes very complex, taking into account the environmental factors that influence flowering and thus pollination, such as meteorological conditions (especially temperatures) [10, 11, 12] and daylight hours. Growing Degree Days (GDD) is probably the most common pheno-climatic model used to forecast the flowering time [13, 14, 15, 16, 17]. In Perugia (Umbria-Central Italy) the aerobiological monitoring has been active continuously since 1982, and the great quantity of data collected can be processed to obtain a lot of information about pollen seasons of many allergenic *taxa*. In fact, some models of pollen season forecast have already been published [18, 19, 20], and other works are in progress [21]. In 1995, Bricchi et al. proposed a simple model of time linkage between the pollination onsets of 14 *taxa* monitored in the area of Perugia from 1982–1992 [22]. This model relies on the fact that the phenological development of some species can be used as an 'indicator' to predict phenophases occurrence in other species. They showed how, starting from the correlation existing in the flowering dates of some *taxa*, these can be forecasted using a statistical model based on linear regression, which does not require meteo-climatic information.

OBJECTIVE

This study aims at updating the model proposed in 1995 by Bricchi et al. [22]. Data on pollination of 12 *taxa*, collected in a 30-year period (1984–2013) were integrated and analysed to calculate more precisely the time linkages between their pollination onsets, and thus to forecast their approximate beginning date through an updated form of the regression-based model.

MATERIALS AND METHOD

Pollen grains were collected using a 7-day volumetric Hirst-Type [23] pollen trap (Lanzoni, Bologna) located in Perugia on the rooftop of the Department of Agricultural, Food and Environmental Science, at about 20 m above ground level.

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Perugia lies on a hill (493 m above sea level) and overlooks the middle valley of the river Tevere, between Lake Trasimeno and the Tyrrenian side of the Marches-Umbrian Appenine Mountains. The climate can by classified as sub-continental by means of continentality index [24]. For each *taxon*, over a 30-year period (1984–2013) of pollen monitoring, dates of the beginning of the main pollen season (MPS) were calculated using the Lejoly-Gabriel method (starting on the day by which 5% of annual total pollens had been released) [25]. The time linkages between these starting dates were then estimated considering them in pairs and calculating the linear regression coefficients. Forecasting models were obtained by means of linear regression analysis.

RESULTS

Mean date of pollination start, its standard deviation, earliest date, latest date and the ranges between these were calculated for the 12 analysed *taxa* (Tab. 1). Some *taxa* showed high year-to- year variability in the date of their pollination onset. For example, *Corylus* and *Ulmus* have ranges of 55 and 42 days, respectively. This behaviour is particularly recognisable in *taxa* flowering in winter and spring, especially arboreous ones, the main cause being that winter duration and temperatures control the pollination onset of various tree species. Following an unusually short, warm winter, many trees bloom early in the season, but an unusually long winter will delay the date of pollination [22]. Also, *Pinus*, with its 49-days long range, seems to undergo this effect, despite having a slightly later flowering period.

Table 1. Beginning of the main pollen season (MPS)

	Mean date	S.D.	Earliest date	Latest date	Range (days)
Corylus	15 Jan (15)	12	29 Dec (-3)	21 Feb (52)	55
Ulmus	18 Feb (49)	10	3 Feb (34)	17 Mar (76)	42
Populus	3 Mar (62)	8	14 Feb (45)	20 Mar (79)	34
Salix	22 Mar (81)	9	7 Mar (66)	8 Apr (98)	32
Platanus	2 Apr (92)	9	19 Mar (78)	21 Apr (112)	34
Pinus	15 Apr (105)	12	23 Mar (82)	11 May (131)	49
Quercus	27 Apr (117)	6	12 Apr (102)	8 May (128)	26
Gramineae	2 May (122)	7	15 Apr (105)	17 May (138)	33
Plantago	11 May (131)	17	14 Apr (104)	22 Jun (173)	69
Olea	2 Jun (153)	7	20 May (140)	22 Jun (173)	33
Castanea	17 Jun (168)	7	2 Jun (153)	28 Jun (180)	27
Artemisia	7 Aug (219)	4	28 Jul (210)	17 Aug (229)	19

(S.D. – Standard Deviation; numbers in brackets indicate conversion of the dates in number of days from 1 January)

On the other hand, some *taxa* showed ranges shorter than 30 days (*Quercus* – 26 days, *Castanea* – 27 days, *Artemisia* – 19 days) which are more typical for late spring/summer flowering species that are not influenced by the duration of winter. In addition, it has to be considered that while the flowering of early spring plants is greatly influenced by temperatures, late spring and summer flowering species also undergo the effect of photoperiod, which does not vary from year to year.

An exception in this study is represented by *Plantago*: its mean pollination onset date is 11 May, but it shows the maximum registered range (69 days), having pollination onset dates between 14 April (2008) – 22 June (2013) in the 30 considered years.

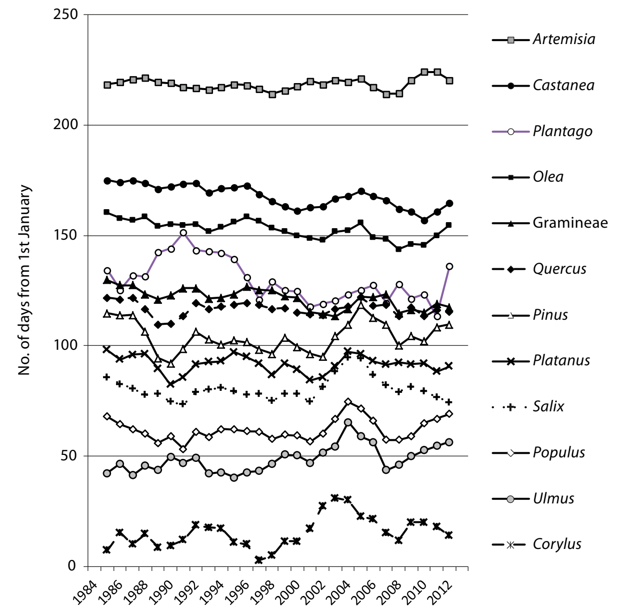

Figure 1. Dates of start of pollination (centred moving averages of three consecutive years) for the 12 taxa over the studied period

Figure 1 shows the trends of the pollination onset for the 12 studied *taxa*. As observed by Bricchi et al. in 1995 [22], *Corylus* and *Artemisia* show particular pollination patterns. The beginning of their pollen season does not seem to be linked to any of the other *taxa* (Tab. 2). The only isolated exception is a linear regression coefficient of 0.608 between the pollination onsets of *Corylus* and *Ulmus,* which is quite close to their natural pollination starting periods. The reason for this almost total 'unlinkage' could be that *Corylus avellana* is the first species flowering in January and, as already stated it is strongly influenced by temperature requirements to be released from dormancy, resume growth, and bloom [26]. Thus, its beginning, relying on the temperatures in the immediately preceding period, is untied from the later ones (except *Ulmus*). Instead, the pollination start of *Artemisia* could be unrelated with all the others because of its good constancy in time (lowest standard deviation and range).

The yearly onset dates of each *taxon* were correlated in pairs to investigate if there were linkages between the beginning of flowering of the studied species. Time linkages between the start of the main pollen season of different plants could be of great importance for constructing forecasting models capable of predicting the flowering period of a species, starting from the pollination of previous ones. All the *r* coefficients, obtained with the linear regression method, are shown in Table 2, together with their level of significance. Highest significant correlations were obtained for *taxa* whose flowering periods are close, but there were some cases of strong correlation also between *taxa* with a range between their mean pollination onset dates (warning days, WD) higher than 30 days (Gramineae/*Castanea*, 47 WD; *Quercus*/*Olea*, 36 WD; *Corylus*/*Ulmus*, 34 WD; Gramineae/*Olea*, 32 WD).

Table 3 shows the couples of *taxa* with the highest correlation levels, their linear regression coefficients

Table 2. Linear regression coefficients

	Artemisia	*Castanea*	*Olea*	*Plantago*	*Gramineae*	*Pinus*	*Quercus*	*Platanus*	*Salix*	*Populus*	*Ulmus*	*Corylus*
Corylus	0.259	0.125	0.174	0.099	0.321	0.303	0.125	0.111	0.334	0.150	0.608***	-
Ulmus	0.252	0.167	0.090	0.017	0.330	0.227	0.019	0.048	0.331	0.506**	-	
Populus	0.358	0.051	0.281	0.130	0.070	0.496**	0.349	0.456**	0.647***	-		
Salix	0.163	0.059	0.180	0.193	0.129	0.518**	0.380*	0.565**	-			
Platanus	0.071	0.281	0.477**	0.039	0.346	0.641***	0.494**	-				
Quercus	0.204	0.491**	0.547**	0.087	0.567**	0.816***	-					
Pinus	0.304	0.379*	0.497**	0.033	0.412*	-						
Gramineae	0.097	0.592***	0.671***	0.020	-							
Plantago	0.094	0.396*	0.229	-								
Olea	0.211	0.770***	-									
Castanea	0.006	-										
Artemisia	-											

*p<0.05; **p<0.01; ***p<0.001

Table 3. Correlation coefficients (*r*) of starting dates of the main pollen season between different *taxa* over a 30-year period and forecasting model. For the *taxa* which, combined in pairs, gave the highest coefficients of linear regression (coefficients > 0.547), mean warning days before the start of pollination of the second *taxon* of the pair and forecasting models are shown. Coefficients of determination (R^2) is higher than 0.5 only for the first two models, which fit the best

Correlated taxa	*r* coefficient (and R^2)	Mean warning days	Forecasting model and *standard error*
Pinus → *Quercus*	0.816*** (0.666)	12	$y_{quercus}=0.3998x_{pinus}+75.074 \pm 6.865$
Olea → *Castanea*	0.770*** (0.592)	15	$y_{castanea}= 0.719x_{olea}+57.926 \pm 4.239$
Gramineae → *Olea*	0.671*** (0.450)	32	$y_{olea} = 0.6706x_{gramineae} + 71.878 \pm 5.269$
Populus → *Salix*	0.647*** (0.419)	18	$y_{salix}= 0.7067x_{populus} + 36.357 \pm 6.992$
Platanus → *Pinus*	0.641*** (0.411)	13	$y_{pinus}= 0.8653x_{platanus}+25.228 \pm 9.116$
Corylus → *Ulmus*	0.608*** (0.370)	34	$y_{ulmus}= 0.4782x_{corylus}+41.581 \pm 7.744$
Gramineae → *Castanea*	0.592*** (0.350)	47	$y_{castanea}= 0.5533x_{gramineae} + 100.95 \pm 5.348$
Quercus → Gramineae	0.567** (0.321)	5	$y_{gramineae}= 0.693x_{quercus} + 40.581 \pm 5.853$
Salix → *Platanus*	0.565** (0.318)	11	$y_{platanus}= 0.5415x_{salix} + 48.443 \pm 7.261$
Quercus → *Olea*	0.547** (0.299)	36	$y_{olea}= 0.6677x_{quercus} + 75.343 \pm 5.949$

*p<0.05; **p<0.01; ***p<0.001

(*r*), coefficients of determination (R^2), warning days and forecasting models. Obviously, the more anticipated the forecast is, the more useful it is. As mentioned above, the longest-term forecast models are those obtained starting from Gramineae for *Castanea* (p<0.001) and *Olea* (p<0.001), from *Corylus* for *Ulmus* (p<0.001) and from *Quercus* for *Olea* (p<0.01). Medium-term forecast (10–20 WD) are possible by applying the model to *Populus* for *Salix* (11 WD; p<0.001); *Salix* for *Platanus* (11 WD; p<0.01); *Pinus* for *Quercus* (12 WD; p<0.001); *Platanus* for *Pinus* (13 WD; p<0.001); *Olea* for *Castanea* (15 WD; p<0.001). Finally, a short-term linkage was found between *Quercus* and Gramineae (5 WD; p<0.01).

DISCUSSION

As mentioned previously, a species whose pollination is linked to that of another gives information in forecasting the pollination of the latter, providing warning days. Every year, a specific equation should be used to forecast the onset of pollination of a particular *taxon*. The general model is $y_{date} = ax_{date} + b$ (± *standard error)*; once the pollination of the former species begins (x_{date}), the y_{date} value can be calculated by means of the forecast equation models shown in Table 3, in order to obtain the probable date of the start of pollination of the latter species, and a 'risk interval' of time around it (result: y_{date} = start date expressed in number of days from 1 January ± error days). Despite the significant *r* coefficients displayed, R^2 coefficients are not very high (except those for *Pinus* – *Quercus* and *Olea* – *Castanea* regressions), showing that the model's accuracy on the observed data is quite low. This was predictable, because using a simple linear regression to describe a process influenced by a multitude of factors, such as the beginning of pollination, implies an over-simplification. More effective models are obtained when meteo-climatic conditions are considered [8]. The presented study, anyway, proposes a simple and fast method to identify in advance the time lapse in which the pollination of the *taxa* should begin, and the linear regression has proven to work for this purpose. The graphic in Figure 2 shows a comparison between the start dates for the pollination of *Olea* detected by monitoring (x-axis) and calculated using the equation obtained by means of Gramineae linkage (y-axis). The distribution of values around the regression line, *r* coefficient and *p value* prove that the model is fairly reliable.

The application of this model requires a particular approach to calculate the starting date of a *taxon* when we want to forecast the beginning of flowering of another one linked to it before the former has finished its pollen season. In fact, the 5% method cannot be used until the season ends and the pollen index (yearly total pollen count) can be calculated for the current year. Therefore, an alternative system based on the cumulative thresholds [27, 28] is proposed. As there is no consensus on what threshold should be used to define the start of a pollen season, they were obtained with the following elaboration: for each one of the 12 analysed *taxa*, the mean pollen index has to be extrapolated from data of the 30 years of the study. The 5% fraction of this mean pollen index is

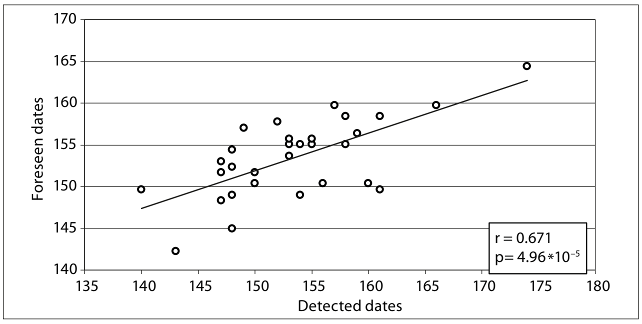

Figure 2. Start dates for the pollination of Olea in the 1984-2013 period. Correlation between detected dates and foreseen ones, calculated using the equation obtained by means of Gramineae linkage (values indicate the number of days from 1st January). p value proves that the model is reliable

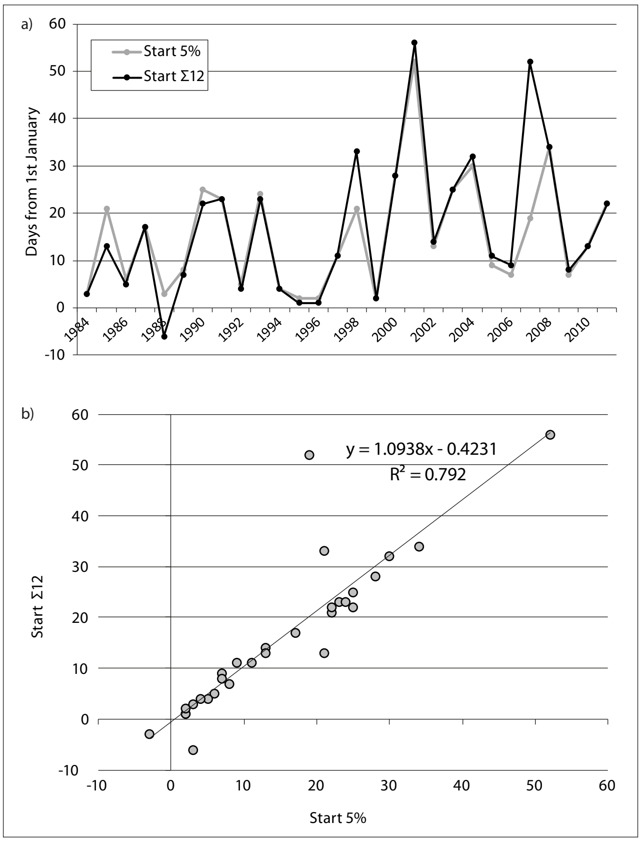

Figure 3. a) The graphic plots the starting dates of the main pollen season of Corylus from 1984 to 2013. Gray line refers to the onset dates calculated with the 5% method, while black one to those calculated with the sum method. We used as threshold the number of 12 pollen grains, extrapolated as 5% of the mean pollen index (see table 3). b) Regression line of the distibution of the two series of onset dates. The slope of the line is very close to 1, indicating a substantial equivalence between the data sets (linear regression coefficient = 0,89, R2 = 0,792, p < 0,001).

calculated, and used as threshold of the sum method to establish extemporarily the onset of that *taxa* for the ongoing season. This strategy allows having the x_{date} immediately disposable to forecast the starting date of the following linked species (y_{date}), applying the models in Table 3. Table 4 shows all the mean pollen indexes and thresholds obtained. As an example, Figure 3 shows two graphics comparing the starting dates of *Corylus* pollen season from 1984 – 2013, calculated with the 5% method and the Σ12 method. It is clear that the two models overlap almost perfectly (Fig. 3a), and are statistically equivalent (Fig. 3b). These observations legitimate the use of the sum method for the ongoing year,

Table 4. Mean yearly total pollen counts (pollen index, P.I.) observed for each *taxa* in the area of Perugia and their 5% fractions, to be used as threshold to establish the start date of the current pollen season with the sum method

	Mean Pollen Index (1984–2013)	5% of mean P.I. (Σ threshold)
Corylus	250	12
Ulmus	266	13
Populus	389	19
Salix	131	7
Platanus	172	9
Pinus	415	68
Quercus	16	800
Gramineae	3.73	187
Plantago	191	10
Olea	3.42	171
Castanea	592	30
Artemisia	154	8

while the forecasting models are constructed using start dates calculated with the 5% method. It has to be considered that these thresholds, being alculated on the data set collected in Perugia (Central Italy), reflect the characteristics that the pollen seasons of those *taxa* have in this specific area. In different zones, both the models and the thresholds should be adapted using the area-specific data set.

CONCLUSIONS

The existence of a data set constructed over more than 30 years of aerobiological monitoring in Perugia (Central Italy), has allowed reliable estimation of the linkage between the pollination onset dates of several species. The possibility to predict the start of the pollen season of the *taxa* presented in this study could be of great importance from the allergological point of view. In fact, an early or delayed flowering can have considerable effects on the prophylaxis programming and efficacy.

The forecasting model here proposed is simple and purely statistic: it does not involve meteorological parameters, using instead the significant correlation existing between the occurrence of the flowering phenophase in various species. A multiple regression approach, involving other variables, e.g. data about temperatures and rainfall, would surely produce a better fitting and precise model, but would not be as fast and easy to apply. Moreover, these models are very useful in all those cases in which forecasting must be carried out in climatically heterogeneous areas, such as the Perugia region.

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