

Effect of meteorological parameters on Poaceae pollen in the atmosphere of Tetouan (NW Morocco)

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Abstract Poaceae pollen is one of the most prevalent aero-allergens causing allergenic reactions. The aim of this study was to characterise the grass pollen season in Tetouan during the years 2008–2010, to analyse the effect of some meteorological parameters on the incidence of the airborne Poaceae pollen, and to establish forecasting variables for daily pollen concentrations. Aerobiological sampling was undertaken over three seasons using the volumetric method. The pollen season started in April and showed the highest pollen index in May and June, when the maximum temperature ranged from 23 to 27 °C, respectively. The annual pollen score recorded varied from year to year between 2,588 and 5,404. The main pollen season lasted 114–173 days, with peak days occurring mainly in May; the highest concentration reached 308 pollen grains/m³. Air temperature was the most important meteorological parameter and correlated positively to daily pollen concentration increase. An increase in relative humidity and precipitation was usually related to a decrease in airborne pollen content. External validation of the models performed using data from 2011 showed that Poaceae pollen concentration can be highly predicted (64.2–78.6 %) from the maximum temperature, its mean concentration for the same day in other years, and its concentration recorded on the previous day. Sensitive patients suffering allergy to Poaceae pollen are at moderate

to highest risk of manifesting allergic symptoms to grass pollen over 33–42 days. The results obtained provide new information on the quantitative contribution of the Poaceae pollen to the airborne pollen of Tetouan and on its temporal distribution. Airborne pollen can be surveyed and forecast in order to warn the atopic population.

Keywords Poaceae · Pollen · Aerobiology · Meteorological parameters · Modelling · Tetouan · Morocco

Introduction

Poaceae pollen is one of the most important cause of allergic diseases in Morocco and 10 % of patients suffering from pollinosis are sensitive to this pollen. Its seasonal prevalence ranges from 22 % in Meknes to 6.3 % in Safi (Yazidi et al. 2001). The genera causing pollinosis are unknown but, in a previous study (Aboulaich et al. 2009), we have shown that only a small number of species are responsible for the majority of the airborne spectrum: *Gaudinia fragilis*, *Hordeum murinum*, *Lolium rigidum* and *Trisetaria panicea*. The main pollen contributing species were found at all areas studied, their pollen production ranged from 1.5×10^4 to 12.8×10^6 grains per inflorescence, production often being higher in perennial species (Aboulaich et al. 2009).

Climate directly or indirectly defines the vegetation of a given region and therefore all anemogames species whose pollen can be present in the air. Despite genetic and physiological control of pollen production, environmental factors are determinants (Kasprzyk and Walanus 2010).

In general, meteorological parameters act on two levels: (1) during the stages prior to flowering, and (2) during the pollen season. In the case of herbaceous taxa, temperature affects vegetative development and determines the beginning of flowering (Clot 1998; Sánchez-Mesa 2003; Recio et

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al. 2010). Precipitation is also important and its effect will depend on the phenological state of plants, season or period during which it is registered, and the intensity with which it occurs (Alba 1997; Recio et al. 2010). During anthesis, pollen is washed out of the air by rainfall. Under drought environment, the anther walls become dehydrated, promoting their rupture and the release of pollen grains, while the capacity of pollen to absorb moisture makes it heavier and more likely to settle. Others meteorological factors, such as light intensity and wind speed and direction also determine pollen release, transport and/or dispersion (Emberlin et al. 2000; Laaïdi 2001; Puc and Puc 2004; Kasprzyk and Walanus 2010).

The study was carried out to characterise different parameters of the pollen season in order to determine daily, monthly and year-to-year pollen variation, the effect of meteorological parameters on the incidence of airborne Poaceae pollen in Tetouan, and to establish regression models to obtain the most accurate predictions of the daily Poaceae pollen so as to estimate pollen levels with special attention to the threshold concentrations at which allergy reactions are induced.

Materials and methods

The city of Tetouan is located in the eastern sector of the Tingitan Peninsula in the northwest of Morocco (Fig. 1), in the thermomediterranean bioclimatic level, at an altitude of 65 m a.s.l. For the years 2008–2010, the average annual mean temperature was 19.9 °C and mean annual rainfall was 902 mm. The mean annual maximum temperature oscillated between 22.5 °C and 23.1 °C whereas in the case of minimum temperatures the average ranged from 16.7 °C to 17.6 °C. The coldest months are December or January depending on the year. It should be stressed that, throughout the study period, we never recorded minimum temperature below 6 °C, and the mean temperature rarely drops to 10 °C.



Fig. 1 Location of the sampling site in Tetouan, Morocco

Due to the geographical situation of the city between two mountain ranges, the dominant winds are those blowing from the NE (known locally as “Chergui”) and SW (known locally as “Gharbi”).

Air sampling was conducted during the years 2008–2010 using a Burkard 7-day volumetric spore trap located on the flat roof of the department of Biology of the Faculty of Sciences (University Abdelmalek Essaâdi) 15 m above ground level. The sampler was calibrated to aspirate an air flow of 10 l/min. To collect daily airborne pollen, a trapping surface of Melinex film coated with 2 % silicon solution was mounted on the drum rotating inside the sampler at a speed of 2 mm/h. The drum was changed weekly and the exposed tape was cut into seven segments for daily pollen counts. The 24 h slide was analysed under a microscope with a X40 objective every 2 h using four longitudinal traverse methods according to the Spanish aerobiological network, REA (Galán et al. 2007). Daily concentrations were expressed as the number of pollen grains per cubic metre of air (pg/m^3).

The main pollen season (MPS) was determined by the 95 % method according to Andersen (1991), taking the beginning and end of the MPS as 2.5 % and 97.5 % of the annual pollen accumulated sums. The pre-peak was defined as the period lasting from the beginning of the pollen season to the peak day, whereas the post peak is the period from the peak day to the end of the pollen season.

To estimate the behaviour of Poaceae pollen, we selected rain-free days on which the pollen concentration was equal to or greater than the mean of the MPS (Galán et al. 1991). The values are expressed as 2-h cumulative percentages. To calculate the intradiurnal distribution index (IDI), we used the methodology proposed by Trigo et al. (1997). This index is equal to the ratio of the difference between the maximum and the minimum daily concentration value per 100.

For allergenic categories, the criterion recommended by REA was used (Galán et al. 2007) due to the close vicinity of Spain, and the shared Mediterranean climate conditions of the two countries. REA classifies daily pollen concentration into four categories, with risks being null, low, moderate and high when pollen concentrations are $<1 \text{ pg}/\text{m}^3$, between 1 and 25 pg/m^3 , between 26 and 50 pg/m^3 and $>50 \text{ pg}/\text{m}^3$, respectively.

The correlation coefficients between mean daily pollen concentrations and meteorological parameter values were calculated using Spearman’s correlation test for a statistical significance of $P < 0.001$, $P < 0.01$ and $P < 0.05$. Values were computed by the statistical program SPSS 13.0 for Windows. The meteorological parameters used were: maximum temperature (T_{max}), mean temperature (T_{mean}), minimum temperature (T_{min}), maximum relative humidity (RH_{max}), mean relative humidity (RH_{mean}), minimum relative humidity (RH_{min}) and precipitation. Meteorological

data were obtained from the Physics Department of the Faculty of Science, which has an automatic meteorological station located 500 m from the sampling site. Meteorological data used for pre-season (1 January to starting date of pollen season) were $T_{\max}$, $T_{\min}$ and rainfall.

To evaluate the parameters forming part of the mathematical model that enable the prediction of the Poaceae pollen concentrations, we used a multiple stepwise regression, using data from 2011 to validate the forecast model. This analysis was applied between dependent variable (Poaceae pollen concentrations of the pre-peak period) and 16 independent variables: firstly with dephased values from the series of pollen values; previous day concentration (PC_{t-1}) and mean concentration for the same day of other years (2008–2010) (D_{mean}), and secondly with 14 meteorological parameters was selected for this study (mean, maximum and minimum temperatures; mean, maximum and minimum relative humidity; rainfall; mean and maximum wind speed; percentages of four directions of winds and calm). The Wilcoxon test was made to select the reasonable predictor variables by comparing averages of the observed and the predicted series. Spearman's correlation test was also performed to estimate the degree of association between these two series.

Results

Pollen data and meteorology

The annual pollen counts recorded in the Tetouan atmosphere varied from year to year, with values oscillating between 5,404 in 2009 and 2,588 in 2008, registering an average annual value of 3,802 (Table 1). Poaceae pollen is the third pollen type in abundance order in the atmosphere of Tetouan, representing 8.2 % of the annual total. Pollen count showed the highest incidence between April and June; May always recorded the maximal monthly pollen counts of Poaceae pollen followed by June and April (Figs. 2, 3).

Poaceae pollen was also detected during other months but at low concentration.

Start dates of the pollen season varied from the end of March to 8 April. End dates of the pollen season were 15 July in 2008 and in the second half of September in 2009 and 2010 (Table 2). The MPS period lasted 114–173 days according to the year, with a variation of between 8 and 59 days. The intensity and timing of the peak concentration varied each year and reached 125 pg/m^3 on 13 May in 2008, 308 pg/m^3 on 21 May in 2009 and 208 pg/m^3 on 2 June in 2010 (Table 2).

During April, May and June, the average monthly maximum temperatures oscillated between 21 and 27 °C and minimum temperatures between 16 and 20 °C. Rainfall recorded a monthly average of 4–8 mm (Fig. 3).

The rainfall and the average daily maximum and minimum temperatures of the pre-season and the MPS were analysed over the 3 years of study. The pre-seasons 2009 and 2010 recorded values of 228.5 and 352.0 mm, respectively, i.e. higher than the 127.5 mm of 2008 (Table 1). A higher incidence of total pollen was observed when pre-seasonal rainfall was high (2009, 2010), whereas lower pollen frequency was obtained in pre-season with low precipitations (2008) (Table 1). The daily mean minimum temperatures of the pre-season oscillated between 12.65 and 14.04 °C, and between 18.75 and 20.77 °C during the MPS. Pre-season, the highest index of Poaceae pollen in 2009 coincided with the lowest daily average of maximum and minimum temperatures (Table 1). During the MPS, pollen counts greater than 25 pg/m^3 occurred when daily average of maximum and minimum temperatures were 24.01 and 17.95 °C, respectively, and mean rainfall was lower than 0.7 mm. The air temperature parameters seem not to affect pollen count categories.

The number of days without pollen grains in the atmosphere of Tetouan recorded a mean value of 117 days, ranging between 97 in the last 2 years of the study and 156 in 2008 (Table 3). Following the allergenicity categories proposed by the REA, a low pollen count category of 1–25 pg/m^3 was

Table 1 Means of maximum and minimum temperature and precipitation totals during the main pollen season (MPS) and pre-season in Tetouan, 2008–2010

	Precipitation (mm)				Tmax (°C)		Tmin (°C)		Total amount pg/ m ³
	Pre-season		MPS		Pre-season	MPS	Pre-season	MPS	
	mm	Number of days	mm	Number of days					
2008	127.5	16	74.0	14	18.09	24.47	13.55	18.75	2,588
2009	228.5	27	72.0	10	16.94	26.89	12.65	20.77	5,404
2010	352.0	32	145.8	23	18.81	26.73	14.04	20.14	3,484

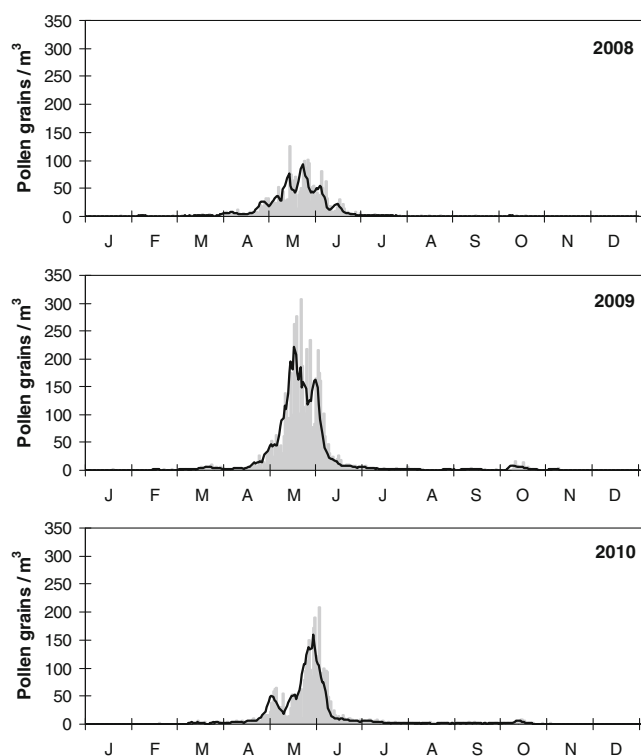


Fig. 2 Daily mean concentrations of Poaceae, 2008–2010

registered during 176 and 226 days in 2008 and 2009, respectively, with an average of 208 days. A moderate pollen category of 26–50 pg/m^3 was found on 19 days (5.2 %) in 2008, 12 days (3.3 %) in 2009 and 10 days (2.8 %) in 2010. The number of days when pollen concentration exceeded the threshold of 50 pg/m^3 was 15 (4.1 %), 30 (8.2 %) and 23 (6.5 %) in 2008, 2009 and 2010, respectively (Table 3).

Concerning the number of weeks of the MPS occurring in low to high concentration categories, a high variability was observed between years (ranging from 2 to 19 weeks). The number of weeks corresponding to the low pollen category varied between 11 and 19 weeks according to the year. During the 3 years of the study period, pollen counts fell within the moderate category for 2–3 weeks, accounting for 8.3 to 18.75 % of the MPS in weeks. In 2009, the highest

pollinosis risk occurred in 4 weeks (16.6 %). Over the years 2008 and 2010, 2 (12.5 %) and 3 (12 %) weeks, respectively, recorded this pollen category (Table 2).

The intradiurnal variation showed a gradual increase in pollen concentration since the morning, reaching a peak toward midday or early afternoon (Fig. 4). In the evening, lower percentages occurred and the lowest value was recorded at midnight. Intradiurnal variation presented a similar pattern in all 3 years with minor variations, and registered an IDI of 0.11 on average ranging from 0.09 to 0.14 in 2008 and 2009, respectively. In 2009, the pollen concentration showed a peak of 16.7 % of the daily pollen content at 1400–1600 hours. In 2008, the peak occurred around 1200–1400 hours, registering a percentage of 13.8 %.

Spearman's correlation analysis

From the data obtained (Table 4), correlations between pollen concentration and meteorological parameters showed different results depending on the period and the weather variable. The correlation between the pollen content of the MPS on the one hand and T_{max} and T_{mean} on the other showed highly significant negative correlation coefficients during 2008 and significant positive associations during 2009. The coefficients were highly significant and negative with relative humidity in 2010. The same statistical significance with maximum relative humidity was observed only during 2008. The association between rainfall and pollen concentration did not show a significant correlation but presented a negative value in 2010.

Considering the periods pre- and post-peak separately, daily maximum, minimum and mean temperatures were always correlated positively and with a highly statistical significance ($P \leq 0.001$) during the pre-peak. Conversely, during the post-peak, the correlation coefficients were always negative, with daily maximum, mean and/or minimum temperatures giving a level of confidence of $P \leq 0.001$ in 2008 and 2009. The association between relative humidity and the pollen content was negative and very highly significant during the pre-peak for 2010, although not with the

Fig. 3 Monthly averages of daily Poaceae pollen concentrations, maximum temperature (T_{max}), minimum temperature (T_{min}) and rainfall for 3 sampling years

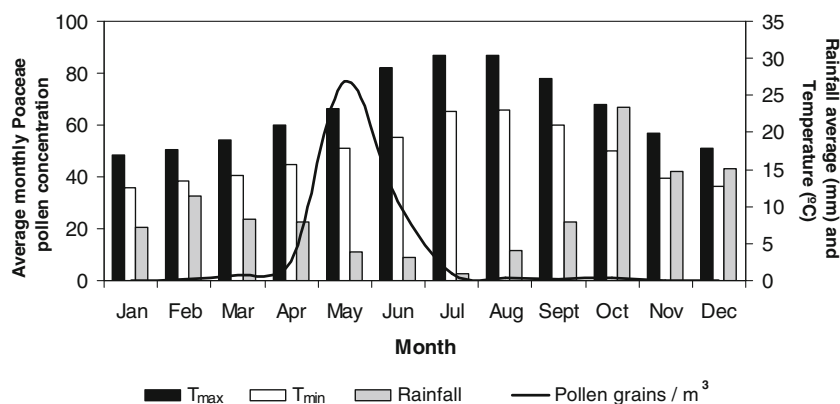


Table 2 Parameters of the MPS and the number of weeks for allergenicity categories, 2008–2010. *SDP* Starting date of pollen season, *EDP* end date of pollen season

	Main pollen season				Pollen peak		Number of weeks			
	SDP	EDP	Duration		Day	value	Rate of allergenicity			
			Day	weeks			Low 1-25 ^a	Moderate 26-50 ^a	High >50 ^a	
2008	30/03	21/07	114	16	13 May	125	11	3	2	
2009	04/04	15/09	165	24	21 May	308	16	2	4	
2010	08/04	27/09	173	25	02 Jun	208	19	2	3	

^a Pollen grains / m³

same significance degree during the post-peak for 2008 and 2009—correlation with this latter year showing a positive sign. The negative effect of rainfall occurred only during the pre-peak in 2009 and 2010, which was marked by a highly significant correlation (Table 4).

Stepwise multiple regression analysis

In the stepwise multiple regression analysis, which included 14 meteorological parameters, the variable that was introduced in the first step and which obtained the highest coefficient ($R^2=0.442$) was mean temperature. When maximal wind speed was incorporated into the equation, the regression coefficient was slightly higher ($R^2=0.472$).

When only the pollen variables, namely the mean of pollen concentration for the same day (D_{mean}) and Poacea pollen concentration of pollen recorded 1 day before (PC_{t-1}), were included in the equation, did the resulting R^2 satisfactorily predict future concentrations at a high confidence level ranging from 64.2 % to 74.2 % (Table 5). When more meteorological variables were introduced into the equation, the regression coefficients reached the highest values (Table 5).

The Wilcoxon test was used to compare the results from the predicted values and the pollen data for the season 2011 (Table 6), indicating that there were no significant differences between series compared when models 1, 2 and 3

were selected. This was also corroborated by the Spearman's correlation test, which indicated a very high degree of association between the observed and predicted series, showing model 3 as the most efficient to predict the overall trend of this pollen in the air. Figure 5 provides a graphic comparison of the results of this model by means of the regression equation and the observed pollen data over the pre-peak of the year 2011.

Discussion

Trends of pollen during the study period

The total annual value recorded for Poaceae pollen in Tetouan is comparable to that reported in Brussels and Zagreb (Spieksma et al. 2003; Peternel et al. 2006). Six locations in Catalonia (NE Spain) presented lower indices, with averages ranging from 1,140 to 2,177 (Latorre and Belmonte 2004), while in Vigo, the annual total pollen registered an average of 4,566 pollen grains (Rodríguez-Rajo et al. 2010). However, a higher annual pollen index around 6,000 was observed in Derby, Cardiff and Leyde (Spieksma et al. 2003). Values equal to about 6,000 grains were also observed during the season 2001–2003 in

Table 3 Number of days per allergenicity categories, 2008–2010

	No <1 ^a	Low 1-25 ^a	Moderate 26-50 ^a	High >50 ^a
2008	156	176	19	15
2009	97	226	12	30
2010	97	223	10	23
Average	117	208	14	23

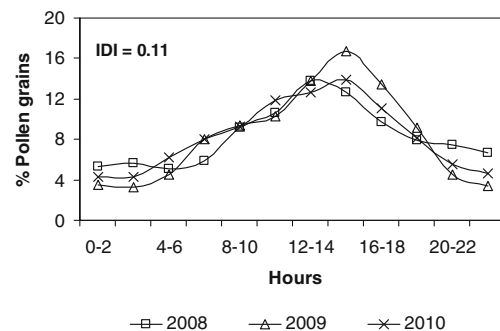
^a Pollen grains / m³**Fig. 4** Intradaily distribution pattern of Poaceae pollen concentration, 2008–2010

Table 4 Spearman's correlation coefficients between Poaceae pollen counts and meteorological parameters during the main pollen season, the pre-peak and post-peak periods, 2008–2010. T_{max} Maximumtemperature, T_{mean} mean temperature, T_{min} minimum temperature, RH_{max} maximum relative humidity, RH_{mean} mean relative humidity, RH_{min} minimum relative humidity, $Precip$ precipitation

	2008			2009			2010		
	MPS ($N=114$)	Pre-peak ($N=45$)	Post-peak ($N=69$)	MPS ($N=92$)	Pre-peak ($N=48$)	Post-peak ($N=44$)	MPS ($N=110$)	Pre-peak ($N=57$)	Post-peak ($N=53$)
T_{max}	−0.247**	0.516***	−0.674***	0.216*	0.714***	−0.551***	−0.098	0.639***	−0.248
T_{mean}	−0.253**	0.646***	−0.727***	0.224*	0.860***	−0.704***	−0.091	0.664***	−0.257
T_{min}	−0.302***	0.492***	−0.769	0.183	0.805***	−0.804***	−0.124	0.445***	−0.227
RH_{max}	−0.301***	0.037	−0.358**	0.043	−0.025	0.191	−0.468***	−0.618***	−0.436***
RH_{mean}	−0.130	0.067	0.129	0.025	−0.105	0.314*	−0.453***	−0.623***	−0.406**
RH_{min}	0.074	0.068	−0.090	−0.030	−0.165	0.268	−0.311***	−0.598***	−0.222
$Precip.$	0.010	−0.214	0.163	−0.236*	−0.318*	0.162	−0.160	−0.493***	0.179

*** $P<0.001$, ** $P<0.01$ and * $P<0.05$

Szczecin (Puc and Puc 2004). These differences are attributed to different biogeographic characteristics and local climates between the different regions as well as differences in grass species composition.

Monthly pollen indices are highest during the pollination period from April to June capturing 60, 70 and 61 %, of the annual total Poaceae pollen during 2008, 2009 and 2010, respectively. Outside this period, pollen concentrations of the Poaceae showed a low content due to the scarce number of flowering species. In Madrid, only two months (May and June) accounted for 79 % of the total annual Poaceae pollen (Subiza et al. 1992). In the atmosphere of Catalonia, more than 75 % of the Poaceae pollen is present from May to August. As in Tetouan, May and June are the months with highest pollen levels in all sites studied and years (Latorre and Belmonte 2004). Poaceae pollen occurs abundantly over the majority area of Poland from the second half of May until the second week of August (Kasprzyk 1995; Piotrowska and Weryszko-Chmielewska 2003).

The peak days were registered in May during the first 2 years, and the maximal concentration reached 125 pg/m^3 on 2008 and 308 pg/m^3 on 2009—this latter value is the highest maximum for the entire study period. In Zagreb, the major peak was also observed in May (Peternel et al. 2006).

The maximum peak values occurred in May or June in Catalonia, and in July in Vigo (Latorre and Belmonte 2004; Rodríguez-Rajo et al. 2010). Poaceae pollen showed many peaks as flowering periods of the numerous genera and species of the family differ from one taxa to another.

The duration of the MPS recorded a maximal difference of 59 days between 2008 and 2010. Start dates of the pollen season oscillated between the end of March in 2008 and the 1st week of April in 2009 and 2010. The period of pollen season recorded approximately 141 days in Vigo (Rodríguez-Rajo et al. 2010) and varied from 157 to 173 days in Zagreb (Peternel et al. 2006). In Szczecin, the pollen season lasted between 109 and 157 days (Puc and Puc 2004). The length of the grass pollen season is shorter in some European cities such as London, Bilbao, Leon, Cordoba and Santiago de Compostela (Emberlin et al. 1993; Antepara et al. 1995; Fernández-González et al. 1999). Puc and Puc (2004) concluded that shorter pollen seasons are characterised by higher annual pollen content.

According to Emberlin et al. (2000) and Sánchez-Mesa et al. (2003), the period of MPS of Gramineae varies with latitude. In more temperate regions, this period starts earlier in comparison to higher latitudes and colder climates. The highest concentrations of pollen are produced from March

Table 5 Predictive equation by stepwise multiple regression with indication of equation derived at each model after inclusion of new variable. R^2 Regression coefficient, PC_{t-1} Poaceae pollenconcentration recorded 1 day before, D_{mean} mean concentration for the same day, T_{max} maximum temperature, WS_{max} maximum wind speed, $Fr2Q$ frequency of the wind second quadrant (SE)

Model	Regression equations	R^2	$P <$
1	$y = 1.172 D_{mean} - 2.834$	0.642	0.000
2	$y = 0.695 D_{mean} + 0.539 PC_{t-1} - 4.013$	0.742	0.000
3	$y = 0.559 D_{mean} + 0.495 PC_{t-1} + 4.248 T_{max} - 91.636$	0.766	0.000
4	$y = 0.643 D_{mean} + 0.438 PC_{t-1} + 4.598 T_{max} - 0.178 WS_{max} - 88.815$	0.781	0.000
5	$y = 0.676 D_{mean} + 0.419 PC_{t-1} + 3.989 T_{max} - 0.154 WS_{max} - 0.249 Fr2Q - 72.434$	0.786	0.000

Table 6 Spearman's correlation coefficients and comparison of averages by the Wilcoxon test between daily Poaceae pollen during the pre-peak of the year 2011 (observed) and data from the linear regression equations (predicted)

	Spearman's correlation r	Wilcoxon Test			
		Rank +	Rank -	z	P
Observed 2011 vs predicted Model 1	0.811***	27	30	-1.714	0.087 n.s.
Observed 2011 vs predicted Model 2	0.848***	26	34	-0.862	0.389 n.s.
Observed 2011 vs predicted Model 3	0.794***	24	35	-0.091	0.928 n.s.
Observed 2011 vs predicted Model 4	0.790***	35	24	-2.159	0.031
Observed 2011 vs predicted Model 5	0.790***	37	22	-3.382	0.001

*** $P < 0.001$; n.s. not significant

to June in the Mediterranean region (D'Amato and Lobefalo 1989) as observed in this study. During the three sampling years in Tetouan, May showed the highest concentration of grass pollen grains. In Mediterranean areas, the development of Poaceae is influenced positively by water availability (Clary et al. 2004). The amount of precipitation in the period prior to the season favours seed germination, influences plant growth, and determines the start of the MPS (Emberlin et al. 1993; Recio et al. 2010).

As regards intradiurnal variation of pollen counts throughout the day, we observed a similar mean daily course during the 3 years analysed, with peak concentrations being reached at 1400 and 1600 hours in 2009 and 2010, respectively. In Malaga (Trigo et al. 1996) and Cordoba (Galán et al. 1991), the highest concentrations occurred earlier: around midday. However, in Derby and London, pollen levels were higher in late afternoon and early evening, showing a different model (Corden and Millington 1991; Norris-Hill and Emberlin 1991). A parallel increase in diurnal temperature parameters and pollen concentrations suggest that temperature parameters play a role in decreasing relative humidity and, hence contribute indirectly to the dehiscence of anthers and, in this way, to pollen release.

Correlation with meteorological parameters

Meteorological variables are the most important environmental parameters affecting variation in daily pollen concentrations. Air temperature shows the strongest Spearman

association with Poaceae pollen concentrations (Table 4). Previous studies have shown that maximum temperatures are the main factor contributing to high atmospheric levels of airborne Poaceae pollen (Sánchez-Mesa et al. 2003; Rodríguez-Rajo et al. 2003; Puc and Puc 2004; Kasprzyk and Walanus 2010). However, most authors have studied the main pollen season. Our results showed positive correlation values during the pre-peak and negative correlation values during the post-peak. This latter result could be due explicitly to high temperatures unbearable by grass plants leading to a general decrease in pollen production. Norris-Hill (1997) has outlined that temperatures between 20 and 25 °C are the most favourable for pollen. In Tetouan, the pollen season (April–June) corresponds to the maximum temperature, ranging from 21 to 27 °C. Temperatures above 27 °C lead to a net decline in pollen counts due to plant withering and drought conditions.

In recent years, Recio et al. (2010) observed increased levels of Poaceae pollen in Malaga, and this was attributed to increased rainfall and minimum temperature during early spring. Thus, the abundance of this pollen type requires a pre-flowering period where the temperatures reach higher values to allow the vegetative development of these plants. Thermal parameters contributed to the increased levels of Poaceae pollen observed in the atmosphere of Lugo, whereas rain washes pollen from the atmosphere (Rodríguez-Rajo et al. 2003). For daily values of pollen registered in Tetouan, it is necessary to note the low concentrations detected during 2008. In this study, rain prior to the pollen season contributed to the higher annual total level of pollen recorded during 2009 and 2010. According to González-Minero et al. (1998) and Recio et al. (2010), the intensity of Poaceae pollination is associated with rainfall prior to flowering in the South of Spain. However, although the quantities of rainfall prior to flowering were highest in 2010, levels of airborne pollen of Tetouan were lower than in 2009. It seems that rainfall during the pollen season is related to a reduction in the levels of pollen after its liberation. The correlation analysis indicated a negative effect of rainfall during the pre-peak pollen season for 2009 and 2010, the coefficient of correlation being highly significant for the latter year. High temperature, a critical photoperiod and

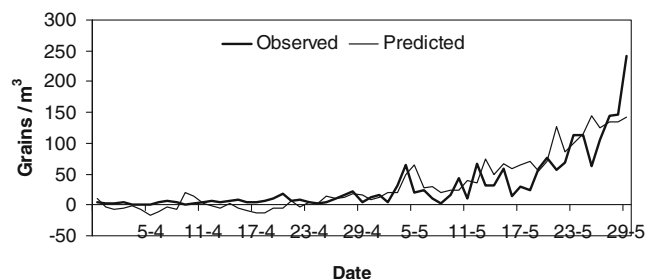


Fig. 5 Graphic representation of the Poaceae pollen concentration during the pre-peak of 2011 (observed) and expected values developed by the third model

low relative humidity contribute to high levels of atmospheric Poaceae pollen (Sánchez-Mesa et al. 2005). An increase in the relative humidity is related to a decrease in the pollen level in the atmosphere (Kasprzyk and Walanus 2010).

Forecast models and validation

The forecast models constructed for the daily evolution of Poaceae pollen at the city of Tetouan indicate that both the mean pollen concentration for the same day in other years and pollen concentration on the previous day, as well as maximum temperature, are the most appropriate variables for predicting the variability of Poaceae pollen in the air. This was reflected by the third mathematical model, which offered the best results, with a high percentage of forecast (76.6 %) validated with data from 2011 (Table 5).

In addition, Spearman's correlation test verified the significant positive coefficients between the two numerical series (observed and expected) (Table 6), confirming that both present similar behavioural patterns. The Wilcoxon test corroborated that there were no significant differences between the series compared when models 1, 2 and 3 were selected, verifying that the regression models selected were valid for predicting Poaceae airborne pollen. However, for models 4 and 5, significant differences were found, the mean and sum of the range observed data prevailing over the predicted ones, which finally led us to reject these regression models.

The graphic comparison of the predictive pollen series with the observed data of the pre-peak of 2011 (Fig. 5) revealed that the forecast data generally conformed well to the behaviour of the pollen season, reflecting a seasonal dynamic similar to that observed. However, the model does not offer good results in predicting lower values. To solve this problem, some researchers, such as De Pablos Alcázar (2001), delete pollen data that deviate from the seasonal mean.

Pollen categories

The period over which the grass pollen exceeded the threshold value of 30 pg/m³ ranged from 28 to 73 days in Brisbane (Green et al. 2004) and from 24 to 55 days in Szczecin (Puc and Puc 2004). In Tetouan, pollen counts higher than the threshold of 25 pg/m³ occurred over a period oscillating between 33 and 42 days. In Vigo, values higher than 50 pg/m³ able to produce allergic symptoms in patients with pollinosis varied between 13 and 33 days according to the year (Rodríguez-Rajo et al. 2010). In Girona (Catalonia, Spain), a high pollinosis risk index was registered on between 1 and 5 weeks. In the same region, this pollen category was reached only once in Tarragona (Latorre and Belmonte 2004). These values are consistent with the results obtained in Tetouan. In Zagreb, following the Catalanian

scale of allergenicity, grass pollen occurred in the low to moderate category in 6–15 weeks per year. Patients with allergy to Poaceae pollen are at the highest risk over 3–8 weeks (Peternel et al. 2006). This differs from the 2–4 weeks that recorded the same allergenic category in Tetouan.

This study provides new knowledge on Poaceae pollen emissions in the air of Tetouan and allows us to determine the threshold values of pollen concentration able to cause respiratory allergy and to monitor air quality. Regression models will be developed to predict the onset of the Poaceae season to take preventives measures to protect allergic patients against exposure to Poaceae pollen.

Conclusion

Poaceae pollen is present abundantly in the atmosphere of Tetouan from April to June, with May and June being the months with the highest values. Regarding the length of the grass pollen season, it lasted between 114 and 173 days and few discrepancies were found with numerous European cities equipped with monitoring stations. The period of the pollen season starts earlier in comparison to more septentrional regions. Days with maximum temperatures between 21 and 27 °C show an increase in Poaceae pollen content. In contrast, a decrease in pollen score was noted with high relative humidity and rainfall. From the results of predictive models using meteorological and pollen variables, it was concluded that Poaceae pollen concentrations can be predicted from the maximum temperature, its mean concentration for the same day in other years, and its concentration recorded on the previous day. Taking into account the days with pollen counts higher than 25 pg/m³ patients with pollinosis could manifest allergic symptoms over a period ranging from 33 to 42 days. These aerobiological results are of great clinical importance for health improvement and forecasting of respiratory allergy in the atopic population within our region.

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