

# Poaceae pollen in the atmosphere of Tetouan (NW Morocco): effect of meteorological parameters and forecast of daily pollen concentration

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**Abstract** The Poaceae pollen season has been characterized in Tetouan during a 7-year period, and the effect of weather conditions on daily concentrations was examined. The forecast models were produced using a stepwise multiple regression analyses. Firstly, three models were constructed to predict daily Poaceae pollen concentrations during the main pollen season, as well as the pre-peak and post-peak periods with data from 2008 to 2012 and tested on data from 2013 and 2014. Secondly, the regression models using leave-one-out cross-validation were produced with data obtained during 2008–2014 taking into account meteorological parameters and mean pollen concentrations of the same day in other years. The duration of the season ranged from 70 days in 2009 to 158 days in 2012. The highest amount of Poaceae pollen was detected in spring and the first fortnight of July. The annual sum of airborne Poaceae pollen concentrations varied between 2100 and 6251. The peak of anthesis was recorded in May in six of the other years studied. The regression models accounted for 36.3–85.7% of variance in daily Poaceae pollen

concentrations. The models fitted best when the mean pollen concentration of the same day in other years was added to meteorological variables, and explained 78.4–85.7% of variance of the daily pollen changes. When the year 2014 was used for validating the models, the lowest root-mean-square errors values were found between the observed and estimated data (around 13). The reasonable predictor variables were the mean pollen concentration of the same day in other years, mean temperature, precipitations, and maximum relative humidity.

**Keywords** Aerobiology · Grass pollen · Concentration changes · Meteorology · Modeling · Stepwise regression analysis

## 1 Introduction

The Poaceae family is an important group within the Plantae kingdom and widespread representing almost 20% of the world's vegetation cover (Mabberley 1987). The family comprises an extensive number of diverse species and ecotypes that grow in different habitats characterized by a wide range of environmental conditions. Most plants of this family are anemophilous with the exception of some cleistogamous and a smaller number of entomophilous species (Adams et al. 1981). In Tetouan, NW Morocco, pollen production per inflorescence varied between 12,000

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and 15 millions grains, mean total production by perennial species was, on average, 4.25 times higher than by annual species (Aboulaich et al. 2009). In the same study, total pollen production per square meter ranged between  $0.23 \times 10^9$  and  $1.86 \times 10^9$  depending on the area studied. Only few species (*Gaudinia fragilis*, *Hordeum murinum*, *Lolium rigidum*, and *Trisetaria panacea*) were responsible for the most pollen production in the studied areas (Aboulaich et al. 2009). Poaceae pollen is recognized as one of the most allergenic in Europe including the Mediterranean region, although its frequency differs regionally (D'Amato et al. 2007). In Morocco, seasonal prevalence of Poaceae pollen-related asthma and rhinitis has risen to 10% of patients with clinical respiratory diseases (Yazidi et al. 2001).

The effect of environmental factors prior the flowering and during the main pollen season of Poaceae is well documented in the literature (Sánchez-Mesa et al. 2003; Rodríguez-Rajo et al. 2003; Puc and Puc 2004; García-Mozo et al. 2009; Kasprzyk and Walanus 2010; Recio et al. 2010). The major environmental factors that determine flowering are temperature, photoperiod, and water availability. Grasses begin flowering in spring, when air temperatures reach more or less species-specific thresholds ranging between 10 and 12 °C that trigger flowering early in spring, if soil moisture is available (King and Heide 2009). Water stress can also be important through its effect on growth (Dahl et al. 2013). The production and emission of pollen are determined by interacting environmental factors. 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). Norris-Hill (1997) has outlined that temperatures between 20 and 25 °C are the most favorable for Poaceae 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 airborne pollen concentrations due to plant withering and drought conditions (Aboulaich et al. 2013). Recent studies have outlined the influence of rainfall on grass pollen season intensity (Sánchez-Mesa et al. 2005; Smith and Emberlin 2006). Rainfall before the main pollen season increases the vegetal biomass of

herbaceous plants, Clary et al. (2004) demonstrated experimentally that the development of Mediterranean Poaceae is positively influenced by water availability.

In a previous study in Tetouan (Morocco), a predictive model using meteorological and pollen variables was constructed by Aboulaich et al. (2013) to forecast the daily mean concentration of Poaceae pollen. The main difficulty to develop forecasts for this family is the high variability between years on pollen season parameters. This may be related to its high number of species, i.e., 38 species were found in Tetouan (Aboulaich et al. 2009). Many different species, with different response to environmental conditions contribute to the inter-annual variability in pollen content. Since it is currently impossible to consider the partial contribution of each species or genera to the pollen spectrum in aerobiological studies, it is necessary to find generalized parameters for pollen, if prediction models to be developed.

This study, related to the previous paper published by Aboulaich et al. (2013), aims to determine the relationship between the meteorological parameters and the daily Poaceae pollen concentration. The authors also aim to develop a forecast model with accurate prediction of the daily Poaceae pollen taking into account the effect of meteorological and biological parameters during pollen season.

## 2 Materials and methods

The city of Tetouan is located in the eastern part of the Tingitan Peninsula in the northwest of Morocco (35°34'N, 5°22'W), in the thermomediterranean stage of the vegetation and Mediterranean climate, at an altitude of 65 m a.s.l. For the years 2008–2014, the average annual mean temperature was 19.1 °C, and mean annual rainfall was 709 mm. The mean annual maximum temperature oscillated between 21.9 and 23.3 °C, whereas in the case of minimum temperatures, the average ranged from 14.3 to 17.0 °C. The coldest months are December, January or February depending on the year. It should be stressed that, throughout the study period, minimum temperature below 3 °C was scarcely recorded, and the mean temperature rarely drops to 10 °C. During the pre-season from January to March, monthly maximum and minimum temperatures varied between 16.9 and

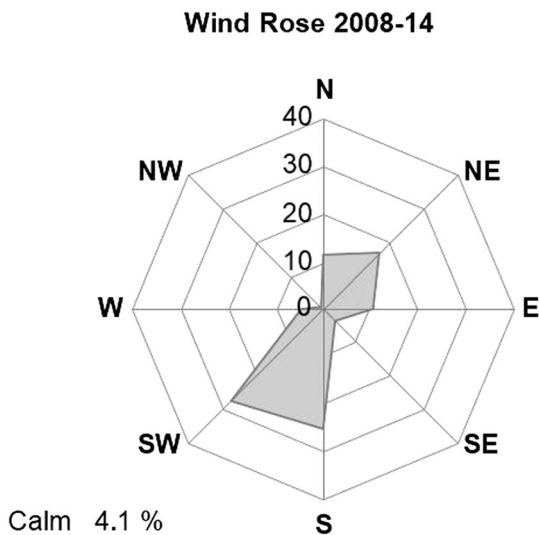


**Fig. 1** Wind rose of Tétouan for the period 2008–2014

18.4 °C and 11.9 and 13.5 °C. It is situated between two mountain ranges, one located to the northwest (the Haouz-Ghorghiz) and the other one to the southeast (the Rif range), which determines that the prevailing winds are those blowing from the NE (known locally as “Cherki”) and those blowing from SW (Known locally as “Gharbi”) (Fig. 1a, b).

## 2.1 Sampling

Pollen monitoring was performed during 2008–2014 using a Burkard 7-day-recording volumetric spore trap sampler, located on the flat roof of the department of Biology of the Faculty of Sciences (University Abdelmalek Essaâdi) approximately 15 m above ground level in an open space with no nearby buildings that could interrupt the movement of air. 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 samples were prepared and counted under a microscope with a  $\times 40$  objective every 2 h using four longitudinal traverse methods as proposed by the Spanish Aerobiology Network (Galán et al. 2007). The daily pollen concentration in the air was expressed as number of pollen grains per  $\text{m}^3$  within 24 h.

## 2.2 Data analysis

The main pollen season (MPS) was determined by the 90% method according to Nilsson and Persson (1981) assuming the beginning and end of the main pollen season as 5 and 95% of the annual sum of accumulated pollen. As the relation between grass pollen concentration and environmental conditions tends to vary during the pre-peak and post-peak periods (Galán et al. 1995; Sánchez-Mesa et al. 2003), the pollen season was divided into two periods, 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 from the day after the peak to the end of the pollen season.

Daily Poaceae pollen concentrations and meteorological data were computed into Spearman’s correlation test using statistical package SPSS in order to determine which factors had the most influence on daily variations of grass pollen counts through the MPS defined the 95% method, the pre-peak and the post-peak for the period 2011–2014 (results for 2008–2010 were published by Aboulaich et al. 2013). This analysis was performed for a statistical significance of  $p < 0.01$  and  $p < 0.05$ . The meteorological parameters used were: daily maximum temperature ( $T_{\text{max}}$ ), mean daily temperature ( $T_{\text{mean}}$ ), minimum daily temperature ( $T_{\text{min}}$ ), maximum daily relative humidity ( $\text{RH}_{\text{max}}$ ), mean daily relative humidity ( $\text{RH}_{\text{mean}}$ ), minimum daily relative humidity ( $\text{RH}_{\text{min}}$ ), daily precipitation (Pr), mean and maximum wind speed during the day ( $\text{WS}_{\text{mean}}$ ,  $\text{WS}_{\text{max}}$ ), frequencies of four directions of wind during the day [northeast (NE), southeast (SE), southwest (SW), northwest (NW)]. For each wind direction, total hours per day were expressed as a percentage. Meteorological data were provided by the meteorological station of the physics department of the Sciences Faculty of Tetouan, which is located 500 m far from the monitoring site.

Firstly, three models were constructed, one that predicted daily Poaceae daily average pollen concentrations during the MPS and two models that predicted daily average pollen concentrations during the pre-peak and post-peak periods. These regression models were constructed using data from 2008 to 2012 (172–558 entries) and tested on data from 2013 and 2014 the years with the highest and lowest pollen concentrations, respectively. Secondly, to predict the daily Poaceae pollen concentrations of the pre-peak

period, we used a multiple stepwise regression by forward selection using data from 2008 to 2014 making as many models as there are years (193–207 of entries were used depending on the analyzed years), but each time we leave one of the years out and use it only for test set to validate the obtained models by leave-one-out cross-validation. The pollen data were transformed by a logarithmic function ( $\text{Log}_{10}$ ) and normalized before being entered into the analysis. Because of the possibility of collinearity between variables that are highly correlated it was decided to not combine into the multiple regression analysis interdependent predictors (i.e.,  $T_{\min}$ ,  $T_{\max}$  and  $T_{\text{mean}}$  or  $\text{RH}_{\min}$ ,  $\text{RH}_{\max}$  and  $\text{RH}_{\text{mean}}$ ). Multiple stepwise regression was applied between the dependent variable (daily average Poaceae pollen concentrations of the pre-peak period) and independent variables: nine daily meteorological parameters described previously were selected for this study (mean temperature; maximum relative humidity; rainfall; maximum wind speed; percentages of four directions of winds and calm), as wells as the daily average Poaceae pollen concentration for the same day in other years ( $P_{\text{mean}}$ ; 14 models were obtained). The models were chosen on the basis of the highest adjusted coefficient of the regression and when increasing value of  $R^2$  was not significant. Colinearity between the predictor parameters was examined by the test of variance inflation factors (VIF). The autocorrelation in the error term of

the model was examined by the Durbin–Watson test (D–W) at the confidence level  $\alpha = 0.05$ . The root mean square error (RMSE) was made to calculate the error of the differences between the observed and the predicted series. Spearman's correlation test was also performed to estimate the degree of association between these two series.

### 3 Results

#### 3.1 Aerobiological data

The aerobiological study reports the behavior of the airborne Poaceae pollen in Tetouan throughout 7 years. Poaceae pollen is the third pollen type in abundance order in the atmosphere of Tetouan and accounts 8.5% of the total pollen spectrum. The MPS was during spring and the first fortnight of July, the highest monthly total concentrations were recorded in April, May and June, while lowest levels occurred in other months (Fig. 2). Total annual airborne pollen concentrations in Tetouan varied between 2100 in 2014 and 6251 in 2013. In all study years, start days of the Poaceae pollen season ranged between 9 April and 26 April, with a peak day in the second half of May in 6 years. The end dates of the season varied from 3 July (2008) to 29 September (2014). The duration of the pollen season lasted 70–158 days according to the

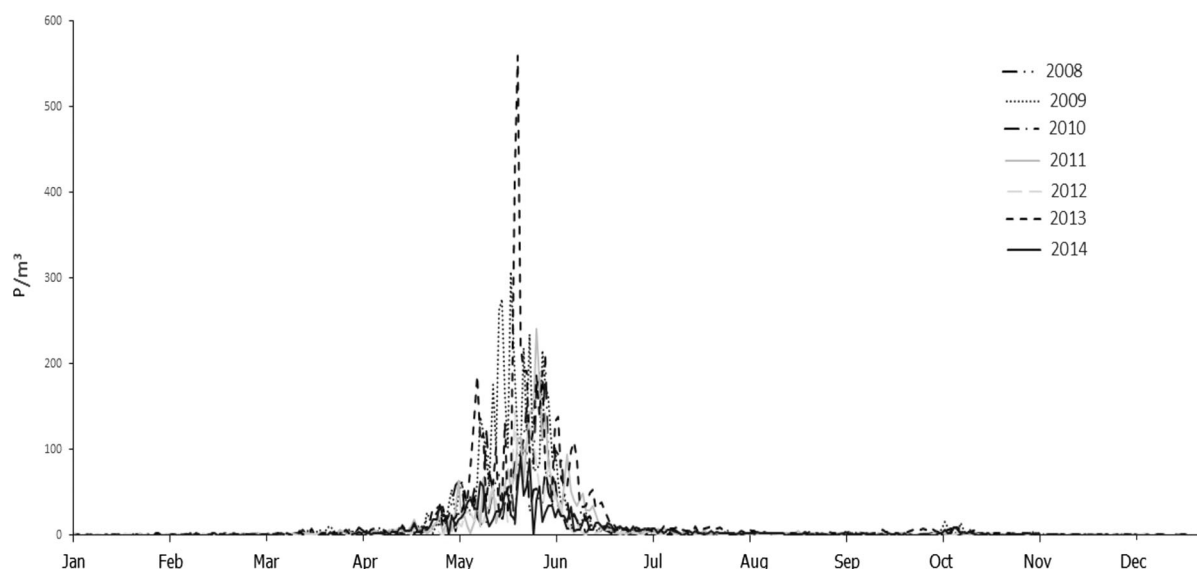


**Fig. 2** Daily mean concentrations of Poaceae pollen during the period 2008–2014

**Table 1** Parameters of the main pollen season (MPS) of *Poaceae*, 2008–2014

|      | Main pollen season (MPS) |         |          |                | Pollen peak |       | Annual total |
|------|--------------------------|---------|----------|----------------|-------------|-------|--------------|
|      | SDP<br>Day               | EDP     | Duration | Total recorded | Day         | Value |              |
| 2008 | 09 April                 | 20 July | 103      | 2329           | 13 May      | 125   | 2588         |
| 2009 | 25 April                 | 03 July | 70       | 4728           | 21 May      | 308   | 5409         |
| 2010 | 26 April                 | 30 July | 96       | 3020           | 02 Jun      | 208   | 3485         |
| 2011 | 19 April                 | 27 Aug  | 131      | 3215           | 29 May      | 241   | 3671         |
| 2012 | 21 April                 | 25 Sept | 158      | 2018           | 22 May      | 145   | 2217         |
| 2013 | 27 April                 | 29 Sept | 156      | 5542           | 23 May      | 560   | 6251         |
| 2014 | 20 April                 | 13 Sept | 147      | 1890           | 24 May      | 92    | 2100         |

SDP starting date of MPS,  
EDP end date of MPS

**Table 2** Monthly rainfall during the pre-season in Tetouan, 2008–2014

|      | Monthly total (in mm) |          |       | Total rainfall |
|------|-----------------------|----------|-------|----------------|
|      | January               | February | March |                |
| 2008 | 26.5                  | 92       | 9     | 127.5          |
| 2009 | 64.5                  | 119      | 45    | 228.5          |
| 2010 | 106                   | 159      | 87    | 352            |
| 2011 | 140                   | 113.0    | 87    | 341            |
| 2012 | 53.6                  | 11.2     | 24.2  | 89             |
| 2013 | 75                    | 30.6     | 157   | 262.2          |
| 2014 | 50.8                  | 47.8     | 35.6  | 134.4          |

year with a variation between 26 and 88 days. A high year-to-year variation was observed in the maximal pollen concentration (92–560 p/m<sup>3</sup>) (Table 1).

The rainfall of the pre-season was analyzed over the 7 years of study in order to understand the variation from year to year in pollen productivity. The pre-seasons 2009, 2010, 2011 and 2013 recorded values of 228.5, 352, 341 and 262.2 mm, respectively. For the other years, the rainfall oscillated between 82.2 and 134.2 mm (Table 2). A higher pollen load was recorded when pre-seasonal rainfall was high (2009, 2010, 2011 and 2013). The lowest annual total pollen was observed in pre-seasons with low precipitation.

### 3.2 Correlation analysis

Correlation analysis revealed that temperature was the parameter that generally had the most significant relationship with daily airborne *Poaceae* pollen concentrations during the pre-peak period ( $r = 0.752$ ;  $P < 0.01$  with  $T_{\text{mean}}$  on 2012). In contrast, during the post-peak period, the correlation coefficients were

always negative (Table 3). Temperature was only related negatively with respect to MPS ( $r = -0.794$  at  $P < 0.01$  with  $T_{\text{min}}$  on 2013). Relative humidity was associated negatively with daily pollen concentration in 2013 ( $r = -0.623$ ;  $P < 0.01$  on 2013). Negative indices were obtained in terms of daily rainfall with respect to the pre-peak period in 2012, 2013 and 2014 ( $P < 0.05$ ) and the post-peak in 2013 ( $P < 0.01$ ). The positive and significant effect of wind speed occurred only during the MPS and the post-peak period in 2013. Percentages of SE, NE, and SW wind directions displayed positive and significant correlation coefficients but the results differed depending on years and periods of the MPS.

### 3.3 Stepwise multiple regression analyses

Three multiple regressions equations, for the MPS, the pre-peak and pos-peak periods, were constructed and used to predict daily *Poaceae* pollen concentrations throughout the years 2013 and 2014. The adjusted regression coefficient ranged between 0.757 and 0.857 (Table 4). Using stepwise multiple regressions leaving out one year and including only meteorological parameters, seven models for forecasting daily pollen concentration of the pre-peak were developed. One to two variables were included per model as independent variables. The adjusted regression coefficients varied between 36.3 and 52.3% of variance (Table 5). The main meteorological factors introduced into the regression equations were mean temperature, the percentage of wind directions (NE), and calm. When the mean pollen concentrations of the same day in other years ( $P_{\text{mean}}$ ) was added to meteorological variables the regression coefficients were higher ranging from 78.3 to 81.4% (Table 5). With regard

**Table 3** Spearman's correlation coefficients between Poaceae pollen concentrations and meteorological parameters during the main pollen season, the pre-peak and post-peak periods, 2011–2014

|                    | 2011           |                    |                     | 2012           |                    |                      | 2013           |                    |                      | 2014           |                    |                      |
|--------------------|----------------|--------------------|---------------------|----------------|--------------------|----------------------|----------------|--------------------|----------------------|----------------|--------------------|----------------------|
|                    | MPS<br>N = 131 | Pre-peak<br>N = 41 | Post-peak<br>N = 90 | MPS<br>N = 158 | Pre-peak<br>N = 32 | Post-peak<br>N = 126 | MPS<br>N = 156 | Pre-peak<br>N = 27 | Post-peak<br>N = 129 | MPS<br>N = 147 | Pre-peak<br>N = 35 | Post-peak<br>N = 112 |
| $T_{\max}$         | -0.442**       | 0.679**            | -0.180              | -0.434**       | 0.580**            | -0.246**             | -0.425**       | 0.748**            | -0.313**             | -0.583**       | 0.421*             | -0.466**             |
| $T_{\text{mean}}$  | -0.536**       | 0.856**            | -0.358**            | -0.571**       | 0.752**            | -0.374**             | -0.709**       | 0.743**            | -0.630**             | -0.736**       | 0.546**            | -0.702**             |
| $T_{\min}$         | -0.582**       | 0.682**            | -0.511**            | -0.608**       | 0.495**            | -0.446**             | -0.794**       | 0.573**            | -0.738**             | -0.678**       | 0.159              | -0.553**             |
| $RH_{\max}$        | 0.067          | -0.051             | -0.297**            | -0.187*        | 0.381*             | -0.302**             | -0.543**       | -0.346             | -0.564**             | 0.107          | 0.000              | -0.053               |
| $RH_{\text{mean}}$ | 0.079          | 0.000              | -0.215*             | -0.075         | 0.042              | -0.181*              | -0.623**       | -0.351             | -0.644**             | 0.087          | -0.128             | -0.065               |
| $RH_{\min}$        | 0.116          | 0.033              | -0.143              | -0.021         | -0.162             | -0.099               | -0.557**       | -0.495**           | -0.565**             | 0.085          | -0.108             | -0.043               |
| Precip             | 0.160          | -0.353*            | -0.028              | -0.003         | -0.338             | -0.146               | -0.005         | -0.466*            | -0.242**             | 0.132          | -0.403*            | 0.143                |
| $WS_{\max}$        | 0.164          | -0.323*            | -0.046              | 0.155          | -0.078             | 0.216*               | 0.285**        | -0.631**           | 0.320**              | -0.030         | -0.316             | -0.004               |
| $WS_{\text{mean}}$ | -0.120         | -0.456**           | -0.409**            | 0.135          | -0.236             | 0.217*               | -0.146         | -0.068             | -0.079               | 0.011          | -0.340*            | 0.006                |
| %NE                | 0.074          | 0.364*             | -0.176              | -0.167*        | 0.450**            | -0.181*              | -0.433**       | -0.264             | -0.370**             | -0.019         | 0.287              | -0.060               |
| %SE                | -0.037         | 0.287              | -0.226*             | 0.058          | -0.501**           | -0.134               | 0.281**        | 0.151              | 0.256**              | 0.084          | 0.168              | -0.073               |
| %SW                | -0.051         | -0.464**           | 0.248*              | 0.171*         | -0.259             | 0.234**              | 0.298**        | 0.236              | 0.255**              | -0.298**       | -0.041             | -0.271**             |
| %NW                | -0.146         | -0.559**           | 0.003               | -0.225**       |                    | -0.112               | -0.187*        | 0.015              | -0.114               | -0.009         | -0.229             | 0.147                |

$T_{\max}$  Maximum temperature,  $T_{\text{mean}}$  mean temperature,  $T_{\min}$  minimum temperature,  $RH_{\max}$  maximum relative humidity,  $RH_{\text{mean}}$  mean relative humidity,  $RH_{\min}$  minimum relative humidity,  $Precip$  precipitation,  $WS_{\max}$  maximum wind speed,  $WS_{\text{mean}}$  mean wind speed,  $NE$  wind of northeast,  $SE$  wind of southeast,  $SW$  wind of southwest,  $NW$  wind of northwest

\*\*  $p < 0.01$  and \*  $p < 0.05$

**Table 4** Multiple regression equations between MPS, pre-peak and post-peak daily Poaceae pollen concentrations and selected variables during 2008–2012

| Model regression equations                                                                | $R^2$ |
|-------------------------------------------------------------------------------------------|-------|
| Meteorological variables + $P_{\text{mean}}^{***}$                                        |       |
| Mod. MPS $y = 1.011P_{\text{mean}} + .020T_{\text{mean}} - .004V_{\text{max}} - 0.630$    | 0.845 |
| Mod. pre-peak $y = .645P_{\text{mean}} + .093T_{\text{mean}} - .011\text{Precip} - 1.309$ | 0.757 |
| Mod. post-peak $y = .945P_{\text{mean}} - .006\text{Calm} + .004V_{\text{max}} - 0.083$   | 0.857 |

**Table 5** Regression equations made by stepwise multiple regression leaving out one year at each application during 2008–2014

\* Models developed by multiple stepwise regression using the test set year, <sup>a</sup> 2008, <sup>b</sup> 2009, <sup>c</sup> 2010, <sup>d</sup> 2011, <sup>e</sup> 2012, <sup>f</sup> 2013 and <sup>g</sup> 2014

| Models* regression equations                                                                                                  | $R^2$ |
|-------------------------------------------------------------------------------------------------------------------------------|-------|
| Meteorological variables**                                                                                                    |       |
| Mod. 1 <sup>a</sup> $y = 0.160T_{\text{mean}} - 0.009\text{Calm} - 1.686$                                                     | 0.425 |
| Mod. 2 <sup>b</sup> $y = 0.144T_{\text{mean}} - 0.007\text{Calm} - 1.419$                                                     | 0.363 |
| Mod. 3 <sup>c</sup> $y = 0.174T_{\text{mean}} - 1.958$                                                                        | 0.401 |
| Mod. 4 <sup>d</sup> $y = 0.147T_{\text{mean}} - 0.008\text{Calm} - 1.481$                                                     | 0.380 |
| Mod. 5 <sup>e</sup> $y = 0.157T_{\text{mean}} - 0.017\text{Calm} - 1.647$                                                     | 0.374 |
| Mod. 6 <sup>f</sup> $y = 0.184T_{\text{mean}} + 0.002\%\text{NE} - 2.3$                                                       | 0.523 |
| Mod. 7 <sup>g</sup> $y = 0.157T_{\text{mean}} - 0.008\text{Calm} - 1.669$                                                     | 0.403 |
| Meteorological variables + $P_{\text{mean}}^{***}$                                                                            |       |
| Mod. 8 <sup>a</sup> $y = 0.812P_{\text{mean}} + 0.054T_{\text{mean}} - 0.005\text{RH}_{\text{max}} - 0.39$                    | 0.788 |
| Mod. 9 <sup>b</sup> $y = 0.85P_{\text{mean}} + 0.047T_{\text{mean}} - 0.007\text{RH}_{\text{max}} + 0.001\%\text{NE} - 0.218$ | 0.784 |
| Mod. 10 <sup>c</sup> $y = 0.803P_{\text{mean}} + 0.075T_{\text{mean}} - 0.003\text{RH}_{\text{max}} - 0.904$                  | 0.784 |
| Mod. 11 <sup>d</sup> $y = 0.824P_{\text{mean}} + 0.056T_{\text{mean}} - 0.005\text{RH}_{\text{max}} - 0.471$                  | 0.783 |
| Mod. 12 <sup>e</sup> $y = 0.85P_{\text{mean}} + 0.044T_{\text{mean}} - 0.005\text{RH}_{\text{max}} - 0.278$                   | 0.791 |
| Mod. 13 <sup>f</sup> $y = 0.768P_{\text{mean}} + 0.078T_{\text{mean}} - 0.004\text{RH}_{\text{max}} - 0.910$                  | 0.814 |
| Mod. 14 <sup>g</sup> $y = 0.827P_{\text{mean}} + 0.053T_{\text{mean}} - 0.005\text{RH}_{\text{max}} - 0.471$                  | 0.803 |

to the results of the RMSE, the differences between observed and expected values were 13.2 and 13.3 using external validation data for 2014 (Mod. pre-peak and Mod. 14, respectively; Table 6). The Spearman's correlation between the observed and expected series of pre-peak daily values showed highly significant coefficient of correlations. For all variables in the models, the VIF was less than 2 (Table 7) indicating that explanatory variables are not correlated with each other and not influence the variance of the regression coefficient. In the case of the two models showing the lowest RMSE, goodness-of-fit tests showed that their model residuals were 9.25 and 18.09. The Durbin–Watson test indicated a positive autocorrelation in the error term of the models (Table 7). The graphic comparison of the expected pollen data with the observed data over the pre-peak shows a profile that fits quite well to the ones actually observed (Fig. 2). At

the end of the pre-peak phase, the predicted patterns seem to overestimate the pollen concentration essentially in two periods.

#### 4 Discussion

The spectrum of airborne Poaceae pollen showed many peaks due to the inclusion of numerous genera and species with different flowering periods in this family. The year-on-year variation of the MPS duration could be due to the anthropic weeding undertaken around the sampling site that provokes the resuspension of the Poaceae pollen during the post-peak that lengthens the duration of the season with low daily pollen concentrations. It might be due also to the late flowering response of perennial grasses that reproduce vegetatively by stolons or rhizomes. Pollen production

**Table 6** Spearman's correlation coefficients and errors differences between observed and estimated data of daily Poaceae pollen concentrations of the models developed

|                                                | Spearman's Correlation r | RMSE  |
|------------------------------------------------|--------------------------|-------|
| MPS, pre-peak and post-peak models             |                          |       |
| Observed 2013 versus predicted model MPS       | 0.828**                  | 58.94 |
| Observed 2014 versus predicted model MPS       | 0.826**                  | 20.5  |
| Observed 2013 versus predicted model pre-peak  | 0.864**                  | 129.4 |
| Observed 2014 versus predicted model pre-peak  | 0.740**                  | 13.3  |
| Observed 2013 versus predicted model post-peak | 0.723**                  | 27.3  |
| Observed 2014 versus predicted model post-peak | 0.760**                  | 17.5  |
| Models produced leaving out one year           |                          |       |
| Meteorological variables                       |                          |       |
| Observed 2008 versus predicted model 1         | 0.624**                  | 18.5  |
| Observed 2009 versus predicted model 2         | 0.853**                  | 65.3  |
| Observed 2010 versus predicted model 3         | 0.664**                  | 69.5  |
| Observed 2011 versus predicted model 4         | 0.729**                  | 36.2  |
| Observed 2012 versus predicted model 5         | 0.597**                  | 23.9  |
| Observed 2013 versus predicted model 6         | 0.307*                   | 112.4 |
| Observed 2014 versus predicted model 7         | 0.699**                  | 16.8  |
| Meteorological variables + PC <sub>mean</sub>  |                          |       |
| Observed 2008 versus predicted model 8         | 0.802**                  | 15.0  |
| Observed 2009 versus predicted model 9         | 0.926**                  | 64.0  |
| Observed 2010 versus predicted model 10        | 0.896**                  | 40.9  |
| Observed 2011 versus predicted model 11        | 0.857**                  | 25.4  |
| Observed 2012 versus predicted model 12        | 0.892**                  | 15.5  |
| Observed 2013 versus predicted model 13        | 0.930**                  | 103.4 |
| Observed 2014 versus predicted model 14        | 0.848**                  | 13.2  |

was related to rainfall during pre-season, increasing when pre-seasonal precipitation was high (2009, 2010, 2011 and 2013). However, although the quantities of rainfall prior to flowering were higher in 2010 and 2011, their pollen level was lower than 2009 and 2013. This is due to the precipitations registered during the MPS and the number of days during which it occurs: Tetouan registered 59 and 98 mm of rainfall on 7 and 9 days in April, and 25.9 and 34.5 mm on 5 and 9 days in May 2010 and 2011, respectively. The cause of low pollen severity in 2012 and 2014 might also be sought in the instable meteorological conditions that influence the pollen liberation, dispersion, and/or transport during the MPS. In Tetouan, pollen season starts earlier in comparison to higher latitudes and colder climates (Puc and Puc 2004; Peternel et al. 2006; García-Mozo et al. 2009; Kasprzyk and Walanus 2010; Myszkowska 2014). Comparing spatial variation in grass pollen start dates recorded in Evora (Portugal), Badajoz (Spain) and Worcester (UK),

Fernández Rodríguez et al. (2015) concluded that the grass pollen season started, on average, 2.4 and 2.8 days later per northward degree of latitude.

The most important meteorological parameters affecting variation in daily Poaceae pollen are temperature, relative humidity, rainfall, wind speed, and direction. Numerous studies have demonstrated that temperatures and dry conditions required for anther dehiscence contribute to high atmospheric levels of daily grass pollen season (Puc and Puc 2004; Peternel et al. 2006; García-Mozo et al. 2009; Kasprzyk and Walanus 2010; Aboulaich et al. 2013). As have been obtained in this study, Poaceae pollen correlated positively with temperature during the pre-peak period. Dividing the MPS into pre-peak and post-peak changed the negative correlation between pollen and temperature during the MPS into positive relationship between dependent and independent variable for the pre-peak and increased the coefficient of correlations. Relative humidity and rainfall are also known to

**Table 7** Characteristics of the stepwise multiple regression models

| Model          | Residuals <sup>a</sup> | Durbin–Watson | <i>P</i> value* | Parameters                         | Coefficient** ± ES | VIF <sup>b</sup> |
|----------------|------------------------|---------------|-----------------|------------------------------------|--------------------|------------------|
| Mod. MPS       | 35.73                  | 1.026         | <0.0001         | <i>P</i> <sub>mean</sub>           | 1.011 ± 0.021      | 1.436            |
|                |                        |               |                 | <i>T</i> <sub>mean</sub> (°C)      | 0.02 ± 0.004       | 1.422            |
|                |                        |               |                 | WS <sub>max</sub>                  | 0.004 ± 0.001      | 1.092            |
| Mod. pre-peak  | 9.25                   | 1.409         | <0.0001         | <i>P</i> <sub>mean</sub>           | 0.645 ± 0.055      | 1.420            |
|                |                        |               |                 | <i>T</i> <sub>mean</sub> (°C)      | 0.093 ± 0.010      | 1.495            |
|                |                        |               |                 | Precip                             | −0.011 ± 0.004     | 1.108            |
| Mod. post-peak | 21.29                  | 1.041         | <0.0001         | <i>P</i> <sub>mean</sub>           | 0.945 ± 0.021      | 1.103            |
|                |                        |               |                 | Calm                               | −0.006 ± 0.002     | 1.125            |
|                |                        |               |                 | WS <sub>max</sub>                  | 0.004 ± 0.001      | 1.234            |
| Mod. 1         | 52.86                  | 0.682         | <0.0001         | <i>T</i> <sub>mean</sub> (°C)      | 0.160 ± 0.011      | 1.003            |
|                |                        |               |                 | Calm                               | −0.009 ± 0.003     | 1.003            |
| Mod. 2         | 50.97                  | 0.657         | <0.0001         | <i>T</i> <sub>mean</sub> (°C)      | 0.144 ± 0.011      | 1.008            |
|                |                        |               |                 | Calm                               | 0.007 ± 0.003      | 1.008            |
| Mod. 3         | 49.72                  | 0.646         | <0.0001         | <i>T</i> <sub>mean</sub> (°C)      | 0.174 ± 0.012      | 1.000            |
| Mod. 4         | 50.85                  | 0.628         | <0.0001         | <i>T</i> <sub>mean</sub> (°C)      | 0.147 ± 0.011      | 1.003            |
|                |                        |               |                 | Calm                               | −0.008 ± 0.003     | 1.003            |
| Mod. 5         | 52.75                  | 0.645         | <0.0001         | <i>T</i> <sub>mean</sub> (°C)      | 0.157 ± 0.012      | 1.007            |
|                |                        |               |                 | Calm                               | −0.017 ± 0.004     | 1.007            |
| Mod. 6         | 41.07                  | 0.768         | <0.0001         | <i>T</i> <sub>mean</sub> (°C)      | 0.184 ± 0.010      | 1.000            |
|                |                        |               |                 | %NE                                | 0.002 ± 0.001      | 1.000            |
| Mod. 7         | 54.89                  | 0.547         | <0.0001         | <i>T</i> <sub>mean</sub> (°C)      | 0.157 ± 0.011      | 1.005            |
|                |                        |               |                 | Calm                               | −0.008 ± 0.003     | 1.005            |
| Mod. 8         | 19.39                  | 1.251         | <0.0001         | Log( <i>P</i> <sub>mean</sub> + 1) | 0.812 ± 0.035      | 1.423            |
|                |                        |               |                 | <i>T</i> <sub>mean</sub> (°C)      | 0.054 ± 0.008      | 1.510            |
|                |                        |               |                 | RH <sub>max</sub>                  | −0.005 ± 0.001     | 1.073            |
| Mod. 9         | 17.16                  | 1.326         | <0.0001         | <i>P</i> <sub>mean</sub>           | 0.85 ± 0.035       | 1.332            |
|                |                        |               |                 | <i>T</i> <sub>mean</sub> (°C)      | 0.047 ± 0.008      | 1.417            |
|                |                        |               |                 | RH <sub>max</sub>                  | −0.007 ± 0.002     | 1.316            |
|                |                        |               |                 | %NE                                | 0.001 ± 0.000      | 1.230            |
| Mod. 10        | 17.83                  | 1.253         | <0.0001         | <i>P</i> <sub>mean</sub>           | 0.803 ± 0.036      | 1.370            |
|                |                        |               |                 | <i>T</i> <sub>mean</sub> (°C)      | 0.075 ± 0.009      | 1.392            |
|                |                        |               |                 | RH <sub>max</sub>                  | −0.003 ± 0.001     | 1.076            |
| Mod. 11        | 17.75                  | 1.240         | <0.0001         | <i>P</i> <sub>mean</sub>           | 0.824 ± 0.035      | 1.301            |
|                |                        |               |                 | <i>T</i> <sub>mean</sub> (°C)      | 0.056 ± 0.008      | 1.387            |
|                |                        |               |                 | RH <sub>max</sub>                  | −0.005 ± 0.001     | 1.083            |
| Mod. 12        | 17.53                  | 1.309         | <0.0001         | <i>P</i> <sub>mean</sub>           | 0.850 ± 0.033      | 1.332            |
|                |                        |               |                 | <i>T</i> <sub>mean</sub> (°C)      | 0.044 ± 0.008      | 1.453            |
|                |                        |               |                 | RH <sub>max</sub>                  | −0.005 ± 0.001     | 1.112            |
| Mod. 13        | 15.96                  | 1.469         | <0.0001         | <i>P</i> <sub>mean</sub>           | 0.768 ± 0.035      | 1.547            |
|                |                        |               |                 | <i>T</i> <sub>mean</sub> (°C)      | 0.078 ± 0.008      | 1.630            |
|                |                        |               |                 | RH <sub>max</sub>                  | −0.004 ± 0.001     | 1.093            |
| Mod. 14        | 18.09                  | 1.166         | <0.0001         | <i>P</i> <sub>mean</sub>           | 0.827 ± 0.033      | 1.393            |
|                |                        |               |                 | <i>T</i> <sub>mean</sub> (°C)      | 0.053 ± 0.008      | 1.497            |
|                |                        |               |                 | RH <sub>max</sub>                  | −0.005 ± 0.001     | 1.099            |

<sup>a</sup> Sum of the squared residuals<sup>b</sup> *VIF* variance inflation factors\* Significance level at  $\alpha = 0.05$ \*\*  $P < 0.001$

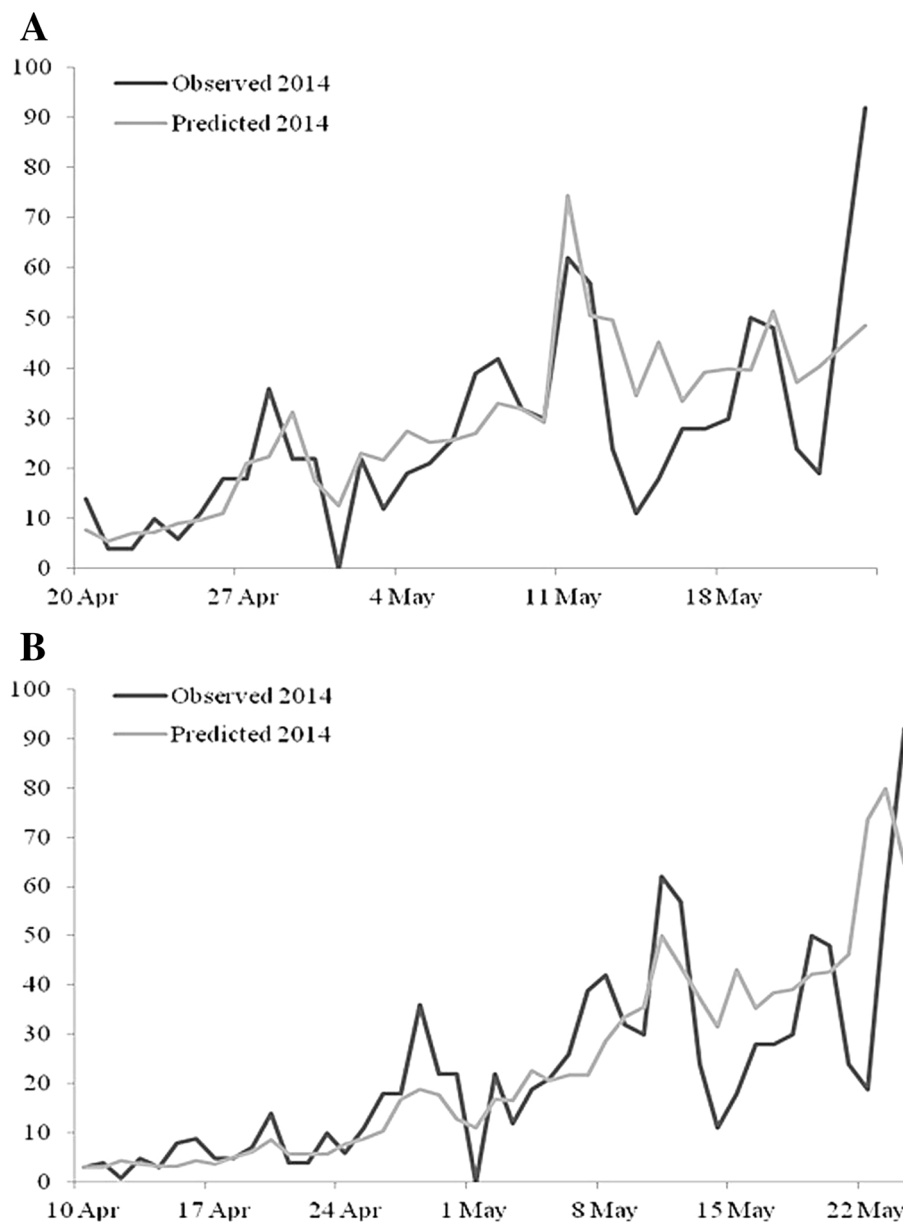


**Fig. 3** Graphic representation of daily Poaceae pollen concentrations during the pre-peak of 2014 (observed) and predicted value developed by the pre-peak model (a) and model 14 (b)

influence daily concentration and seasonal Poaceae pollen counts (Emberlin et al. 1993; Sánchez-Mesa et al. 2005). Increasing relative humidity with decreasing pollen concentrations are well established throughout the literature. In addition to the washing effect of pollen from the atmosphere, precipitation has been documented to inhibit anthesis in some species (Puc and Puc 2004; Green et al. 2004; Kasprzyk and Walanus 2010). This may be also because the water

content of the soil favors vegetative growth rather flowering (Recio et al. 2010). A similar negative association with relative humidity and rainfall and daily pollen concentration was noted in Tetouan, almost not in all years. Wind speed showed a positive effect only during the MPS for 2012 and 2013 and the post-peak for the latter year. Wind direction did not show a very clear pattern as it was heterogeneous from 1 year to another. But in general, winds blowing from

NE and SE were associated with the increase of the level of the Poaceae pollen in the air. In Malaga (Spain), the tendency of the number of days with airborne grass pollen to decrease is associated with significant trends for the annual mean wind speed and the annual frequency of SE winds (Recio et al. 2010).

From the results of the stepwise regression analysis, two models constructed were able to predict efficiently the daily Poaceae pollen concentration at the city of Tetouan between 75.7 and 80.3% of variance. Smith and Emberlin (2005) constructed three multiple regression models to predict the daily grass pollen concentrations for the pre-peak, peak and post-peak periods of pollen seasons in North London., the forecast models achieved between 29.2 and 55.3% accuracy. The model used to forecast daily average grass pollen concentration during the whole season in Poznań reached 61 and 70% variance in 2005 and 2006, respectively (Stach et al. 2008). In the previous paper by Aboulaich et al. (2013), the models explained 76.6–78.6% of variance when the mean of pollen concentrations of the same day in other years and Poaceae pollen concentration recorded one day before were included in the regression equation. However, as we use a 7-day spore trap, it is only practical to use the data from the previous week. For this reason, the Poaceae pollen concentration recorded one day before was not included in the current work and the daily pollen concentrations forecast performance reached 85.7% of variance. The models obtained for the post-peak and the whole of the MPS increased the percentage of variance, but splitting the season up into pre-peak and post-peak improved the models as the RMSE were markedly lower essentially for the former. The pre-peak models fit better within the year 2014 with the lowest pollen concentration and much worse on the year 2013 with the highest airborne pollen concentration. This helped the performance of the forecast and shows the strength of the influence between the independent variables and pollen concentrations during this period. Comparing the two methods, the use of the whole season create one large dataset to produce a single model for all the period, but this should be validated against a worse year. The leave one out procedure is much better as the validation year that improves the performance of the model could be selected.

In this study, the variables that were introduced were daily average Poaceae pollen concentrations, mean

daily temperatures, daily precipitation and daily maximum relative humidity. When the regression formula of the model pre-peak ( $y = .645P_{\text{mean}} + .093T_{\text{mean}} - .011\text{Precip} - 1.309$ ) and model14 ( $y = .872P_{\text{mean}} + .053T_{\text{mean}} - .005\text{RH}_{\text{max}} - 0.471$ ) was applied for predicting daily average Poaceae pollen concentrations during the pre-peak period, the differences between the two numerical series (observed vs expected) showed the lowest RMSE. The patterns seem to diverge at the end of the pre-peak period (Fig. 3). The cause of this discrepancy is due to rainfall events that cause the observed airborne Poaceae pollen concentration to decrease. With the exception of the peak day, the models generally predict the whole pre-peak period with a good effectiveness.

This information can be important in providing warnings for allergic people, or advising medical services for adopting preventive measures and improving allergies diagnostic.

## 5 Conclusion

The MPS of Poaceae generally started at the beginning of April and its pollen productivity and duration varied among years influenced by meteorological parameters prior to flowering and during the season. Pollen production increases with pre-season rainfall and daily concentration is positively correlated with temperature. The present study shows that, among the meteorological and biological variables used in multiple regression analyses, daily mean pollen concentration of the same day in other years, temperature, precipitations and relative humidity were found as the main factors predicting the Poaceae pollen season and make the fit of the models markedly better. The different environment responses between species and/or genera within the Poaceae family make the model development difficult. These models can be used as useful and easy forecast tools and enable us to improve their robustness in future when the length of dataset could be considered sufficiently for regression analysis.

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