

Cyperaceae and *Juncaceae* pollination measured in the air at two sites in SW Spain

Adolfo F. Muñoz Rodríguez ·
Inmaculada Silva Palacios · Rafael Tormo Molina

Received: 15 March 2007 / Accepted: 23 July 2007
© Springer Science+Business Media B.V. 2007

Abstract The presence of airborne *Cyperaceae* and *Juncaceae* pollen was quantified using volumetric aerobiological traps over a 10-year period at two sites in SW Spain separated by 60 km (Badajoz 10 years, Mérida 3 years). The Pearson correlation coefficient was calculated between the daily and hourly concentrations. The values of the principal meteorological parameters—temperature, rainfall, relative humidity, and speed and direction of the wind—were calculated during the study period, and with the accumulated values corresponding to the period prior to pollination. The beginning and ending dates and the duration of the main pollen season (MPS) were also analyzed. Even though both families are anemophilous, the presence of their pollens in the air was low. The annual accumulated daily concentrations were in the

range 1.8–15.8 for *Juncaceae* and 111.8–473.9 for *Cyperaceae*—values far lower than any other anemophilous pollen type. The *Cyperaceae* pollen concentration peaked between 09:00 and 12:00. The meteorological factor most closely related to its daily variations was found to be the wind direction, showing that location of the sources is of great importance. The results lend support to the hypothesis of a limitation of allogamous reproduction in favour of vegetative multiplication in both families. Nevertheless, the principal source of the airborne *Cyperaceae* pollen was found to be *Scirpus holoschoenus*, whose pollen is distinguishable from the rest. Hence, because of its large production of pollen, this species can be characterized as anemophilous and allogamous. Rainfall in the preceding autumn seemed to be responsible for the amount of *Cyperaceae* pollen in the air, since a lack of rain was found to be associated with lower densities in the traps. For the *Juncaceae*, it seems that the temperatures of the preceding December constituted the most limiting meteorological parameter.

A. F. Muñoz Rodríguez
Departamento de Biología Ambiental y Salud Pública,
Facultad de Ciencias Experimentales, Universidad de
Huelva, Avda. Fuerzas Armadas s/n, Huelva 21071, Spain
e-mail: adolfo.munoz@dbasp.uhu.es

I. Silva Palacios
Departamento de Electrónica e Ingeniería
Electromecánica, Escuela de Ingenierías Agrarias,
Universidad de Extremadura, Crta. Cáceres s/n,
Badajoz 06080, Spain
e-mail: insilva@unex.es

R. Tormo Molina (✉)
Departamento de Biología y Producción de los Vegetales,
Facultad de Ciencias, Universidad de Extremadura,
Avda. Elvas s/n, Badajoz 06080, Spain
e-mail: ratormo@unex.es

Keywords Pollination · Anemophily ·
Cyperaceae · *Juncaceae* · Aerobiology

1 Introduction

The *Cyperaceae* and *Juncaceae* families have classically been associated with anemophilous pollination

on the basis of their floral characteristics (Cronquist 1988). There have nonetheless occasionally been descriptions of insects visiting their inflorescences, as in the case of *Carex binervis* (Proctor et al. 1996) and other species of the same genus (Leereveld et al. 1991; Villanueva 1994). The two families are extensively distributed over different types of habitat worldwide, generally associated with moist sites. They both have systems of vegetative multiplication that enable the formation of extensive clones within their populations (Richards 1986). In many locations, including Mediterranean zones, their pollens are only sparsely represented in aeropalynological spectra, appearing in quantities not only far smaller than other anemophilous taxa, but also less than some entomophilous taxa whose contribution to the airborne pollen load is considered to be passive. For this reason, their pollination characteristics have not usually been the subject of aeropalynological studies, except for some locations—e.g., La Plata and Buenos Aires (Argentina) (Pérez et al. 2001; Nitiu 2004), Berhampore and Calcutta (India) (Boral et al. 2004; Banik and Chanda 1992), in which the high concentration of *Cyperaceae* leads to the pollen of this family being amongst the most frequent in the airborne distribution. Even in these zones where the representatives of this family are abundant, *Cyperaceae* pollen is recognized as being an excellent indicator of the surrounding vegetation, reflecting how limited its dispersion is into neighbouring zones. This fact has also made it an excellent tool in palaeobotanical studies (Pardoe 1994; Beecher and Chmura 2004).

While *Juncaceae* pollen consists of tetrads, *Cyperaceae* pollen is released in pseudomonads, i.e., of the four nuclei resulting from meiosis, only one develops into a pollen grain (Fernández 1987a). Palynological studies have shown the pollen of both families to have thin walls, a characteristic which can even hinder their treatment by acetolysis (Fernández 1987a; Van Wichelen et al. 1999) and which could reflect poor adaptation to the adverse environmental conditions represented by their transport in the wind.

There are very little data in the literature on the pollen production of the two families. Histological studies of the anthers of *Juncaceae* species, however, show them to possess few pollen grain mother cells, implying a low production of pollen (Wulff 1939). Histological studies in the *Cyperaceae* family show

that in most of the species the pseudomonads are arranged in a cylinder such that they are all in contact with the tapetum, thereby limiting the production of pollen in this family (Kirpes et al. 1996). As those authors observe in their review, this arrangement would seem to be inconsistent with the anemophily of this family. The most important species in the area of the study are *Scirpus holoschoenus* L., *S. lacustris* L., *Eleocharis palustris* (L.) Roemer & Schultes, *Cyperus longus* L., *C. michelianus* (L.) Link, *C. eragrostis* Lam., *Carex hispida* Willd., *C. divisa* Hudson, *C. hirta* L., *Juncus acutus* L., *J. effusus* L., *J. heterophyllus* Dufour, *J. acutiflorus* Ehrh. ex Hoffm., *J. articulatus* L. and *J. buffonius* L. (Tormo 1995).

The aim of the present work was to analyze some characteristics of pollination in these families on the basis of an aeropalynological study. This was carried out in the towns of Badajoz and Mérida, in the Extremadura Region in the interior of the SW Iberian Peninsula. Both sites are under the influence of extensive irrigation zones. For the *Cyperaceae* case, a study was conducted of the influence of meteorological parameters on the annual and daily pollination data.

There are few published data on the reproductive biology of the species of these two families, except for the possible self-incompatibility of *Scirpus maritimus* (Charpentier et al. 2000), and the self-compatibility of *Carex bigelowii* (Jonsson et al. 1996) and *Carex platyphylla* (Handel 1985). The present work may, therefore, represent a contribution to their knowledge beyond the general overview of their anemophily.

2 Materials and methods

The study was performed using Burkard volumetric traps (Hirst 1952) located in Badajoz (6 m above ground in school of agrarian engineering) and Mérida (15 m above ground in the hospital), which provided daily and hourly data on the particulate concentrations in the air. Daily and hourly pollen counts were determined from four longitudinal scans under optical microscopy at 400× magnification, along the centre of the sample and then transformed into grains/m³. The study was continuous from 1994 to 2003 in Badajoz and from 1996 to 1998 in Mérida.

The two study sites are 60 km apart and surrounded by environments with similar characteristics. They both belong to the same bioclimatic zone—Mesomediterranean—and the same biogeographical province—Luso-Extremadurensis (Ladero 1987). Their immediate environment is strongly influenced by farming activities—the percentage of land area devoted to crops is 66.4% in Badajoz and 70.3% in Mérida (MAPA 1985a, b). Irrigation predominates, because both towns are located on the River Guadiana, in the areas known as the Vegas Bajas and Vegas Altas (Lower and Upper Floodplains), respectively. The remaining vegetation cover is mainly riparian, pasture, and *Quercus rotundifolia* ‘dehesas’ (parkland grazing systems).

With respect to the pollen typing, the pollen of representatives of the *Juncaceae* was identified as a single type. The same was the case for the *Cyperaceae*, since, although different types can be separated with more precise methods (Fernández 1987a), the aerobiological analyses did not allow the characters required for discrimination to be recognized in most of the pollen grains identified. Nevertheless, grains of this family were very frequently observed with pores in the equatorial zone. This would represent the *Carex hallerana* type, which includes the species *Scirpus holoschoenus* (Fernández 1987b), which is very frequent in the environment of the two traps. These grains were often counted, and their percentage estimated relative to the total pollen of the family.

Given how sparsely they were represented, the analysis of the *Juncaceae* data was restricted to the correlation of the annual concentrations with the meteorological parameters, as will be detailed below. In the case of the *Cyperaceae*, the study was completed with respect to the aspects described in the following paragraphs.

The daily concentration data were used to elaborate pollination calendars for each year, determining the main pollen season (MPS) defined as the period from the day when the accumulated concentration reached 5% of the total concentration of that year to the day when it reached 95% (Nilsson and Persson 1981). Each year’s hourly pattern of appearance of pollen was studied by calculating the mean concentration for each hour of the day, using only those days on which the type was represented.

A simple Pearson correlation test was used to study relations between the daily pollen

concentrations and the daily values of the meteorological parameters. Only data corresponding to the MPS were considered, and significance was taken to be $p < 0.05$. The meteorological data, acquired from the Territorial Meteorological Centre of Extremadura for the Badajoz and Mérida meteorological stations, consisted of the mean, maximum, and minimum temperatures (°C), relative humidity (%), rainfall (mm), wind speed (km/h), and the periods of calm and of winds from the NE, SE, SW, and NW quadrants (h). No data corresponding to relative humidity or wind speed were available for 2002 or 2003. The meteorological characteristics of the study period, with yearly cycles by month, were calculated from October to September, and by season from autumn to summer. The reason for this choice of the annual cycle is that both families’ pollination can be regarded as complete at the end of this period, so that the weather in autumn would only influence the following year’s pollination.

To see which meteorological factors might affect the total annual *Cyperaceae* pollen concentrations and the characteristics of the MPS, we calculated the Pearson correlation between the pollen concentrations, the start and end dates (taken as the day number in the calendar year) of the MPS and its duration, and the accumulated rainfall and mean temperatures and relative humidity. These calculations were determined independently for the months between October of the preceding year and September of the same year, and with the accumulated rainfall, mean temperatures and relative humidity of the autumn of the preceding year and of the winter, spring, and summer of the same year. The same study was performed for *Juncaceae* pollen, but using only the total annual concentration.

To study the phenological similarity of the *Cyperaceae* pollination at the two sites during the 3 years when there were data for both sites, we calculated the Pearson coefficient correlation between their hourly mean concentrations and between their daily concentrations within the interval of the MPS that they had in common.

3 Results

Table 1 gives a summary of the meteorological characteristics of the study period. Table 2 lists the

Table 1 Rainfall (mm) and mean seasonal temperatures (°C) of the different periods considered (autumn–summer) in Badajoz site

Rainfall	Autumn	Winter	Spring	Summer	Accumulated
93–94	170.50	115.60	103.40	1.70	391.20
94–95	83.60	56.70	57.70	19.20	217.20
95–96	289.40	221.50	109.20	30.90	651.00
96–97	238.00	112.10	107.60	84.90	542.60
97–98	379.10	98.70	75.80	58.40	612.00
98–99	46.60	54.10	91.60	54.40	246.70
99–00	173.70	38.50	233.90	8.60	454.70
00–01	254.90	190.20	47.00	22.10	514.20
01–02	124.00	164.50	69.90	33.10	391.50
02–03	191.72	131.70	46.00	28.50	397.92
Temperatures	Autumn	Winter	Spring	Summer	Means
93–94	11.72	10.67	18.55	23.99	16.23
94–95	13.70	11.38	20.31	24.82	17.55
95–96	15.80	10.68	19.14	23.56	17.29
96–97	13.45	12.34	18.74	24.32	17.21
97–98	14.45	12.04	18.03	25.20	17.43
98–99	12.00	9.81	19.49	24.18	16.37
99–00	13.49	10.71	18.53	24.42	16.79
00–01	13.44	12.26	19.74	24.64	17.52
01–02	12.58	11.50	19.08	24.18	16.84
02–03	14.56	10.95	20.26	25.61	17.84

measured total annual *Cyperaceae* and *Juncaceae* pollen concentrations (sum of the daily concentrations). One observes the low level of representation of the *Juncaceae*, with values for Badajoz varying between the 1.8 of 1997 and the 15.8 of 2001, and similarly low levels for Mérida (3.0–4.3). The *Cyperaceae* values ranged from the 111.8 of 2002 to the 473.9 of 1998, again presenting similar values in the 3 years of study in Mérida (282.5–530.4). We found that *Scirpus holoschoenus* pollen always represented more than 80% of the *Cyperaceae* count at both sampling sites.

Table 2 also lists data relating to the calendar of appearance of the pollen and to the MPS period of the *Cyperaceae* family, and they are represented in Fig. 1. This family's pollination occurred in spring and summer. The differences between years were basically in the magnitudes of the maximum concentrations reached in the middle of this period—between May and June.

In Badajoz, the MPS commenced between mid-April and the end of May and concluded between the end of July and mid-September. The situation in Mérida was similar. The duration of the period varied

from the 63 days of 1996 to the 150 days of 1995. The case of Mérida was again similar.

The daily concentrations of the two sites within the pollination period that was common to both were significantly positively correlated ($r = 0.788$, $p = 0.0001$, 1996; $r = 0.312$, $p = 0.0004$, 1997; $r = 0.718$, $p = 0.0001$, 1998). Figure 2 shows the mean hourly *Cyperaceae* pollen concentrations in the years of the study for the two sites. In all cases, the lowest concentrations were recorded during the first hours of the day, between 01:00 and 07:00. There was then a rise, with the daily maximum being reached between 09:00 and 12:00, followed by a gradual decline during the afternoon and evening until reaching the nocturnal minima. The pattern was similar at the two sites, as was reflected in the significant positive correlation between their mean hourly values ($r = 0.902$, $p = 0.0001$, 1996; $r = 0.864$, $p = 0.0001$, 1997; $r = 0.929$, $p = 0.0001$, 1998).

Table 3 gives the data for the correlation analysis between the daily *Cyperaceae* pollen concentrations within the MPS and the daily values of the different meteorological parameters. The temperatures showed little relationship with the concentrations at either

Table 2 Comparison of the total annual pollen concentration (sum of the daily concentrations; grain/m³) between *Cyperaceae* and *Juncaceae* pollen during the studied period at the two sampling locations (Badajoz and Mérida)

	<i>Juncaceae</i>		<i>Cyperaceae</i>							
	Badajoz	Mérida	Badajoz				Mérida			
	Total	Total	Total	Onset	End	Days	Total	Onset	End	Days
1994	6.7		248.7	4 May	24 August	113				
1995	6.7		206.8	17 April	13 Noven.	150				
1996	15.2	3.6	399.4	23 May	24 July	63	376.3	24 May	26 July	64
1997	1.8	4.3	279.5	15 April	23 August	131	282.5	21 April	6 Sept.	139
1998	8.5	3.0	473.9	15 May	25 August	103	530.4	17 May	21 August	97
1999	2.4		273.4	6 May	29 August	116				
2000	6.1		292.9	16 May	28 August	105				
2001	15.8		317.2	6 May	30 August	86				
2002	2.4		111.8	16 April	28 August	135				
2003	13.4		280.7	13 May	11 Sept.	122				

Within the *Cyperaceae* plant family the dates of the onset and the end of the main pollination period, as well as the relative duration (days) are also reported

site. A significant negative correlation was shown by the relative humidity in four of the years studied in Badajoz and two in Mérida, and by rainfall in only one year in Badajoz.

With respect to the relationship with the wind parameters at the Badajoz site, it is notable that there were significant positive correlations in four of the years with the duration of the calm periods, but a negative correlation in 1998. There were positive correlations with winds from quadrants 1 (NE) and 2 (SE) in 7 of the 10 years of the study, and negative correlations with quadrants 3 (SW) and 4 (NW) in 5 and 6 years, respectively. In Mérida, there were positive correlations with winds from quadrant 1 in 2 years, and negative correlations with winds from quadrant 3 also in 2 years.

The total annual *Juncaceae* pollen concentrations in Badajoz (Table 2) were significantly correlated with the following parameters: February rainfall ($r = 0.670$; $p = 0.0339$), December relative humidity ($r = 0.723$; $p = 0.0278$), and the mean temperature in December ($r = 0.794$; $p = 0.0061$), June ($r = 0.662$; $p = 0.0372$) and autumn ($r = 0.656$; $p = 0.0396$). Figure 3 shows the relation between the mean December temperatures and the total annual *Juncaceae* pollen concentrations in Badajoz that have the most significant correlation.

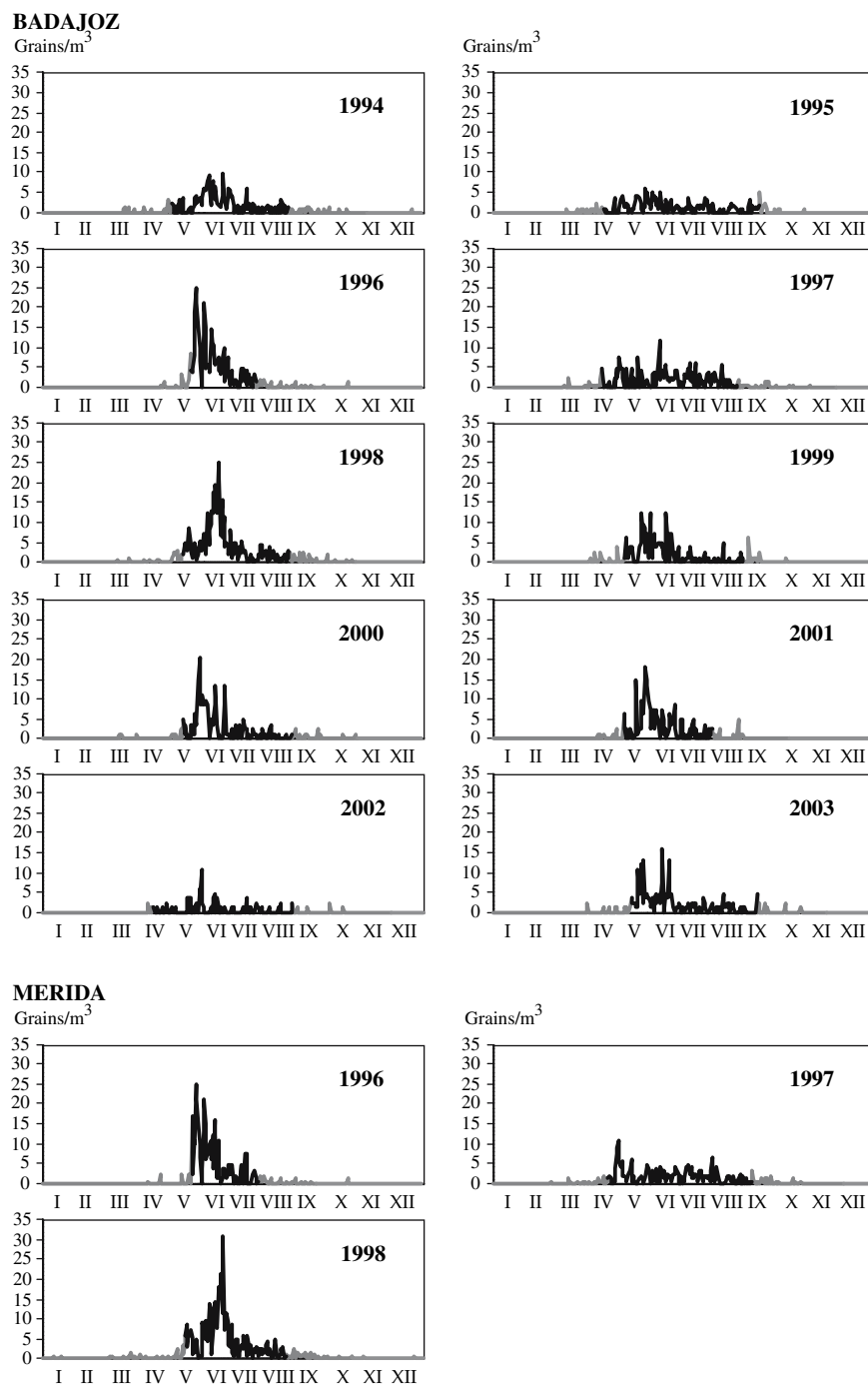
In the case of the *Cyperaceae* family, the total annual pollen concentrations showed significant

positive correlations with the rainfall of November ($r = 0.824$; $p = 0.0034$) and of the autumn of the preceding year ($r = 0.803$; $p = 0.0052$). Figure 4 shows the relation with the November rainfall. With respect to the MPS pollination period, the following significant negative correlations were found: the beginning of the period with the June rainfall ($r = 0.659$; $p = 0.0383$) and with the mean April temperature ($r = 0.660$; $p = 0.0376$); the end of the period with the rainfall of December of the preceding year ($r = 0.744$; $p = 0.0135$), of January ($r = 0.724$; $p = 0.0179$), and of winter ($r = 0.732$; $p = 0.0160$); and the duration of the period with the rainfall of December of the preceding year ($r = 0.633$; $p = 0.0495$).

4 Discussion

There was a very sparse representation of pollen from the *Juncaceae* family in the air. Even in 1996, the year when its presence was greatest in Badajoz, it was only captured on 18 days, with the quantity being estimated at 0.03% of the total pollen count at this site. This proportion was not only far surpassed by the other anemophilous herbs (*Poaceae*, *Plantago*, *Rumex*, *Amaranthaceae*, *Chenopodiaceae*, and *Urticaceae*), but also by other anemophilous taxa

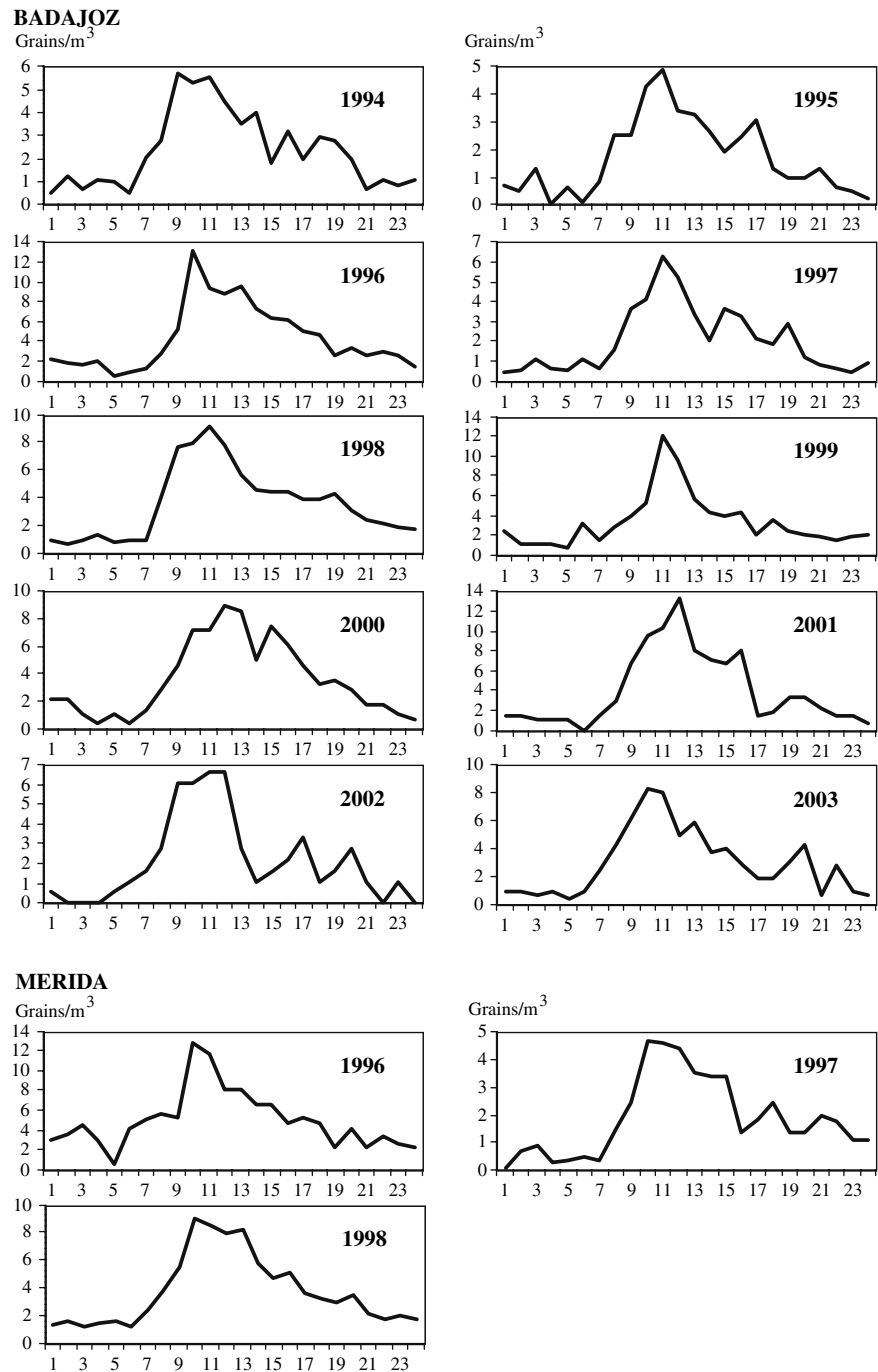
Fig. 1 Annual calendar of *Cyperaceae* pollen (grain/ m^3) in Badajoz and Merida locations during the studied period. Black line marks the daily pollen concentrations occurring during the main pollen season



represented by far fewer species and with a more limited distribution in the Region (*Urtica membranaceae*, Typhaceae, and *Mercurialis*), by some typically entomophilous herbs (*Echium*, Apiaceae, Brassicaceae, and Fabaceae), by the different types recognized as within the Asteraceae (Anthemideae,

Lactuceae, *Senecio*, and *Helianthus*) (Silva 1996), and even by taxa such as *Artemisia* whose sources are in geographical zones that are far from the sampling site (Silva et al. 2000b). There have been similar findings at other locations. For instance, the deposition of the pollen of these two families per unit area

Fig. 2 Mean hourly pollen concentration (grain/m³) of *Cyperaceae* in Badajoz and Merida sites recorded during the studied period



found in the study of Hyde (1950) carried out at eight sites in England showed a situation similar to the present observations in Badajoz.

Although *Cyperaceae* pollen was more frequently represented, given that more than 80% corresponded to *Scirpus holoschoenus*, the importance of the rest of

the family was also far less than expected. Even in the years of greatest abundance, the annual concentration of the pollen of these species, which include the *Carex* and *Cyperus* genera that are very common around both sampling sites—only reached values of around 100.

Table 3 Analysis of correlation and their significance levels between the daily *Cyperaceae* pollen concentrations and the different parameters [mean, maxima and minima temperatures (°C), relative humidity (%), rain (mm), wind velocity (m/s),

period of calm, wind direction (NW, SW, SE, and NE)] measured within the main pollen season, during the studied period at the two different locations (Badajoz and Merida)

BADAJOZ	Mean T^a	Max T^a	Min T^a	RH	Rain	Wind	Calms	NW	SW	SE	NE
1994				-0.211			0.246	0.581	0.340	-0.312	-0.215
$n = 104$				0.0391			0.0085	0.0001	0.0002	0.0008	0.0225
1995								0.166	0.163		
$n = 120$								0.0423	0.0466		
1996								0.417			-0.326
$n = 92$								0.0007			0.0091
1997		0.186		-0.288	-0.184			0.202			
$n = 137$		0.0330*		0.0008	0.0349			0.0207			
1998			-0.243				-0.206		0.294	-0.226	
$n = 132$			0.0135				0.0365		0.0025	0.0214	
1999				-0.283		-0.244	0.461		0.195	-0.327	-0.248
$n = 82$				0.0023		0.0088	0.0001		0.0363	0.0003	0.0073
2000								0.327	0.205	-0.197	-0.255
$n = 82$								0.0007	0.0364	0.0444	0.0086
2001	0.334	0.393		-0.339		-0.289	0.237	0.419	0.260		-0.254
$n = 84$	0.0017	0.0002**		0.0014		0.0071	0.0283	0.0001	0.0156		0.0181
2002				-		-	0.182				
$n = 53$							0.0346				
2003				-		-	-	0.345	0.400	-0.272	-0.195
$n = 95$								0.0001	0.0001	0.0024	0.0314
MÉRIDA	Mean T^a	Max T^a	Min T^a	RH	Rain	Wind	Calms	NW1	SW	SE	NE
1996								0.289		-0.288	
$n = 39$								0.0208		0.0208	
1997				-0.202				0.285			
$n = 149$				0.0170				0.0007			
1998				-0.204						-0.214	
$n = 90$				0.0452						0.0357	

In Badajoz site, relative humidity and wind speed data were not available for the 2002 and 2003 period. In each cell superior figure is r , correlation coefficient, and the inferior figure is, p the probability of $r = 0$, only values with $p < 0.05$ are reported, * when $p < 0.01$ and ** when $p < 0.001$

There may be two reasons for the under-representation of the two families: on the one hand, because their pollen production is low, and, on the other, because its dispersion is limited to the immediate vicinity of the sources. Both reasons would be consistent with the families' pollen and floral characteristics (Fernández 1987b; Tanaka 2000).

With respect to the pollen production, the data of Wulff (1939) correspond to low values for the *Juncaceae*, while, according to the review of Kirpes et al. (1996), the production of pseudomonads in

Cyperaceae is limited by their particular arrangement in the pollen sacs.

The *Cyperaceae* are cited in the work of Richards (1986) as an example of groups of anemophilous plants most of whose pollen is dispersed into the immediate vicinity of their production area. This has been proven in the case of *Carex platyphylla* which, while monoecious, deposits its pollen within a radius of 20 cm of the male spikelets. A result is that the larger the size of the clones formed by vegetative reproduction, the greater the percentage of geitonogamy (Handel 1985). The great value of the

sedimentation of *Cyperaceae* pollen in the representativity of the surrounding vegetation in wet, arctic, and alpine zones is also a reflection of their limited capacity for dispersion (Beecher and Chmura 2004; Van Der Knapp et al. 2001; Yu et al. 2001).

Scirpus holoschoenus does not fit this explanation. As its pollen is distinguishable from the other *Cyperaceae* present in the environment of the traps, it was possible to assess it as being the major source of the pollen of this family. Hence, most of the present study's results for this family may be put down almost entirely to the pollination model of this species.

Furthermore, the *Scirpus holoschoenus* pollination was at a level similar to that of other similarly distributed anemophilous taxa. This may mean that its sexual reproduction requires a certain degree of allogamy. Such a situation has indeed been observed in other species of the genus, such as *Scirpus maritimus*, in which Charpentier et al. (2000) have shown the inability to form fruit under conditions of autogamy and after hand self-pollination, and *Carex bigelowii*, which, in spite of being self-compatible, has been characterized by Strenstrom (1999) as an allogamous species.

The interannual variations of the *Juncaceae* pollen concentrations seemed to be positively correlated with the February rainfall, the December relative humidity, and the December, June, and autumn temperatures. To interpret the influence of these factors on the pollination process would require more knowledge of the physiology of these species at their different stages of development. In the case of the rainfall, however, the relationship between the annual concentrations and rainfall in the winter months was already known at the Badajoz site for other herb pollen types, in particular, for Poaceae, *Rumex*, Anthemideae, and Apiaceae (Silva et al. 1998). Nevertheless being the values of concentration so reduced we showed our reserves about to these conclusions.

In the case of the *Cyperaceae* pollen, the relationships between the annual concentrations and the autumn rainfall—especially that of November—seem to be the only ones capable of explaining the interannual variations in the concentrations. It is clear that, in the case of species associated with wet habitats, the rainfall in the wettest season of the year (Table 1) may affect the density of the populations

and the physiological status of the individuals in those populations, increasing their levels of annual pollination. Indeed, the three wettest years—1996, 1998, and 2001—were those in which the annual concentrations surpassed 300 (Fig. 4). This relationship between autumn rainfall and annual concentrations is also common in Badajoz for other herb pollen types, including *Plantago* (Tormo et al. 2001).

There was some slight variability in the date of the beginning of the *Cyperaceae* main pollen season in the ten years of the study in Badajoz, from mid-April to the end of May. This date seemed to be negatively correlated with the June rainfall and the April temperatures. The latter correlation was to be expected since warmer temperatures at the beginning of pollination would accelerate the process, thereby advancing the dates. The influence of the June rainfall is understandable in that most of the pollination usually occurs in this month, so that rain, in reducing this peak of pollination, would artificially shift the maximum levels to the preceding months, thus advancing the beginning of the MPS. There is support for this argument too in that 1995, 1997, and 2002 were the years with both the lowest June concentrations (Fig. 1) and the earliest beginning of the MPS, in mid-April (Table 2), whereas in the other years this date was in May.

What does seem strange, however, is the negative relationship between the date of the end of the MPS and the December, January, and winter rainfall. That there is also a negative correlation of the period's duration with the December rainfall seems to confirm that there must be a biological explanation for these relationships.

The significant correlations between the two study sites in the 3 years of study in common showed a parallelism in their MPS and in the daily variations of their concentrations, and a similarity in the amounts of pollen collected. Their similar surroundings and the same environmental conditions, thus, determine a similarity in the pollination of the *Cyperaceae* family.

The two sampling sites presented the same pattern of hourly pollen counts. Particularly striking were the large differences between the minimum concentrations (which were recorded in the first hours of the day) and the maxima (which were recorded at around midday). These differences may confirm the proximity of the sources to the traps, according to the

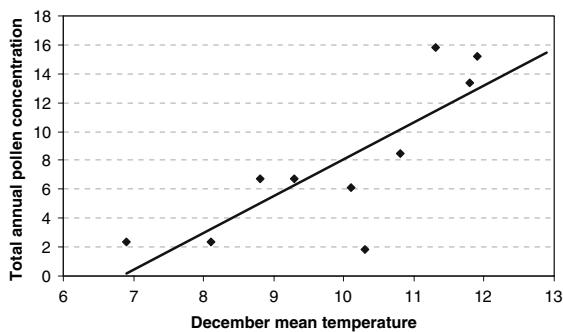


Fig. 3 Relationship between the mean temperature (°C) recorded in December (see Table 2) and the total annual pollen concentration (grain/m³) of *Juncaceae* plant family in Badajoz site during the studied period (1994–2003, $r = 0.794$, $p = 0.0061$)

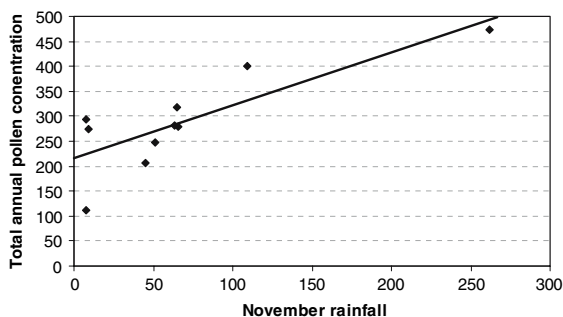


Fig. 4 Relationship between the rainfall (mm) recorded in November and the total annual pollen concentration (see Table 2) of *Cyperaceae* plant family in Badajoz site during the studied period (1994–2003, $r = 0.824$; $p = 0.0034$)

postulates of Trigo et al. (1997). The pattern is similar to that described for the family by Galán et al. (1991) in Córdoba, who found maxima between 11:00 and 13:00 in the 3 years of their study, and to that observed by Nitiu (2004) in La Plata, with maxima at 10:00 again in the three years of study. Kämpylä (1981) in Finland, however, found maximum concentrations of this type occurring around dawn, with multiple peaks reflecting the different species involved, according to the author. A similar situation is described by Pérez et al. (2001) for Buenos Aires, with two daily peaks in concentration—one between 10:00 and 12:00 that would correspond to the maximum of the present study, and the other at night between 22:00 and 04:00 whose concentrations even surpassed those of the daytime peak in one of the 3 years of their study.

The daily *Cyperaceae* pollen concentrations were independent of the daily temperatures at both sites. They seemed to be negatively influenced by the relative humidity, however. While this may, in principle, seem to be incongruous in taxa that are associated with wet habitats, it is not really surprising since such a relationship is presented by a great many anemophilous species, which reduce the release of pollen when the humidity is high and thus could hinder dispersion.

With respect to the wind direction, east winds seemed to increase the concentrations, while west winds reduced them. This effect was clear at the Badajoz site, where it simply reflected the relative location of the trap to the west of the Vegas Bajas, the irrigation zone neighbouring the city (Silva et al. 2000a).

5 Conclusions

Cyperaceae and *Juncaceae* are both anemophilous plants families, although *Juncaceae* species are relatively well represented in the study area their pollen representation in the air is similar to entomophilous species. The contribution of the airborne pollen of *Cyperaceae* family is mainly due to *Scirpus holoschoenus*, a very frequently found plant in the surrounding of the study area, but the pollen amount registered in the atmosphere is not very high, in spite of being also an anemophilous family. These values could be explained because the low pollen production or by their dispersion in the immediate vicinity, although sexual reproduction of *Scirpus holoschoenus* seems to require a certain degree of allogamy.

The interannual variations in pollen concentration in *Cyperaceae* can be explained mainly as a consequence of rainfall during November, that affect the density of the populations and the physiological status of the individuals, in the case of *Juncaceae* it is not clear the meteorological influence but it seems that the temperatures of the preceding December constituted the most limiting meteorological parameter. The beginning of pollination of *Cyperaceae* seem to be affected by June rainfall and April temperatures, first of both parameters reducing the amount in the month peak and the second affecting the advancing in the dates.

The proximity of the sources to the traps could be also confirmed by the pattern of hourly pollen counts, with a great difference between minimum and maxima. Relative humidity affects negatively to pollen concentration, as occur in many other pollen types, because it could hinder dispersion. The relationship between pollen concentration and wind direction reflects the location of the plant sources with respect to the spore trap situations, which are wet places. These include natural ones, such as along rivers, or artificial ones, such as irrigated crops.

References

- Banik, S., & Chanda, S. (1992). Airborne pollen survey of Central Calcutta, India, in relation to allergy. *Grana*, 31, 72–75.
- Beecher, C. B., & Chmura, G. L. (2004). Pollen-vegetation relationships in Bay of Fundy salt marshes. *Canadian Journal of Botany*, 82, 663–670.
- Boral, D., Chatterjee, S., & Bhattacharya, K. (2004). The occurrence and allergising potential of airborne pollen in West Bengal, India. *Annals of Agricultural and Environmental Medicine*, 11, 45–52.
- Charpentier A., Grillas, P., & Thompson, J. D. (2000). The effects of population size limitation on fecundity in mosaic populations of the clonal macrophyte *Scirpus maritimus* (Cyperaceae). *American Journal of Botany*, 87, 502–507.
- Cronquist, A. (1988). *The evolution and classification of flowering plants*. New York: Columbia University Press.
- Fernández, I. (1987a). Contribución al conocimiento palinológico de Cyperaceae. *Acta Botánica Malacitana*, 12, 173–182.
- Fernández, I. (1987b). *Cyperaceae*. En: B. Valdés, M. J. Díez & I. Fernández (Eds.), *Atlas polínico de Andalucía Occidental* (pp. 368–373). Utrera: Universidad de Sevilla.
- Galán, C., Tormo, R., Cuevas, J., Infante, F., & Domínguez, E. (1991). Theoretical daily variations patterns of airborne pollen in the south-west of Spain. *Grana*, 30, 201–209.
- Handel, S. N. (1985). The intrusion of clonal growth patterns on plant breeding systems. *American Naturalist*, 125, 367–384.
- Hirst, J. M. (1952). An automatic volumetric spore trap. *Annals Applied Biology*, 39, 257–265.
- Hyde, A. (1950). Studies in atmospheric pollen. IV. Pollen deposition in Great Britain, 1943. *New Phytologist*, 49, 398–420.
- Jonsson, B. O., Jónsdóttir, I. S., & Crnberg, N. (1996). Clonal diversity and allozyme variation in populations of the arctic sedge *Carex bigelowii* (Cyperaceae). *Journal of Ecology*, 84, 449–459.
- Käpylä, M. (1981). Diurnal variation of non-arboreal pollen in the air in Finland. *Grana*, 20, 55–59.
- Kirpes, C. C., Clark, L. G., & Lersten, N. R. (1996). Systematic significance of pollen arrangement in microsporangia of *Poaceae* and *Cyperaceae*: review and observations on representative taxa. *American Journal of Botany*, 83, 1609–1622.
- Ladero, M. (1987). L España Luso-Extremadurensis. En: M. Peinado & S. Rivas-Martínez (Eds.), *La vegetación de España* (pp. 453–487). Universidad de Alcalá de Henares, Alcalá de Henares.
- Leereveld, H., Meeuse, A. D. J., & Stelleman, P. (1991). Some cases of visiting of anemophiles by syrphid flies in Madagascar. *Israel Journal of Botany*, 40, 219–223.
- MAPA. (1985a). *Mapa de cultivos y aprovechamientos. Badajoz*. Dirección General de la Producción Agraria, Madrid.
- MAPA. (1985b). *Mapa de cultivos y aprovechamientos. Mérida*. Dirección General de la Producción Agraria, Madrid.
- Nilsson, S., & Persson, S. (1981). Tree pollen spectra in the Stockholm region (Sweden), 1973–1980. *Grana*, 20, 179–182.
- Nitui, D. S. (2004). Intradiurnal fluctuation of pollen in La Plata, Argentina. Part I, herbaceous pollen types. *Aerobiologia*, 20, 69–74.
- Pardoe, H. (1994). Surface pollen studies from alpine sub-alpine Southern Norway—Applications to Holocene data. *Review of Palaeobotany and Palynology*, 82, 1–15.
- Pérez, C. F., Gardiol, J. M., & Paez, M. M. (2001). Comparison of intradiurnal variation of airborne pollen in Mar del Plata (Argentina). Part I. Non-arboreal pollen. *Aerobiologia*, 17, 151–163.
- Proctor, M., Yeo, P., & Lack, A. (1996). *The natural history of pollination*. Portland: Timber Press.
- Richards, A. J. (1986). *Plant breeding systems*. London: Unwin & Allen.
- Silva, I. (1996). *Estudio aeropalinológico de la ciudad de Badajoz*. Thesis. University of Extremadura, Badajoz.
- Silva, I., Tormo, R., & Muñoz, A. F. (1998). Differences in phenology and pollination levels between dry and wet years. Badajoz (SW Spain), 6th International Congress on Aerobiology, Perugia.
- Silva, I., Tormo, R., & Muñoz, A. F. (2000a). Influence of wind direction on pollen concentration in the atmosphere. *International Journal of Biometeorology*, 44, 128–133.
- Silva, I., Tormo, R., Muñoz, A. F., Tavira, J., & Moreno, A. (2000b). Presencia de polen de *Artemisia* en la atmósfera de Extremadura (SO España). *Acta Botánica Malacitana*, 25, 141–151.
- Strenstrom, A. (1999). Sexual reproductive ecology of *Carex bigelowii*, an arctic-alpine sedge. *Ecography*, 22, 305–313.
- Tanaka, H. (2000). Size and dispersal of pollen grains in anemophilous angiosperms. *Journal of Japanese Botany*, 75, 116–122.
- Tormo, R. (1995). *Juncaceae, Cyperaceae*. In J. A. Devesa (Ed.), *Vegetación y Flora de Extremadura* (pp. 570–582). Badajoz: Universitas.
- Tormo, R., Silva, I., Muñoz, A. F., Tavira, J., & Moreno, A. (2001). Environmental factors that affect anemophilous pollination in the genus *Plantago*. *Annals of Botany*, 87, 1–8.
- Trigo, M. M., Recio, M., Toro, F. J., & Cabezudo, B. (1997). Intradiurnal fluctuations in airborne pollen in Málaga (S. Spain): A quantitative method. *Grana*, 36, 39–43.

- Van Der Knapp, W. O., Van Leeuwen, J. F. N., & Ammann, B. (2001). Seven years of annual pollen influx at the forest limit in the Swiss Alps studied by pollen traps: relations to vegetation and climate. *Review of Palaeobotany and Palynology*, 117, 31–52.
- Van Wichelen, J., Camelbeke, K., Charle, P., Goetghebeur, P., & Huysmans, S. (1999). Comparison of different treatments for LM and SEM studies and systematic value of pollen grains in *Cyperaceae*. *Grana*, 38, 50–58.
- Villanueva, G. R. (1994). Nectar sources of european and africanized honey bee (*Apis mellifera* L.) in the Yucatán Peninsula (México). *Journal of Apicultural Research*, 33, 44–58.
- Wulff, H. D. (1939). Die Pollenentwicklung der Juncaceen. *Jahrbücher für wissenschaftliche Botanik*, 87, 533–556.
- Yu, G., Tang, L. Y., Yang, X. D., Ke, X. K., & Harrison, P. (2001). Modern pollen samples from alpine vegetation on the Tibetan Plateau. *Global Ecology and Biogeography*, 10, 503–520.