Science of the Total Environment 470–471 (2014) 480–487

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Environmental behaviour of airborne Amaranthaceae pollen in the southern part of the Iberian Peninsula, and its role in future climate scenarios

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HIGHLIGHTS

- A 21-year-set of Amaranthaceae pollen records was analysed to chart environmental reaction.
- Rainfall and maximum temperatures were the parameters more related to the Pollen Index.
- Amaranthaceae species have a rapid response to scarce water availability.
- Amaranthaceae pollen will have a greater impact on future scenarios for pollen allergy.

ARTICLE INFO

Article history:
Received 21 March 2013
Received in revised form 7 October 2013
Accepted 8 October 2013
Available online xxxx

Editor: Lidia Morawska

Keywords:
Amaranthaceae
Airborne pollen
Pollen allergy
Aerobiology
Climate change

ABSTRACT

The Amaranthaceae family includes a number of species which, through a series of specific adaptations, thrive in salty soils, arid environments and altered human settlements. Their ability to tolerate high temperatures favours summer flowering, giving rise to the widespread involvement of Amaranthaceae pollen grains in summer allergies, both in Mediterranean Europe and in areas with arid climates. This study analysed a 21-year set of historical airborne Amaranthaceae pollen records for an area located in the southern part of the Iberian Peninsula, in order to chart species' environmental reaction to changing climate conditions which occurred in the last decades. Airborne pollen data were collected from January 1991 to December 2011 using a Hirst-type volumetric impact sampler. Results showed that Amaranthaceae pollen remained in the atmosphere for over 6 months along the year, from early spring until early autumn. The annual Pollen Index ranged from barely 200 grains to almost 2000 grains, and was strongly influenced by rainfall during the flowering period, which prompted the development of new individuals and thus an increase in pollen production. A trend was noted towards increasingly early pollen peak dates; peaks were recorded in August–September in years with summer rainfall, but as early as May–June in years when over 50% of annual rainfall was recorded in the months prior to flowering. The gradual decline in the annual Pollen Index over later years is attributable not only to growing urbanisation of the area but also to a change in rainfall distribution pattern. High maximum temperatures in spring were also directly related to the peak date and the Pollen Index. This ability to adapt to changeable and occasionally stressful and restrictive, environmental conditions places Amaranthaceae at a competitive advantage with respect to other species sharing the same ecological niche. An increased presence of Amaranthaceae is likely to have a greater impact on future scenarios for pollen allergy diseases associated with climate change.

1. Introduction

The Amaranthaceae family is a merger of the Chenopodiaceae and Amaranthaceae families, based on molecular systematics (Angiosperm Phylogeny Group, 2009). Most members of this family are annual and perennial herbs, together with some shrubs, which have adapted to salty soils, arid environments and altered human settlements, in which they profit from high nitrogen concentrations. They largely originate in the Steppes of Central Asia, although some of the most common *Amaranthus* species are of American origin; they were used in America for making both flour and drinks, and also in rituals, due to their alkaloid content (De la Cruz, 1991; Izco et al., 2004). The family includes species of agricultural interest, such as *Beta* spp., *Spinacea oleracea*, *Chenopodium quinoa*, *Atriplex hortense*, ornamentals (*Celosia cristata*, *Amaranthus caudatus*), and species of economic interest (e.g. cattle feed or extraction

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http://dx.doi.org/10.1016/j.scitotenv.2013.10.024

of NaOH from *Salsola* spp.). However, a number of species are considered invasive or infestant: indeed, some are listed among the world's worst weeds, e.g. *Chenopodium ambrosioides*, *Bassia scoparia*, *Amaranthus muricatus* (Bunce et al., 2002; Dana et al., 2003; Holm et al., 1977; Lambdom et al., 2008; Villarías, 2006). Amaranthaceae are able to tolerate highly-arid habitats and very salty soils thanks to a series of specific adaptations. These include extremely high seed production – ranging between 13,000 and 50,000 seeds per plant, depending on the richness of the soil (Holm et al., 1977) – and a fruit dispersal mechanism involving the whole plant, e.g. tumbleweed. Both mechanisms are intended to ensure plant survival during arid periods and in hostile environments. The tolerance of some species to accumulate high arsenic concentrations in different parts of its organism, without exhibiting decreased growth, contributes to their use as toxic-fixatives in highly polluted soils (Tapia et al., 2013).

With regard to pollen grain morphology, a number of studies have highlighted small structural differences between the pollen grains of monoecious and dioecious species of the genus *Amaranthus* (Franssen et al., 2001), as well as differences in sexine thickness between the former Chenopodiaceae and Amaranthaceae families, allowing the separation of some genera (Deák et al., 2013; Fernandez-Illescas et al., 2008; Ianovici, 2008; Pla-Dalmau, 1957). However, the family as a whole shares a number of pollen-grain morphological features that render its members indistinguishable under light microscopy: grains are spheroidal, with a polypantoporate aperture arrangement (Trigo et al., 2008). Because of this strong similarity, identification of species in local airborne pollen spectra requires identification and phenological monitoring of the major Amaranthaceae present in the study habitat (Fernández-Illescas et al., 2010). Pollen production and release tend to be very low, reflecting the pollen economy characteristic of xerophytic species, which minimize energy output to match resource availability (Izco et al., 2004). Amaranthaceae flower in summer, once the main pollination period of most species in temperate latitudes has finished (Fernández-Illescas et al., 2008). Because of this seasonality, and because pollen is windborne, Amaranthaceae pollens are among the major causes of summer allergies in Mediterranean Europe (Bousquet et al., 1984; Cariñanos et al., 2004a,b; D'Amato et al., 2007; Galán et al., 1989; Guerra et al., 1990) and in areas with desert climates (Al-Dowaisan et al., 2004; Crimi et al., 1988; Ezeamuzie et al., 2000; Räsänen, 2000).

Pollen production is regulated not only by plant-intrinsic factors but also by the environmental conditions in which plants grow. When conditions are restrictive and/or adverse, a decrease in pollen production is likely due to the shortening of the reproductive phase. Several studies have reported reduced production following frost damage during budburst due to a sharp drop in temperatures (Cannel and Smith, 1984) or, by contrast, following record-breaking heat waves and droughts (Gehrig, 2006; Penel and Sanjuan, 2004). Airborne pollen counts may be used as an indicator of vegetation status under certain environmental conditions (Alba et al., 2009; Cariñanos et al., 2004a, 2010; Emberlin, 1994; Garcia-Mozo et al., 2007; Trigo et al., 2006). Analysis of variations in long-term pollen data sets provides evidence of the dynamics, behaviour and reactions of different species to changing climate conditions (Alcázar et al., 2009; Cariñanos et al., 2004b; Frenguelli, 2002; Frenguelli et al., 2004; Garcia-Mozo et al., 2006; Recio et al., 2010; Stach et al., 2007), and more particularly of the impact of climate change on pollen levels (Spieksma et al., 1995; Teranishi et al., 2000), pollen season (Emberlin, 1994; Huynen and Menne, 2003), plant and pollen distribution (Peetet, 2000; Weber, 2002), and even pollen allergenicity (Allholm et al., 1998; Hjelmroos et al., 1995). The present study examined a 21-year set of historical airborne Amaranthaceae pollen records for the city of Córdoba, in southern Iberian Peninsula, in order to chart species' environmental reaction to changing climate conditions. The spread of Amaranthaceae species in unstable environments, and its potential role in future climate scenarios of allergy diseases are also addressed.

2. Material and methods

2.1. Study area

The study was carried out in Córdoba, a medium-sized city in Southern Spain, Mediterranean Europe (4°45′W, 37°50′N). Biogeographically, it belongs to the Mediterranean Region, with mild, rainy winters and hot, dry summers with temperatures frequently above 40 °C; rainfall is irregular, with over two consecutive months of drought (Torreño and Requena, 1997). According to records for the last 30 years, the annual average temperature is 17.6 °C. Due to year-to-year fluctuations in local weather patterns, the climate is defined as Mediterranean with a certain degree of aridity (Allue-Andrade, 1990), with mean annual rainfall of 674 mm over the period 1971–2000 (National Institute of Meteorology, 2001).

The natural vegetation in the area is composed of abundant thermophilic elements belonging to the series of vegetation features of the area: *Paeonio coriaceae–Querceto rotundifoliae* in the South of the province and *Pyro bourganeae–Querceto rotundifoliae* in the northern zone (Costa-Pérez, 2005). However, in many areas this vegetation, being one of the world's largest surface areas, has been almost completely replaced by non-irrigated arable crops, especially by olive grove (Galán et al., 2001). A third type of vegetation consists of taxa of flora ornamental components of urban green spaces, many of them of exotic origin (Staffolani et al., 2011).

2.2. Studied plant group: Aerobiology and allergenicity

The catalogue *Western Andalusian Flora* lists 14 genera of Amaranthaceae in Córdoba province, 11 belonging to the former Chenopodiaceae and 3 to the former Amaranthaceae; the most common are: *Amaranthus* (12 species), *Chenopodium* (10), *Atriplex* (7), *Salsola* (5), *Suaeda* (3) and *Salicornia*, *Sarcocornia* and *Beta* (1 species each) (Valdés et al., 1987). Preferred habitats of presence include ruderal, ditches/gutters and non-cultivated lands. However, the recent changes in the land use, with the abandonment of agricultural land, changes in crop management and intense urbanisation, have allowed the spread of some species catalogued as invasive (Dana et al., 2005), being among them *Amaranthus albus*, *Amaranthus blitoides*, *Amaranthus hybridus*, *A. muricatus* and *Amaranthus retroflexus*. It is noteworthy that several of these species have been installed in the west and north-west area of the city, on hiper-nitrophilous grasslands, crops in fresh soil and abandoned urban areas (Dana et al., 2005).

Most of the species start to flower in early summer, due to ease of adaptation to drought and high temperatures, extending its flowering to autumn. During this period, airborne Amaranthaceae pollen counts range from low–moderate (1–50 pollen grains/m^3 air/day) to high (over 50 pollen grains/m^3 air/day), according to the aerobiological scale for allergenic pollen (Galán et al., 2007). Strikingly, despite relatively low counts, Amaranthaceae pollen is among the six main pollen types causing allergies in the Spanish population, with a sensitivity ranging from 8% (Galán et al., 1989), to over 90% in Central Spain (Moral et al., 1996). It is the primary cause of pollen sensitization in the cities of Elche and Toledo, and in arid south-eastern areas of the Iberian Peninsula, and the second most important cause in Logroño, Ciudad Real and Zaragoza (Cariñanos et al., 2000a; Feo-Brito et al., 1998; Fernandez et al., 1998; Moral et al., 1998; Pola et al., 1998). In Córdoba city, 22% of allergy sufferers are sensitive to Amaranthaceae pollen (Dominguez et al., 1993; Guerra et al., 1990).

2.3. Sampling method

Airborne monitoring was performed using a Lanzoni VPPS 2000 impact sampler (Lanzoni s.r.l., Bologna, Italy), located in the south-western part of the city. This is a semi-rural area marked by strong urban growth over the last decade; the rural environment has gradually given way to housing areas (Bermejo-Pérez et al., 2011). The sampler, placed at 25 m a.g.l., worked uninterruptedly from January 1991 to December 2011. Sample analysis was performed using the standard protocol recommended by the Spanish Aerobiology Network (Galán et al., 2007), providing daily average pollen counts per cubic meter of air. For each year, the following phenological and aerobiological parameters were calculated: the start of the season (first day on which at least 1 pollen grain/m^3 was recorded, followed by five consecutive days with 1 or more pollen grains), the end of the season (the last day on which at least 1 pollen grain/m^3 was recorded, followed by five following days below this level), the length of the season (number of days between the start and the end of the season), the peak date (date in which the maximum pollen value was recorded), peak value (maximum pollen value of the yearly season) and Pollen Index (annual sum of daily values).

2.4. Meteorological data

Weather data – maximum, minimum and average temperature and rainfall for the period 1991–2011 – were supplied by the Territorial Centre for Western Andalusia, AEMET, from an automatic station located 5 km from the sampler. These data were used to chart responses and behaviour of seasonal pollen data under varying climate conditions. The general pattern of winds prevalent in the area was also considered to analyse the possible arrival of material from other potential source areas.

2.5. Statistics

Aerobiological and meteorological variables were fitted to a simple lineal regression line to analyse trends. To ascertain the impact of weather related parameters on airborne Amaranthaceae pollen counts over the time series, Spearman's non-parametric correlation test was applied between the main meteo-variables and the phenological and the aerobiological parameters. Lastly, Stepwise multiple regression model was performed to identify the most influencing parameters in the presence of pollen concentrations. IBM SPSS 20.0 Statistics Software package was used to perform all the statistical analysis.

3. Results

Fig. 1 shows the weekly average values of Amaranthaceae pollen records in the atmosphere of Cordoba during the 21-years of continued monitoring. As an average, this pollen type is present 35 weeks along the year, with average records remaining under 5 pollen grains/m^3 of air, peaking on May or September.

The trends followed by the main characteristics of the Amaranthaceae pollen season in Córdoba along the series are shown in Fig. 2a–e. The pollen season started between late March and late April, in most years, with a difference of 42 days between the earliest and latest start-dates.

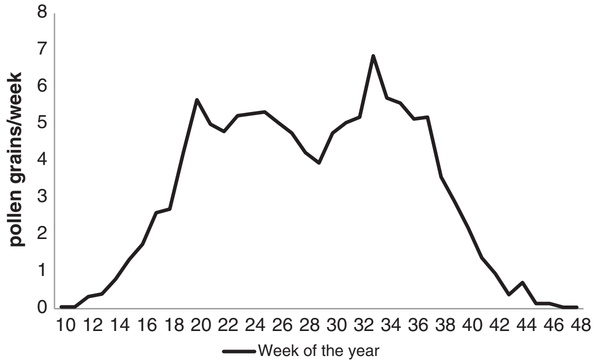

Fig. 1. Weekly average of Amaranthaceae pollen records during the period 1991–2011.

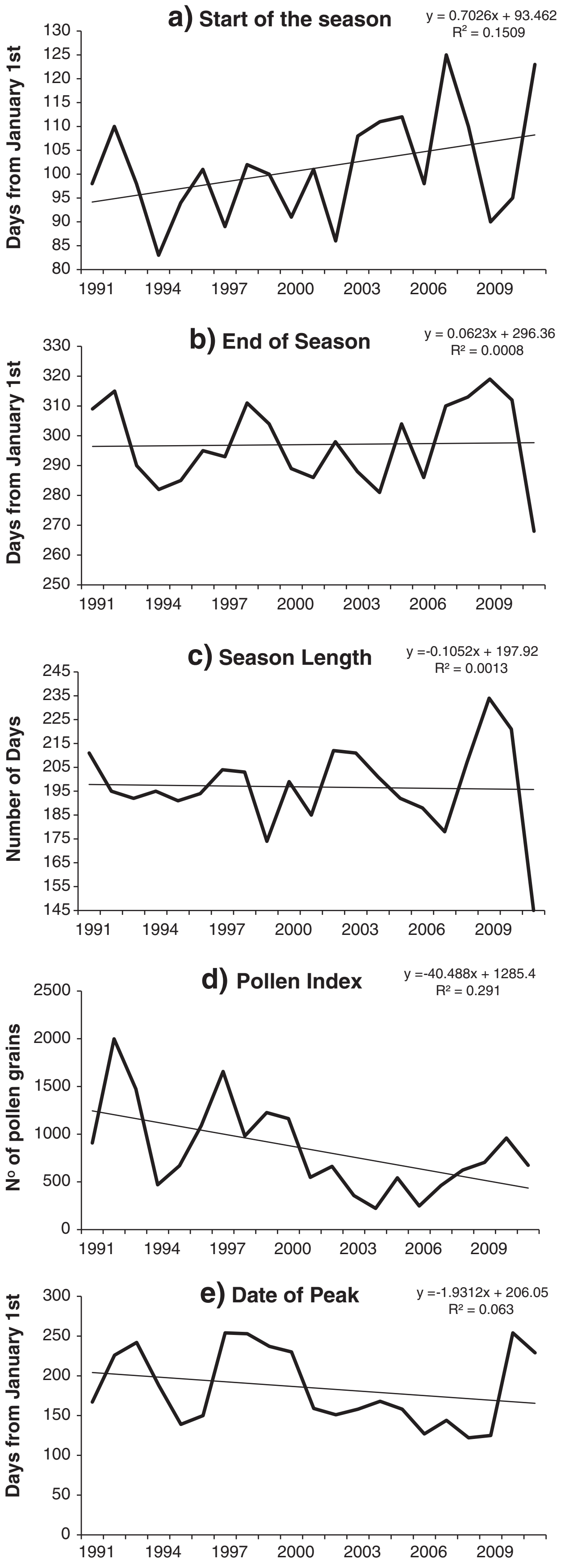

Fig. 2. Trends of Amaranthaceae pollen records during 1991–2011 for phenological and aerobiological variables. a: Start of the season; b: end of the season; c: season length; d: Pollen Index; e: date of peak.

A certain trend was observed towards an increasingly late start to the Amaranthaceae pollen season (Fig. 2a). End of season-dates ranged from late October to the first fortnight of November, with a difference of 45 days between the earliest and the latest end-date (Fig. 2b). The season length thus ranged from 145 the shortest to 234 days the longest, with a more or less stable trend throughout the series, in which alternate short duration seasons with other of greater duration, with an average of 200 days per year (Fig. 2c).

The Pollen Index records proved fairly irregular: in some years counts exceeded 1000 pollen grains, while in others they hardly reached 500 grains, a minimum of 222 pollen grains was recorded in 2004. From 2001 onwards, there was a significant decreasing trend in values ($p < 0.05$), although a slight recovery was noted at the end of the series (Fig. 2d).

Two different patterns were detected for peak pollen dates: in earlier years, peaks were recorded during August or September (from day 200 since January 1st), while towards the end of the series, peaks were registered in May or June (day 150 to 200 since January 1st). In the latter case, season length was not affected by the occurrence of an early peak (Fig. 2e). Linear trend shows a significant advance of almost 2 days through the years.

The trends followed by the most influencing meteorological parameters on the presence of Amaranthaceae pollen records in the atmosphere of the area are shown in Table 1. Though only the minimum temperatures of spring and summer (SpmT, SumT) showed a significant upward trend ($p < 0.05$), noticeable is the widespread increase in trends of yearly average temperatures and yearly annual rainfall, and, on the contrary, the decline in the Winter Maximum Temperatures (WMTs) and spring and summer rainfall (SpRf, SuRf). In detail, the average annual temperature for the series was 18 °C, with some outlying values, such as 20 °C in 2002 due to a minimum temperature around 3–4 °C higher than in other years and 7 °C higher than the minimum temperatures in the coldest year (Fig. 3). Spain has been suffering from summer heat waves since 2002; as in most European countries, the summer of 2003 was particularly extreme. The annual average temperature in 2005 also lays outside the range noted above, due to unusually low local winter temperatures. There was considerable year-on-year variation in rainfall, with marked oscillations around the average value of 600 mm; maximum values exceeded 1000 mm and minima approached 300 mm. Three cycles of severe droughts were detected, the first in 1992–1994, the second in 1998 and the third which started in autumn 2005 and lasted until the beginning of 2007. There were also variations in rainfall distribution: winter rainfall, i.e. winter months to the start of the Amaranthaceae flowering period, represented scarcely a third of the annual total in the early years (from 1991 to 2000), while in later years winter rainfall increased until it accounted a 50% of the annual total, with a maximum of up to 65% in 2004, giving rise to a very dry flowering season.

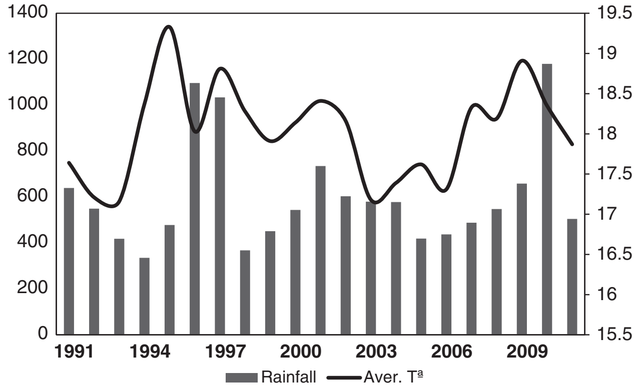

Fig. 3. Yearly average temperatures (in °C) and total annual rainfall (in mm) during the period 1991–2011 in Córdoba.

Spearman correlation analyses between the different aerobiological and seasonal meteorological parameters displayed significant bilateral correlation at 95% level ($p < 0.05$) between the Maximum Spring Temperature (SpMT) and the Pollen Index and peak date, and also between the amount of rainfall in spring (SpRf) and the peak value (Table 2). The rainfall in summer (SuRf) showed also significant relationship with the end of the season date. Although the rest of the meteorological parameters did not displayed significant correlation with the phenophases, in general, spring and summer rainfall had a positive effect on all, while the Spring Maximum Temperatures (SpMTs), on the contrary, pointed a negative effect.

The Stepwise regression test performed to identify the most influencing parameters in the presence of Amaranthaceae pollen concentrations in the air of Cordoba generates two models in which the variable rainfall in June can explain up to 52.2% of variance; whereas if the maximum temperature of September is also included as predictor, then the R^2 value of the model can explain up to 65.8% of the observed variance (Table 3).

Table 1
Slope value and significance (p) for the main meteorological parameters affecting the presence of Amaranthaceae pollen records through the period 1991–2011. In bold, significant values ($p < 0.05$).

	Slope	p
Annual aver. Tª	0.008	0.69
Annual max. Tª	0.009	0.69
Annual min. Tª	0.021	0.45
Annual rainfall	3.884	0.65
Winter		
Max. Tª	−0.049	0.33
Min. Tª	0.053	0.36
Rainfall	2.848	0.48
Spring		
Max. Tª spring	0.057	0.12
Min. Tª spring	**0.082**	**0.01**
Spring rainfall	−0.033	0.99
Summer		
Max. Tª	−0.036	0.32
Min. Tª	**0.044**	**0.04**
Rainfall	−0.557	0.54

Table 2
Spearman correlation between seasonal meteorological parameters and aerobiological variables. WMT: Winter Maximum Temperature; WmT: Winter minimum Temperature; WRf: Winter Rainfall; SpMT: Spring Maximum Temperature; SpmT; Spring minimum Temperature; SpRf: Spring Rainfall; SuMT: Summer Maximum Temperature; SumT: Summer minimum Temperature; SuRf: Summer Rainfall. *=significant values at < 0.05.

	Start date	End date	Length of season	Pre-PI	PI	Peak date	Peak value
WMT	−0.343	0.123	0.091	0.262	0.352	0.141	**0.547***
	0.12	0.59	0.69	0.25	0.118	0.54	**0.01**
WmT	−0.074	0.036	0.287	−0.179	−0.016	0.053	−0.047
	0.74	0.87	0.20	0.438	0.94	0.81	0.84
WRf	−0.080	0.025	0.419	−0.307	−0.169	−0.081	−0.375
	0.73	0.91	0.05	0.175	0.46	0.72	0.09
SpMT	0.041	−0.190	−0.389	**−0.444***	−0.351	**−0.495***	−0.212
	0.860	0.41	0.08	**0.04**	0.11	**0.02**	0.35
SpmT	0.188	−0.054	−0.397	0.041	0.131	0.109	0.262
	0.41	0.81	0.07	0.86	0.57	0.63	0.25
SpRf	0.306	0.226	−0.039	0.312	0.340	0.342	**0.317***
	0.17	0.32	0.86	.16	0.13	0.12	**0.046**
SuMT	0.067	0.062	0.180	0.039	−0.216	0.131	0.094
	0.77	0.78	0.43	0.86	0.34	0.57	0.83
SumT	0.108	0.298	0.289	−0.090	−0.122	0.193	−0.144
	0.64	0.19	0.20	0.69	0.59	0.40	0.53
SuRf	0.021	**0.542***	0.267	0.016	0.269	−0.034	0.269
	0.92	**0.01**	0.24	0.94	0.23	0.88	0.23

Table 3
Stepwise multiple regression model between the seasonal meteorological parameters and the annual Pollen Index. RainJun: total amount of rainfall during June; TmaxSept: average of maximum temperatures during September.

Model	R^2 corr.	Model
1	0.522	IP = 11.274 + 0.722RainJun + 2.47
2	0.658	IP = 13.462RainJun − 0.395TmaxSept + 44.915

Data for 2011 were excluded from the model and used for validation.

4. Discussion

The results show that airborne Amaranthaceae pollen is present in Córdoba for an average 196 days, i.e. more than 6 months of the year, its presence lasting longer than that of any other taxon in the total pollen spectrum of the area (Alcázar et al., 2002; Cariñanos et al., 2000b); and longer than that of other herb types with which it shares habitats, such as *Plantago*, *Rumex* and Urticaceae (Alcázar et al., 2009). This pollen season is longer than that reported for other areas with similar bioclimatology (Fernández-Illescas et al., 2010; Recio et al., 2006); it bears certain similarities to patterns recorded for the most arid areas of the region (Cariñanos et al., 2004a). This may be attributable in part not only to the extremely high species biodiversity in Mediterranean areas, but also to the fact that local climate conditions – Mediterranean with a certain degree of aridity – favour the presence of several species of the same family with differing ecological requirements (Deák et al., 2013; Prieto-Baena et al., 2003).

No relationship was found between the Pollen Index and pollen season length; indeed, some of the longest seasons recorded very low pollen counts, for example in 2002, 2003 and 2004. The most productive pollen season seemed to be related to rainfall in late summer and early autumn, which favoured the flowering of new individuals and, therefore a release of more pollen grains into the atmosphere. This was particularly evident in 1992, 1993, 1997, 1998, 1999 and 2000; in virtually all these years, the Pollen Index exceeded 1000 pollen grains, and peak pollen dates were recorded in August or September, following a certain amount of rainfall. Some late summer rainfall in 2005 also prompted a second peak, especially species that bloom in mid to late summer, as strategy to avoid the periods of the highest temperatures (Fernandez-Illescas et al., 2010). It is also significant that the annual maximum temperature in these years, except for 1992, was over 25 °C, suggesting that high temperatures do not impede the reproductive cycle in many species of Amaranthaceae. Some studies have concluded that the warming recorded over the last twenty years has led to a bringing-forward of flowering-season start-dates in those species which depend on winter temperatures to start their reproductive cycle (Alcázar et al., 2011; Garcia-Mozo et al., 2002; Levetin, 2001; Teranishi et al., 2000), while summer-flowering species, including most Amaranthaceae, display an extended pollen season (Huynen and Menne, 2003). Similar findings have been reported for grasses and Urticaceae, for which rising temperatures have led to longer pollen seasons (D'Amato et al., 2002; Emberlin et al., 1997; Frenguelli, 2002; Garcia-Mozo et al., 2010). This is borne out by the significant correlation between maximum temperatures in the period April–June and some aerobiological parameters.

During periods of drought, there was a sharp fall in the Pollen Index, but the pollen season was not shortened. After the first two drought cycles (1992–1994 and 1998), renewed rains prompted a recovery of pollen counts in the following rainy period. However, in more recent drought cycle, such as the one started in 2004, the recovery of the Pollen Index was less marked, even though annual rainfall was close to the local mean. These findings are in part attributable to rainfall distribution over the year. In the last eight years of the series, over 50% of total annual rainfall was recorded prior to the start of flowering; in 2004, this figure rose to 65%. This led, in some years, to an extremely dry flowering season: thereafter, once individuals coming into flower at the start of the season completed their reproductive cycle, there was no renewal in the community with new individuals growing after rain, due to the scarce water availability, essential for the cycle of herbal species. This might be evidence of a reduction in the number of individuals per community, but may also be indicative of pollen economy (Izco et al., 2004; Fernandez Martinez et al., 2012).

The direction of the winds prevalent in the area has been considered to analyse the possible arrival of pollen from other potential source areas. According to data of AEMET, in Cordoba, the 66% of annual winds blow from S to SW direction, i.e. flowing along the Guadalquivir Valley, in the intra-mountainous corridor of the Sierras Béticas. This situation could favour the transport of Amaranthaceae pollen from other parts of the mainland, i.e. salt marshes in the Mediterranean, Atlantic coast, in which are found some of the highest pollen levels of the Iberian Peninsula (Fernandez-Illescas et al., 2008, 2010), and even from more remote areas, transported with dust clouds from North African origin (Cariñanos et al., 2004b).

In addition to the decline in pollen counts prompted by changes in the rainfall pattern, there was a considerable drop in counts from 2001 onwards. As indicated earlier, the sampled area has undergone intense urbanisation over the last few years, and the construction of a nearby motorway also affected the environment in the vicinity of the sampler. Some reports on the evolution of land use experienced in Cordoba in the last 50 years point to a loss of 4% of forest and natural areas, and, on the other hand, an increase of 400% of the land dedicated to built-up areas and infrastructure, much of it in the metropolitan area of the capital. In this area, many of the traditional plots of agricultural irrigation were urbanized to conform the current urban map (Bermejo-Pérez et al., 2011; Torres-Márquez, 2006). This would have an effect not only in the increasing distance between the area source and the sampler, but also on the mechanism necessary to transport the pollen, mainly wind speed and direction (Jones and Harrison, 2004). The management of local ruderal communities has also been exacerbated by occasional cleaning and mowing activities intended as a preventive measure against forest fires. These activities, carried out in early summer, when most herb species are starting to wither, might account for the bringing forward of pollen peak dates to May and June, as well as for the low value of peaks, since flowering had not yet reached its peak. Human intervention, though altering the normal progress of the flowering season, does not appear to alter the development of new individuals due to spontaneous regeneration (Deák et al., 2013) or pollen production by the rest. In 2005, late summer rainfall prompted a second peak of similar intensity to that detected in June, and an annual Pollen Index considerably higher than that of earlier years, despite greater drought intensity. During this year, 63.3% of the total 314.4 mm of annual precipitation were recorded over the first 9 months, while 115 mm were recorded in torrential precipitations in a single fortnight in October. In comparative terms, the decline detected in Amaranthaceae pollen counts was less marked than that observed in counts for other species sharing the same ecological niche: grasses, *Rumex*, *Plantago*, *Echium*, Brassicaceae (Alcázar et al., 2002, 2009; Cariñanos et al., 2000b), and even *Artemisia*, some of whose species are characteristic of most arid areas (Cariñanos et al., 2000a; Munuera, 1999; Stach et al., 2007). The majority of species, with the exception of certain summer-flowering grasses or some disturbance-tolerating species (Buckland et al., 2001), do not display any recovery of pollen levels after cleaning and mowing activities; most start to wither due to the high local summer temperatures (often over 40 °C). Similar situations have been observed in other biogeographical areas. In Switzerland very low pollen levels for grasses, normal levels for *Urtica*, *Rumex* and *Plantago* and very high levels for *Chenopodium* (Gehrig, 2006) were recorded after a record-breaking heat wave. In the case of *Ambrosia*, an invasive plant causing allergies in North America and numerous countries in Continental Europe, a considerable decrease has been also detected after an extreme heat wave and drought (Penel and Sanjuan, 2004). In desert areas of China, the increase in the number of species of *Chenopodium* is used as an indicator of progressive aridification in the region (Li et al., 2005). In brittle lands, Amaranthaceae species are more prevalent because soils may not have enough total moisture to support woody cover (Savory, 1999). It is therefore evident that the Amaranthaceae family is better placed to resist high temperatures and drought than other herb species.

There is a growing body of evidence that the vegetational response to changeable climate conditions may be rapid (Peetet, 2000). Some of the latest model-based forecast of the future impact of climate change suggests a change in the mediterraneo–eurosiberian climatic border of the Iberian Peninsula. This would involve a major change in bioclimatic belts, with major expansion of thermomediterranean belt on the Southwest Peninsula (Fernández-González et al., 2005; Felicisimo, 2011), and an extension of the arid ombrotype by the Valley of the Guadalquivir, a result of the aridization of the climate (Moreno, 2005). This situation is likely to prompt a redistribution of existing vegetation, with a progressive reduction of the potential species richness (Felicisimo, 2011; Garcia-Mozo et al., 2010; Martínez-Villalta et al., 2002; Ogaya et al., 2003; Peñuelas and Boada, 2003) and to increased inter-specific competition (Turngate et al., 2007). In general, climate conditions are expected to be more favourable for xerophytic annual and opportunistic species benefiting from agile dispersal mechanisms and efficient transpiration systems (Fernández-González et al., 2005), characteristics found in a number of species belonging to the Amaranthaceae family. The already invasive behaviour of some of the species of the family in the area (*A. albus*, *A. blitoides*, *A. hybridus*, *A. muricatus*) positions them advantageously to continue increasing its future presence area. A recent study in Central Europe that has evaluated the risk potential and expansion potential due to climate change of 8 taxa concludes that the Chenopodiaceae will not just survive, but also some species spread out in the landscape (Deák et al., 2013).

Other studies have recently suggested that wind-pollinated plant species may have an advantage in terms of being able to increase pollen production associated with CO_2 concentrations (Rogers et al., 2006; Weber, 2002; Ziska and Caufield, 2000). Virtually all Amaranthaceae are wind-pollinated, and although they produce less pollen than other anemophilous species (Piotrowska, 2008), they display a longer flowering period, which may last from June to October (Trigo et al., 2008). Amaranthaceae pollen is therefore involved in pollen allergies, and may cause symptoms in sensitive people even at low concentrations (Galán et al., 1989; Guerra et al., 1990; Pola et al., 2009). It may also significantly explain the temporal variation of allergy symptoms, being the first environmental variable that enters in the stepwise multiple regression models for the rhinitis alone or rhinitis/headache and eye irritation symptoms in some areas (Robertson and Lebowitz, 1984). Traditionally, *Salsola kali* and *Chenopodium album* have been noted as the two main Amaranthaceae species related with clinical symptoms of allergy, highlighting in the first three major allergens (Sal k 1, Sal k 4 and Sal k 5), and other three in the second (Che a 1, Che a 2 and Che a 3) (Assarehzadegan et al., 2010; Barderas et al., 2002, 2004; Ferrer et al., 2010; Sousa et al., 2011). However, recent studies suggest that up to 11 different species of this family may induce allergic sensitization, recommending its use in diagnoses and treatments (Ferrer et al., 2012; Würtzen et al., 1995). Other aspect to consider is the impact that the level of urbanisation of the area may have on the structure, protein profile and allergens of *Chenopodium* pollen grains, causing an increase in its allergenicity (Ferrer et al., 2012; Sousa et al., 2011). This could lead to the increase of allergenic potential of the pollen grains, though the Pollen Index decreases as the urbanisation in the area of the city extends, driving down the minimum concentration threshold necessary for the development of allergy symptoms. This is also of importance at time to adapt the panel of pollen extracts for human environmental exposure (Bosh-Cano et al., 2011).

It must also be taken into consideration the possibility of establishing cross-reactivity between Amaranthaceae pollen and other allergens. Some of the major allergens of the species mentioned above are relevant panallergens that display cross-reactivity with some *Olea* allergens (Barderas et al., 2004; Florido et al., 2000; Salamanca et al., 2010). Due to the area of study is one of the world's largest surface areas of olive groves, being olive pollen the major local cause of allergy (Dominguez et al., 1993; Galán et al., 2001), an increase in the poly-sensitizations to this pollen type is expected. This could be mainly conditioned by the new agronomic techniques for the maintenance of ground cover in olive and the incorporation of irrigation (Ouhmad-Sbitri and Serafini, 2007). Other authors have revealed in their studies the existence of a glycoprotein in *C. album* pollen wall of similar molecular weight of Che a 1, which is recognized by polyclonal antibody against maize pollen profiling ZmPR3 (Sousa et al., 2011). This indicates the presence of cross-reactivity with grasses, responsible for a high percentage of pollinosis worldwide (D'Amato and Cecchi, 2008), and one of the main pollen types with the greatest impact on the effects of climate change on allergic asthma (Cecchi et al., 2010). Given this situation, it could be expected that the Amaranthaceae pollen will increase its role in allergic response of the population in future environmental scenarios, and get to position itself as one of the primary causes of pollen sensitization not only in the Mediterranean areas, as has happened in some Iberian locations (Pola et al., 2009).

5. Conclusions

The results suggest that a progressive change in the environmental conditions, with alterations in the annual rainfall distribution pattern and a gradual rise in temperatures across southern Iberian Peninsula, may lead to an increase in species and individuals belonging to the Amaranthaceae family. This would be due to their high degree of adaptability to conditions considered adverse for other species, and to their rapid response to scarce water availability. An increased presence of Amaranthaceae is also likely to have a greater impact on future scenarios for pollen allergy diseases associated with climate change.

Acknowledgements

The authors thank University of Granada Own Program through Project PP2012-PI05, and Innovation, Development and Enterprise Council of Regional Government Junta de Andalucia for financial support through Project P10-RNM-5958.

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