



Pollen calendars of Cartagena, Lorca, and Murcia (Region of Murcia), southeastern Iberian Peninsula: 2010–2017

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Abstract Pollen allergens are one of the most important causes of respiratory allergies in industrialized countries. Aerobiological studies, including pollen and spore concentrations, allow for the defining of different palynomorph concentrations throughout the year. Pollen calendars summarize the aerobiological information of a locality in a single figure. They report which types of pollen are present at each time of the year and highlight the relative importance of some with respect to others. In this paper, the pollen calendar of three cities in the Region of Murcia, Cartagena, Lorca, and Murcia, is presented for the period 2010–2017. Sixty-three pollen types were identified in the bioaerosol of the Region of Murcia.

Fourteen pollen types make up the pollen calendar of Cartagena, while 15 form those of both Lorca and Murcia. The spore types *Cladosporium cladosporioides*, *Cladosporium herbarum*, and *Alternaria*, have been included in the same format. The results show important qualitative and quantitative differences among the three cities. Lorca presents an aerobiological profile related to agricultural activities, while Murcia shows higher influence from anemophilous species coming from gardens and parks, and finally, given its proximity to the sea, Cartagena registers lower levels in most pollen types. The intensity of some of the pollen taxon and fungal types requires a deeper study of their responsibility for allergies in the area.

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1 Introduction

In temperate climate regions, where seasons are clearly defined, vegetation synchronizes its development following meteorological seasonal changes (Frenguelli et al. 2002). The phenology of plants growing in these climates depends mainly on temperature, water availability, and photoperiod (Wielgolaski 2001). Changes in these variables influence the intensity and length of phenophases in different years.

Aerobiological observations based on pollen and spore concentration in the air provide knowledge about the concentration of palynomorphs in the air throughout the year. These aerobiological data are considered to be reliable phenological indicators for species with anemophilous pollination (García-Mozo 2011).

Many factors influence shifts in the aerobiological concentrations from year to year. Among the most important factors we find meteorological variability, land use modification, or the introduction of ornamental species into gardens and parks (Cristofori et al. 2010; Singh et al. 2017). Furthermore, climate and vegetation characteristics produce spatial variations in relatively close sampling stations (Martínez-Bracero et al. 2015). The three cities under study have very different geographical features. Cartagena is a coastal city surrounded by a range of mountains, and the growth of the city has been influenced by the presence of industrial and mining facilities. Murcia is the capital city of the Region with the highest population. Developed along the Segura River Valley, it has fully occupied the area, displacing the traditional agriculture fields. Meanwhile, Lorca has the second largest municipal area in Spain, with agricultural activity as its main economic activity.

A pollen calendar is a graphic representation that synthesizes the annual dynamic of the main pollen types in a location, ordered according to their flowering periods. These graphs summarize all the aerobiological information of a certain location in a single picture, which helps make the pollen composition in the atmosphere easier to understand, depicts the pollen types of interest in each moment of the year, and highlights the relative importance among pollen types. A short series of 3–5 years permits a first approach to the aerobiological dynamics of an area (Myszkowska et al. 2011), while longer temporal series allow a better identification of the periods in which different pollen types are present, and the calculation of any tendencies or variations due to climatic or anthropogenic changes (Votolini et al. 2000). Rodríguez-Rajo et al. (2004) pointed out that 7 years is the minimum time required to obtain a representative estimation of pollen concentration in the atmosphere of an area.

Pollen grains in the atmosphere are one of the main causes of respiratory allergies in Europe (Kruczek et al. 2017). For more than 50 years, a continuous increase in the prevalence of allergic diseases has been observed in the industrialized world (World Allergy

Organization (WAO) 2013). According to data from the European Academy of Allergy and Clinical Immunology, 30% of the European population suffers one type of chronic allergy, and this is expected to rise to more than 50% of the European population by 2025, regardless of age, social group, or geographical area (European Academy of Allergy and Clinical Immunology (EAACI) 2016)).

The multicenter report Alergológica 2015 (SEAIC 2017) shows that in Spain, in 70.8% of patients suffering from rhinoconjunctivitis, at least one triggering agent is pollen allergens, while in the Region of Murcia, this number is 74.3%. It is also found that 42.2% of allergic patients in Spain are only sensitized to pollen allergens. With respect to allergic asthma, pollen allergens are responsible for 65.6% of the cases, a value that has increased by 50% since 2005. According to this report, the most prevalent pollen types in relation to rhinoconjunctivitis and allergic asthma are Poaceae, *Olea*, Cupressaceae, Amaranthaceae (*Salsola*), *Platanus*, *Plantago*, *Parietaria*, and *Artemisia*. Aerobiological surveillance in the atmosphere is a valuable tool for the prevention, diagnosis, and treatment of allergic diseases (Thibaudon et al. 2013).

Aerobiological studies in the Region of Murcia started back in 1990 in the city of Cartagena, due to several epidemic outbreaks of asthma which occurred in the city in 1987 and 1988 (Moreno-Grau and Montes Cepeda 2015). In 2009, the Murcia Aerobiological Network was established (REAREMUR), with the installation of samplers in Murcia, and subsequently, in Lorca. Pollen concentrations have been available for the 3 cities since 2010. The objective of this paper is to present the pollen calendar of Cartagena, Lorca, and Murcia from 2010 to 2017. An analysis of the analogies and differences has also been carried out, qualitatively, through pollen types, and quantitatively, through the intensity of pollination and date.

2 Materials and methods

2.1 Study area

The Region of Murcia is located in the southeastern part of the Iberian Peninsula, enclosed between parallels 37°20'20" and 38°45'15"N and meridians



Fig. 1 Location of the Region of Murcia and the three cities under study in the Iberian Peninsula

0°42'2" and 2°20'0"W, with a total surface area of 11,317 km², of which 23% is less than 200 m above sea level (asl), 44.7% between 200 and 600 m asl and 32.2% over 600 m asl. Figure 1 shows the location of the Region of Murcia and the three cities under study in the Iberian Peninsula.

The climate of the Region of Murcia is typically Mediterranean, with warm summers and mild winters. The dry season is summer (Alonso Sarriá 2007). The climate of the 3 cities under study, Cartagena, Lorca, and Murcia, is defined as a local steppe. The biogeographic characteristics of the area are shown in Table 1.

In the Region of Murcia, 5 bioclimatic belts can be found: littoral (infra-Mediterranean), sub-littoral (thermo-Mediterranean), plateau (meso-Mediterranean), mountain (supra-Mediterranean), and high mountain (oro-Mediterranean) (Alcaraz Ariza 2007).

The infra-Mediterranean belt is found in a narrow band close to the coast. These areas are semi-deserts free of winter frosts and mild summers, due to the humid winds coming from the Mediterranean. Among

the plants present in this belt are *Periploca angustifolia*, *Stipa tenacissima*, and *Thymus* spp.

The thermo-Mediterranean belt is widespread in the southern third of the Region. In this belt, winter frosts rarely occur. For this reason, thermophile species are present: *Chamaerops humilis*, *Pistacia lentiscus*, or *Asparagus albus*, *A. horridus*. In the mountains of Cartagena, endemic Iberian-African species such as *Tetraclinis articulata* and *Zizipus lotus* are present. The most frequent conifer is *Pinus halepensis*, which has been favored by human activities. Agricultural and urban land usage has displaced the natural vegetation, but tussock grass and thyme still prevail in less degraded areas.

The meso-Mediterranean belt is the most common in the Region, ranging from 400–600 m asl to 1000–1300 m asl, where colder temperatures limit the growth of thermophile species. It is characterized by an open forest of Aleppo-pines and undergrowth of kermes oak (*Quercus coccifera*) and mastic or tussock grass. In more humid areas, the presence of holm oaks (*Quercus rotundifolia*) is possible.

Table 1 Biogeographic characteristics of the cities under study

City	Geographical coordinates	Average temperature (°C)	January average temperature (°C)	August average temperature (°C)	Annual temperature range	Rainfall (mm)	Climate ^a	Mediterranean bioclimatic belt
Cartagena	37°36'00"N 00°59'00"W	18.2	11.0	26.0	15.0	296	BSh	Infra-Mediterranean Thermo-Mediterranean
Lorca	37°40'00"N 01°42'00"W	16.7	9.2	25.3	16.1	313	BSk	Thermo-Mediterranean
Murcia	37°59'00"N 01°07'00"W	18.1	10.3	26.3	16.0	293	BSh	Thermo-Mediterranean

^aKöppen-Geiger climatic classification (Kriticos et al. 2012). BSk dry, steppe, cold. BSh dry, steppe, warm

The supra-Mediterranean belt, from 1300 to 1700 m asl, has low-temperature winters. The presence of holm oaks is frequent, and the dominant perennial species are *Pinus nigra subsp. mauretanica* and *Juniperus thurifera*, and *Acer granatens* or *Quercus faginea* among deciduous.

The oro-Mediterranean belt is found over 1700 asl, a height reached only by a few summits of the northwestern mountains. These are abrupt, rocky areas with strong prevailing winds and open vegetation forests of *Pinus nigra subsp. mauretanica*, and pastureland undergrowth.

2.1.1 Cartagena

Cartagena is the capital of the region called “Campo de Cartagena,” with an estimated population of 400,000 inhabitants and a surface of 1850 km². The municipality of Cartagena has a surface area of 558.3 km² (Comunidad Autónoma de la Región de Murcia 2012) and a population of 215,134 inhabitants in 2016 (Ayuntamiento de Cartagena 2018). The city is located at sea level.

2.1.2 Lorca

Lorca is the capital of the region called “Alto Guadalentín,” with an estimated population of 142,000 inhabitants and a surface area of 2071.8 km². The municipality of Lorca has a surface area of 1675.3 km² and a population of 91,730 inhabitants in 2016. It is located at 353 m asl (Ayuntamiento de Lorca 2016; Centro Regional de Estadística de Murcia 2018a).

2.1.3 Murcia

Murcia is the capital of the Region of Murcia, and its metropolitan area has a surface area of 1183.4 km² and an estimated population of 619,000 inhabitants. The municipality of Murcia has a surface area of 886 km² and a population of 441,003 inhabitants in 2016. It is located at 43 m asl (Centro Regional de Estadística de Murcia 2018b).

2.2 Sampling

Aerobiological data were obtained from the Region of Murcia Aerobiological Network (REAREMUR), by means of three Hirst-type volumetric samplers (Hirst 1952) with a suction volume of 10 L/min, located in the cities of Cartagena (railway station, 37°36'N 0°58'W); Lorca (Rafael Méndez Hospital, 37°38'N 1°44'W); and Murcia (Reina Sofía Hospital, 37°59'N 1°7'W). The distance between Cartagena and Murcia is 43 km, between Cartagena and Lorca is 62 km, and between Lorca and Murcia is 61 km.

The device has a drum which rotates at 2 mm/h over cellophane tape coated with a silicone-based adhesive, on to which particles ranging between 1 and 100 µm adhere (Galán et al. 2007). This tape was sliced into 48-mm sections in the laboratory, each section corresponding to the 24 h of each day of weekly sampling. Subsequently, each daily fraction was mounted with glycerogelatin on slides for observation under a microscope. Aerobiological monitoring was conducted following the methodology approved by the Spanish Aerobiology Network (Galán et al. 2007).

2.3 Data treatment

ISO 8601 regulation (AENOR 1988) was followed to define weekly periods, and the average weekly pollen concentrations of major pollen types were calculated from 2010 to 2017. Major pollen types (MPT) are defined as those whose annual pollen integral (Galán et al. 2017) (the total accumulated for that pollen type in a year, API_n) is equal or superior to 100 grains/m³. The same procedure was carried out with the spore types studied in the three cities: *Alternaria*, *Cladosporium herbarum*, and *C. cladosporioides*. The complex heterogeneous *Cladosporium herbarum* and *Cladosporium cladosporioides* comprise several genetically and morphologically distinguished species (Bensch et al. 2012). The *Cladosporium herbarum* and *C. cladosporioides* spore types have been differentiated as indicated in Mediavilla-Molina et al. (1998), Schubert et al. (2007), and Bensch et al. (2010).

The days belonging to week 53 have been added to week 52 or week 1, depending on the year they belong to. Then, 52-weekly average values are obtained and categorized into 10 arbitrary classes, similar to those found in other pollen calendars (Boi and Llorens 2013; Martínez-Bracero et al. 2015; Bicaçci et al. 2017): 0 (< 1); 1 (1 ≤ 3); 2 (3 ≤ 6); 3 (6 ≤ 12); 4 (12 ≤ 24); 5 (24 ≤ 48); 6 (48 ≤ 96); 7 (96 ≤ 192); 8 (192 ≤ 384); 9 (> 384) (Fig. 1).

3 Results

In the Region of Murcia, 63 different pollen types have been identified (52 in Cartagena, 59 in Lorca and Murcia) together with 88 different fungal types (determined by non-viable methods).

Table 2 depicts the MPT (API_n ≥ 100 grains/m³) and API_n of total pollen concentrations for (a) Cartagena, (b) Lorca, and (c) Murcia, as well as the API_n minimum and maximum for each MPT and total concentrations, and the years in which they occurred. The MPT found in the cities under study represents the following percentages from the total pollen concentrations: 14 MPT in Cartagena 95.1% (range 94.0–96.3%), 15 MPT in Lorca 95.7% (range 94.9–96.4%), and 15 MPT in Murcia 96.5% (range 95.8–96.9%). From the API_n of total pollen concentrations, the percentage of arboreal types that belong to

the MPT represents 55.5% in Cartagena (range 52.6–60.6%), 62.2% in Lorca (range 54.1–70.5%), and 56.8% in Murcia (range 50.0–60.9%).

Figure 2 depicts the API_n of total pollen for each city and year. The arboreal species of the MPT are shown in blue, and the herbaceous species are shown in red. The input due to non-MPT, both arboreal and herbaceous, that is not represented in the pollen calendar is shown in green.

Figure 3 shows the MPT pollen calendar of Cartagena, Lorca, and Murcia from 2010 to 2017. The weeks, months, and meteorological seasons are depicted in the abscissa. The scale used in the figure is explained in Fig. 4.

Table 3 includes the values of the annual spore integral (ASIn) of fungal types *Cladosporium herbarum*; *Cladosporium cladosporioides*; and *Alternaria*, for the three cities, along with the maximum and minimum of the ASIn and the years in which they occurred. Figure 5 shows the spore calendar for these three spore types in Cartagena, Lorca, and Murcia.

Table 4 depicts Pearson's correlation coefficients with a confidence interval of 95% between the API_n of each MPT and year, among the three cities. Table 5 shows the same results with the ASIn and year.

4 Discussion

4.1 Pollen

From the 63 pollen types identified in the three cities under study, 14 have been classified as MPT in Cartagena and 15 in Lorca and Murcia.

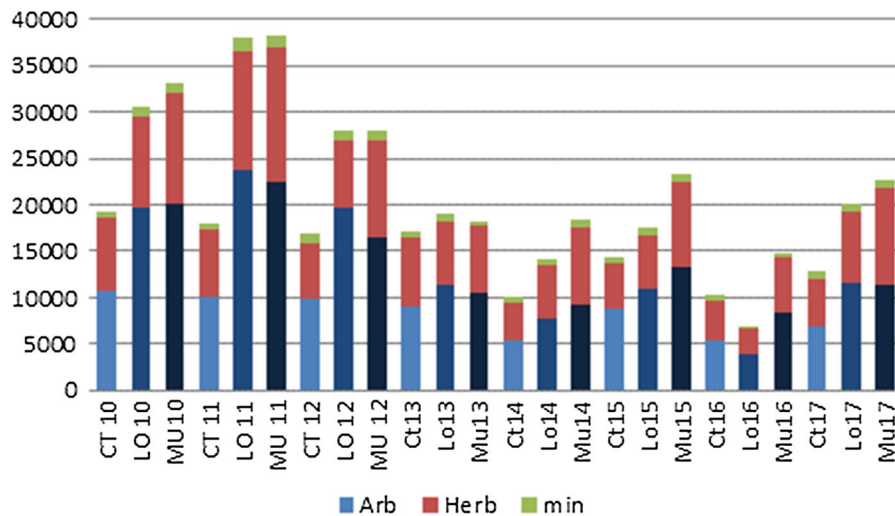
Rumex is only an MPT in Cartagena, Myrtaceae (*Eucalyptus*) in Lorca, *Casuarina* in Murcia, and *Brassicaceae* in both Lorca and Murcia. In total, 14 MPT are present in all three cities. Less than 6% of total pollen concentrations are among the minor pollen types which represent a total of 45 pollen types. In all three cities, for all the years studied, the percentage of arboreal pollen types is higher than herbaceous. In general, the minimum API_ns are found in the second half of the study period. Exceptions are *Morus* (2010) and *Artemisia* (2013), in Cartagena and *Amaranthaceae*, *Pinus*, *Quercus*, *Artemisia*, and *Zygophyllum* (2013) and *Palmae* (2010), in Murcia. However, the maximum API_n occurs in the first half of the study period, with the exception of *Artemisia*, *Zygophyllum*,

Table 2 2010–2017 average annual pollen integral (API_n, pollen grains/m³ and year) in Cartagena, Lorca, and Murcia for MPT and total pollen. API_n minimum and maximum, and the years in which they occurred

Pollen type	Average API _n 2010–2017	API _n minimum	Year API _n minimum	API _n maximum	Year API _n maximum
Cartagena					
Amaranthaceae	2744	1857	2017	3719	2010
Cupressaceae	2365	1291	2016	4456	2011
<i>Olea</i>	2256	999	2014	3853	2010
Urticaceae	1484	924	2016	2425	2011
<i>Quercus</i>	1390	784	2011	2477	2012
<i>Pinus</i>	917	379	2017	1706	2010
<i>Platanus</i>	907	443	2017	1675	2013
Poaceae	709	404	2014	1492	2013
<i>Artemisia</i>	380	261	2013	514	2017
Palmae	317	210	2014	495	2011
<i>Zygophyllum</i>	304	169	2014	496	2017
<i>Plantago</i>	178	70	2014	384	2010
<i>Morus</i>	124	50	2010	257	2017
<i>Rumex</i>	103	34	2014	173	2010
Total	14,904	10,140	2014	19,302	2010
Lorca					
<i>Olea</i>	5014	953	2016	8669	2010
Cupressaceae	4188	1475	2016	9450	2011
Amaranthaceae	2498	742	2016	3641	2017
<i>Artemisia</i>	2094	491	2015	5762	2011
<i>Quercus</i>	1922	339	2016	4019	2012
<i>Pinus</i>	1594	634	2017	3721	2011
Poaceae	1235	252	2016	2321	2013
Urticaceae	816	347	2016	1533	2011
<i>Platanus</i>	442	93	2013	969	2011
<i>Zygophyllum</i>	340	85	2016	525	2012
<i>Plantago</i>	216	32	2016	383	2010
<i>Morus</i>	194	64	2016	690	2011
Myrtaceae	125	32	2016	211	2011
Brassicaceae	114	48	2016	215	2017
Palmae	102	47	2016	145	2017
Total	21,830	6975	2016	37,998	2011
Murcia					
Cupressaceae	5066	2287	2016	9694	2011
<i>Casuarina</i>	4471	2239	2016	6498	2011
<i>Olea</i>	2301	1410	2016	3324	2011
<i>Platanus</i>	2161	823	2014	3313	2011
Amaranthaceae	1846	978	2013	2756	2011
<i>Pinus</i>	1554	590	2013	3592	2010
Urticaceae	1549	1047	2014	2597	2011
<i>Quercus</i>	1521	526	2013	2351	2014
Palmae	882	635	2010	1265	2012
Poaceae	804	646	2016	1012	2013

Table 2 continued

Pollen type	Average APIn 2010–2017	APIn minimum	Year APIn minimum	APIn maximum	Year APIn maximum
<i>Artemisia</i>	557	265	2013	1237	2011
<i>Morus</i>	484	145	2014	938	2011
<i>Zygophyllum</i>	301	127	2013	418	2012
<i>Plantago</i>	135	57	2016	244	2010
Brassicaceae	111	51	2016	216	2015
Total	24,598	14,795	2016	38,232	2011

**Fig. 2** Annual pollen integral values (APIn) for total pollen from 2010 to 2017 in REAREMUR cities. In blue MPT arboreal APIn, in red MPT herbaceous APIn, and in green, the sum of the rest of non-MPT APIn

and *Morus* (2017) in Cartagena, Amaranthaceae, Brassicaceae, and Palmae (2017) in Lorca, and *Quercus* (2014), and Brassicaceae (2015) in Murcia.

4.1.1 Urticaceae

In the Región of Murcia, Urticaceae pollen takes the fourth place for sensitizations in allergy patients (Elvira-Rendueles et al. 2017). It is found in the air from midfall to the first weeks of summer, when the air temperature is high and rain is scarce (Galán et al. 2000). The lowest concentrations are found in Lorca, while the concentrations in Cartagena and Murcia are around the same level.

When compared to other pollen calendars in Spain, Urticaceae pollen is present in the air in Guadalajara

from February until July, but never during autumn or early winter (Rojo et al. 2016). In Catalonia, it is found all year round in Barcelona, Gerona, Lerida, and Tarragona, while in Viella, in the Pyrenees mountain range, it disappears from November until the beginning of February (Belmonte et al. 2017). In Huelva (Andalusia), it shows similar behavior to that in the Region of Murcia. However, in Cadiz, Cordoba, Jaen, Malaga, and Sevilla it vanishes from the air earlier. In Almeria and Granada, it is present during the summer, with the exception of a few weeks (Martínez-Bracero et al. 2015). In other Mediterranean cities such as Trento in Italy, it is present in the air from the end of March to the end of December, with high pollen concentrations during the summer. In Thessaloniki, Greece, it is also

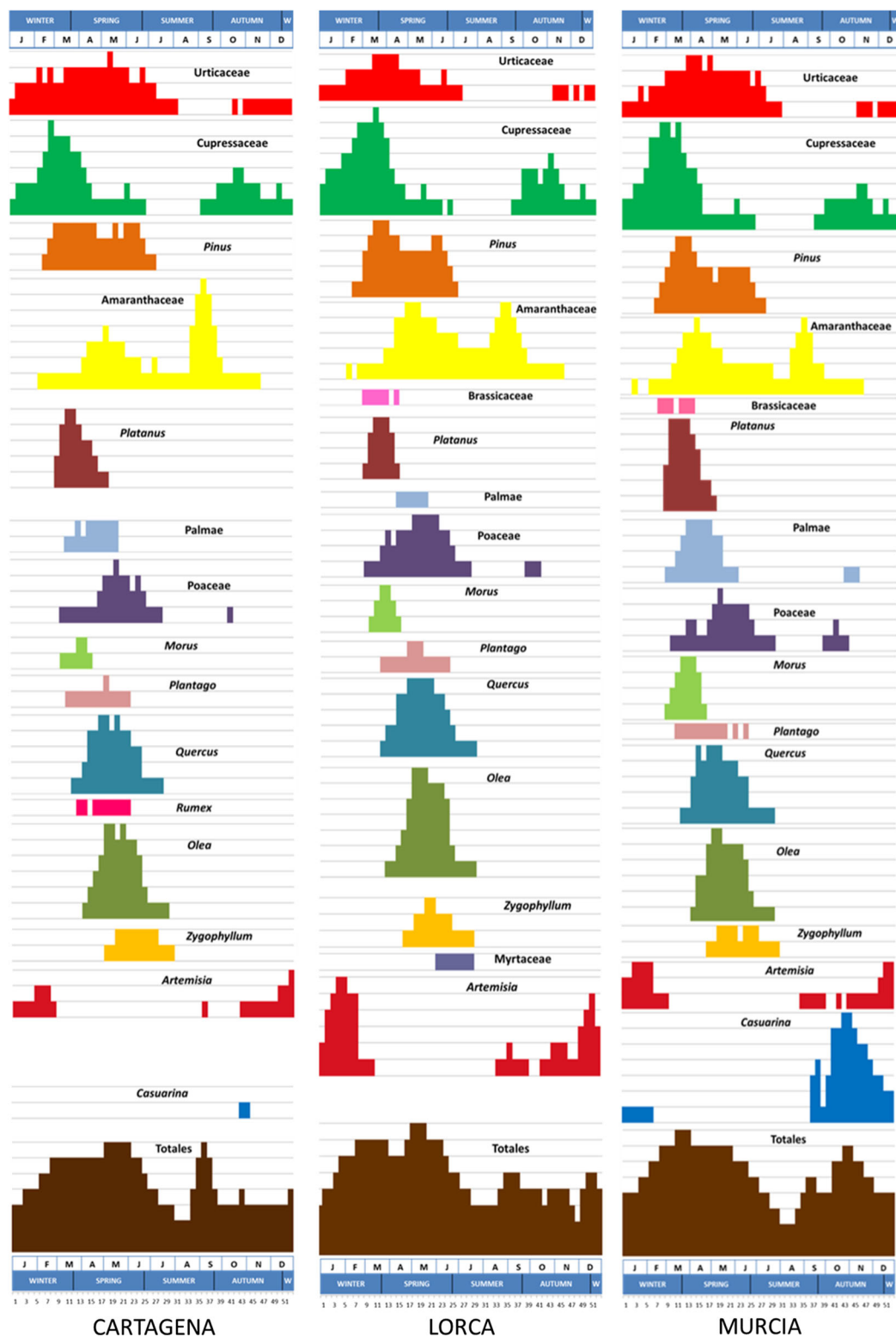


Fig. 3 Pollen calendar of Cartagena, Lorca, and Murcia, 2010–2017

present during the summer, but with low pollen concentrations (Gioulekas et al. 2004).

4.1.2 Cupressaceae

Quantitatively, Cupressaceae is the most important pollen type in Murcia and the second most important in both Cartagena and Lorca. It is present in the air throughout the year, except for most of the summer. In all three cities, it shows an important peak in winter, an upturn in spring, and again a new peak in autumn, with Lorca exhibiting the highest peak. In all three cities, a slight upturn can be seen at the beginning of winter. The presence of different Cupressaceae species with different flowering periods explains these findings: *Cupressus sepervirens* L. and *Thuya orientalis* L. in winter, *Juniperus communis* in spring, *Juniperus oxycedrus* L., and *Juniperus phoenicea* L. and *Cupressus arizonica* in autumn (Boi and Llorens 2013). Special interest is given to *Tetraclinis articulata* (Vahl) Mast., an endemic plant of the Sierra of Cartagena (Ministerio de Medio Ambiente y Medio Rural y Marino 2011), which also flowers in autumn and is widely used as an ornamental plant in parks and gardens (Sánchez Martínez et al. 2008).

In Palma de Mallorca (Boi and Llorens 2013), Almería, Cádiz, Córdoba, Granada, Jaén, and Málaga (Martínez-Bracero et al. 2015), the behavior of airborne Cupressaceae pollen is similar to that in the Region of Murcia. However, in Huelva, Sevilla (Martínez-Bracero et al. 2015), Barcelona, Lérida, Tarragona (Belmonte et al. 2017), Toledo (Perez-Badia et al. 2010), and Guadalajara (Rojo et al. 2016), the autumn peak is not observed. On the Mediterranean side of France, this

pollen type shows the highest risk of provoking allergy, where it is present in the air from the middle of January to the end of June (Thibaudon et al. 2013). In other parts of the Mediterranean, such as in El-Hadjar, Algeria (Necib and Boughediri 2016), and in Thessaloniki, Greece (Gioulekas et al. 2004), the maximum intensity is found between February and March. However, in Trento, Italy (Cristofori et al. 2010), it is found later in March.

4.1.3 Pinus

In all three cities, *Pinus* pollen presents two distinct peaks during the year, the first one at the beginning of spring and the second at the end of spring. The levels in Lorca and Murcia are similar, but the second peak is more intense in Lorca. The concentrations found in Cartagena are much lower than those found in the other two cities.

In the Region of Murcia, four species of *Pinus* genera are described: the most common *Pinus halepensis* Mill., *P. nigra* subsp. *salzmanii* (Dunal) Franco, *P. pinaster*, and *P. pinea* (Sánchez Martínez et al. 2008). *P. halepensis* and *P. pinaster* are responsible for the first peak, while *P. pinea* and *P. nigra* are responsible for the second peak. In Almería, Córdoba, and Granada (Martínez-Bracero et al. 2015), Barcelona, Tarragona, Tortosa, Palma de Mallorca (De Linares et al. 2017), and Thessaloniki (Gioulekas et al. 2004), their behavior is similar.

4.1.4 Amaranthaceae

Amaranthaceae is the most abundant pollen type in Cartagena, the third most abundant in Lorca and the

Fig. 4 Pollen calendar scale ranges grains/m³

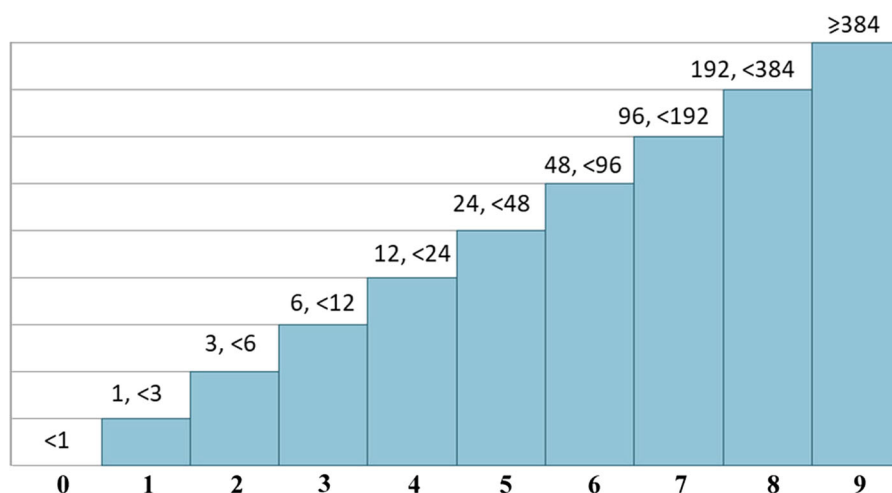
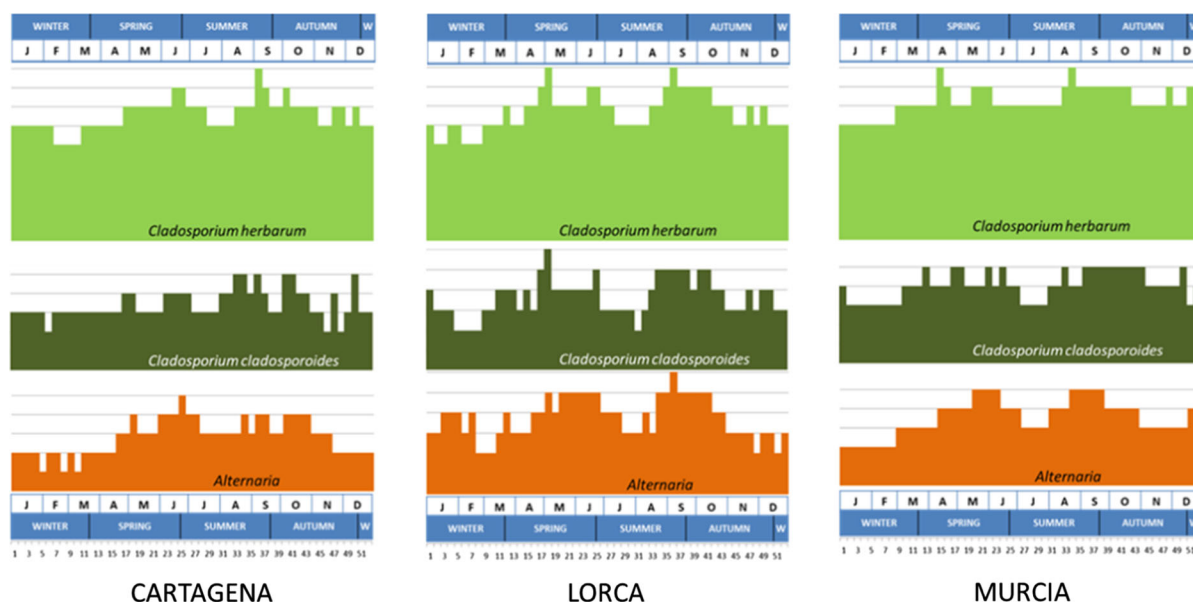


Table 3 2010–2017 average annual spore integral (ASIn, spore/m³ and year) for fungal types *Cladosporium herbarum*, *Cladosporium cladosporioides*, and *Alternaria* from Cartagena,

Lorca, and Murcia. ASIn minimum and maximum values and the years in which they occurred

Fungal type	Average APIIn 2010–2017	APIIn minimum	Year APIIn minimum	APIIn maximum	Year APIIn maximum
Cartagena					
<i>C. herbarum</i>	41,135	28,983	2012	53,640	2017
<i>C. cladosporioides</i>	4462	1933	2017	7545	2013
<i>Alternaria</i> sp.	3306	2091	2011	4264	2011
Lorca					
<i>C. herbarum</i>	46,154	23,307	2012	70,432	2017
<i>C. cladosporioides</i>	5895	1776	2016	10,757	2011
<i>Alternaria</i> sp.	5874	1405	2016	11,807	2011
Murcia					
<i>C. herbarum</i>	59,271	35,179	2013	81,586	2017
<i>C. cladosporioides</i>	7026	3334	2015	13,860	2011
<i>Alternaria</i> sp.	5238	2974	2016	8293	2011

**Fig. 5** *Cladosporium herbarum*, *Cladosporium cladosporioides*, and *Alternaria* calendars from Cartagena, Lorca, and Murcia, 2010–2017

fifth in Murcia. It is recognized as the second largest trigger for pollen allergy in the Region of Murcia (Elvira-Rendueles et al. 2017). It shows two clearly differentiated peaks, the first in spring and the second

at the end of summer and the beginning of autumn. In Lorca and Murcia, both peaks have similar intensity, although the first peak lasts longer. However, in Cartagena, the intensity of the first peak is lower than

Table 4 Correlation coefficients among every APIn pollen type in each city

Pollen type	APIn Ct-APIn Lo	APIn Ct-APIn Mu	APIn Lo-APIn Mu
<i>Amaranthaceae</i>	n.s.	n.s.	n.s.
<i>Palmae</i>	n.s.	n.s.	n.s.
<i>Platanus</i>	n.s.	n.s.	n.s.
<i>Zygophyllum</i>	n.s.	n.s.	n.s.
<i>Artemisia</i>	n.s.	n.s.	0.975**
<i>Morus</i>	n.s.	n.s.	0.747*
<i>Olea</i>	0.852**	n.s.	0.818*
<i>Pinus</i>	n.s.	0.907**	0.743*
<i>Quercus</i>	0.940**	0.760*	0.846**
<i>Poaceae</i>	0.854**	0.812*	0.907**
<i>Cupressaceae</i>	0.950**	0.953**	0.959**
<i>Urticaceae</i>	0.877**	0.851**	0.903**
<i>Plantago</i>	0.914**	0.933**	0.952**

n.s. $p \geq 0.05$; * $p < 0.05$; *** $p < 0.01$

Table 5 Correlation coefficients among every ASIn pollen type in each city

Spore type	ASIn Ct-ASIn Lo	ASIn Ct-ASIn Mu	ASIn Lo-ASIn Mu
<i>Cladosporium herbarum</i>	n.s.	n.s.	n.s.
<i>Cladosporium cladosporioides</i>	0.911**	0.716*	0.828*
<i>Alternaria</i>	0.850**	0.917**	0.850**

n.s. $p \geq 0.05$; ** $p < 0.05$; *** $p < 0.01$

in Lorca and Murcia, and the intensity of the second peak is much higher, the highest intensity peak in this city's calendar. In Guadalajara (Rojo et al. 2016), Toledo (Perez-Badia et al. 2010), Girona (Belmonte et al. 2017), Thessaloniki (Gioulekas et al. 2004), and Trento (Cristofori et al. 2010), only the second peak is present. In Huelva and Almería, both peaks are present. However, the second one shows more intensity (Fernández-Illescas et al. 2010; Martínez-Bracero et al. 2015). In Málaga and Sevilla, again both peaks are present, but the most intense is the first, while in Cádiz, after the first spring peak, slight upturns appear throughout summer and at the beginning of autumn (Martínez-Bracero et al. 2015).

4.1.5 Brassicaceae

Brassicaceae pollen is only present in the pollen calendar of Lorca and Murcia, and in very low levels at

the end of winter and the beginning of spring, with similar behavior to that shown for Toledo (Perez-Badia et al. 2010). In Barcelona, it is present throughout the year, except during the summer months. In Girona and Tarragona, it is not present from the middle of August until the end of September, and in Lerida, it is present from February to the end of November. Nevertheless, the concentrations are very low in all four cities (Belmonte et al. 2017). It is absent in the pollen calendars of Andalucía (Martínez-Bracero et al. 2015) and of Palma de Mallorca (Boi and Llorens 2013).

4.1.6 Platanus

Platanus pollen appears in the atmosphere of the Region of Murcia from late winter to the middle of spring. The presence of this pollen type is intense, but short (Alcázar et al. 2011). It shows asymmetry in

Cartagena and Murcia. The maximum intensity is found in Murcia and the minimum in Lorca. *Platanus* is an ornamental tree widely used in parks and gardens, and therefore, it is most abundant in urban areas (Alcázar et al. 2011). It is present in the pollen calendars of Córdoba, Granada, Huelva, Jaen, Sevilla (Martínez-Bracero et al. 2015), Barcelona, Gerona, Lerida, Tarragona (Belmonte et al. 2017), Palma de Mallorca (Boi and Llorens 2013), and Thessaloniki (Gioulekas et al. 2004). In those cities where it is present, it has been described as an allergenic pollen type (Asam et al. 2015; Varela et al. 1997).

4.1.7 *Palmae*

The highest atmospheric concentrations of *Palmae* pollen are recorded in Murcia, from the end of winter to the middle of spring. Some remnants are found in autumn. In Cartagena, the concentrations are lower than in Murcia and are absent in autumn. The lowest concentrations are found in Lorca, where it is only present in spring.

Palmae pollen is present in Almeria, Cadiz, and Huelva (Martínez-Bracero et al. 2015). In the calendar of El-Hadjar, the genus *Phoenix* is present with low pollen concentrations in December, January, and March, but moderate in June (Necib and Boughediri 2016). It is absent in Toledo (Perez-Badia et al. 2010), Guadalajara (Rojo et al. 2016), Palma de Mallorca (Boi and Llorens 2013), Trento (Cristofori et al. 2010), and Thessaloniki (Gioulekas et al. 2004).

Palms are ornamental plants that are widely used in Mediterranean cities. In Murcia, more than 30 palm species have been identified (Sánchez de Lorenzo-Cáceres 2010), with *Chamaerops humilis* L. being the only autochthonous species (Sánchez Martínez et al. 2008). It is a wild species in the littoral mountains. The great diversity of species causes the flowering period to extend practically all year long. Most of the species flower in spring, but *Phoenix canariensis* can extend this period until November (Díaz de la Guardia et al. 2008). Several palm genera have been described as allergenic, with *Phoenix* among them (Mandal et al. 2008; Serhane et al. 2017).

4.1.8 *Poaceae*

In the Region of Murcia, the *Poaceae* pollen type appears from the end of winter until the end of summer. Its maximum intensity is in spring, reducing its presence at the beginning of summer. It is absent

until autumn, when an upturn can be observed, reaching higher intensity in the city of Murcia. The most intense spring flowering is registered in Lorca, with similar intensity to the other two cities, but more extended in time.

In Lerida, there is a rise in concentration of *Poaceae* pollen at the end of summer and beginning of autumn (Belmonte et al. 2017). In Seville, it appears all year long, and the rise in concentration occurs in October. In Cordoba, it vanishes at the end of summer but reappears slightly in October. In Cádiz and Huelva, the pollen concentrations are low from the end of summer until the middle of autumn (Martínez-Bracero et al. 2015). In Palma de Mallorca, it is present throughout the year, except in December (Boi and Llorens 2013). The ample number of genera and species included in this family means that this pollen type is present throughout the year (Anero-Bartolomé et al. 2009).

Based on the report Alergologica 2015 (SEaic 2017), in Spain, this taxon is the most prevalent allergenic pollen, both in rhinoconjunctivitis and in asthma patients. In the Region of Murcia, it is in the third position after *Olea* and *Amaranthaceae* (Elvira-Rendueles et al. 2017).

4.1.9 *Morus*

Morus pollen is present in the air the last weeks of winter, with a short, less intense flowering period in Cartagena, and maximum intensity in Murcia, where it is present in the air for around 8 weeks. It must be pointed out that in the Region of Murcia, an active traditional silk industry existed in the past, and this plant was cultivated to feed the silkworms (González Marín 2001). Even though the industry has disappeared, the trees are still in existence as ornamental trees in gardens and parks. In Córdoba and Sevilla, this pollen type can be found (Martínez-Bracero et al. 2015). In Uşak, Turkey, there are two peaks in spring and summer. The appearance of the second peak, which is outside the flowering period, has reportedly been caused by the re-suspension of grains (Uğuz et al. 2018). Its allergenic potential has been noted in areas where it is present in the air (El-Qutob López 2016).

4.1.10 *Plantago*

Plantago is a perennial plant that blossoms in the spring in the Region of Murcia. Lorca shows the

highest pollen concentrations, and the lowest are in Murcia. In Barcelona, Gerona, Lerida, and Tarragona, it appears in the air for an extended period of time (Belmonte et al. 2017). It is present in the spring in Almeria, Cordoba, Huelva, Malaga, and Sevilla, but it is absent in Cadiz, Granada, and Jaen (Martínez-Bracero et al. 2015). In Toledo and Guadalajara, the flowering period extends to July, showing higher intensity than in the Region of Murcia (Perez-Badia et al. 2010; Rojo et al. 2016). In Thessaloniki, it is present from spring to the end of summer (Gioulekas et al. 2004). In Uşak, it is present from winter to the end of summer (Uğuz et al. 2018). It is one of the most relevant pollen types as a causal agent for pollen allergies and is the sixth most allergic pollen type for both rhinoconjunctivitis and asthma (SEAIC 2017).

4.1.11 *Quercus*

Quercus pollen is present in the Region of Murcia from spring until the beginning of summer. Its concentration range is similar in all three cities, but it is quantitatively more abundant in Lorca. *Quercus ilex* and *Q. coccifera* are plants that are widely distributed in the Iberian Peninsula, frequently in the Spanish Mediterranean forests. It is present in most of the calendars referenced above (Belmonte et al. 2017; Boi and Llorens 2013; Martínez-Bracero et al. 2015; Rodríguez-Rajo et al. 2004; Rojo et al. 2016). *Quercus* is not listed in the Alergológica 2015 report as an allergenic pollen in Spain (SEAIC 2017), but European COST Action ES0603 on the “Assessment of production, release, distribution and health impact of allergenic pollen in Europe (EUPOL)” includes it among the allergenic trees of Europe (Skjøth et al. 2013), with frequent poly-sensitization and cross-reactions (Puchalska et al. 2015; Valero Santiago and Cadahía García 2002).

4.1.12 *Rumex*

Rumex pollen is only significant in Cartagena during the spring and with low intensity. It is present in Toledo (Perez-Badia et al. 2010), Guadalajara (Rojo et al. 2016), Cádiz, Huelva, Málaga, and Sevilla (Martínez-Bracero et al. 2015). However, it is absent in Vigo (Rodríguez-Rajo et al. 2004), Palma de Mallorca (Boi and Llorens 2013), Tarragona, Barcelona, Lérida, Gerona (Belmonte et al. 2017), Almería,

Córdoba, Granada, and Jaén (Martínez-Bracero et al. 2015). It is not considered an important allergen (McInnes et al. 2017).

4.1.13 *Olea*

Olea pollen is the most abundant in Lorca and the third most abundant both in Cartagena and in Murcia. It is the most prevalent allergenic pollen in the Region of Murcia, affecting 74% of allergic patients (Elvira-Rendueles et al. 2017). In Spain, it is the second cause of pollen allergy with a clear growing tendency since 1992: Alergológica 1992 (27.0%), Alergológica 2005 (29.7%), and Alergológica 2015 (52.1%) (SEAIC 2017). It is among the 12 most allergenic pollen types in Europe. It is frequently found in its natural habitat, the Mediterranean countries, and is also abundant due to its economic interest. The highest pollen levels in Europe are found in the southeastern part of the Iberian Peninsula (Skjøth et al. 2013).

The highest airborne *Olea* pollen concentrations are found in Mallorca (Boi and Llorens 2013) and Jaén (Martínez-Bracero et al. 2015), followed by Granada, Córdoba, Sevilla, and Cádiz (Martínez-Bracero et al. 2015). In Almeria and Huelva (Martínez-Bracero et al. 2015), the levels are close to those of Lorca. In Malaga, it is absent (Martínez-Bracero et al. 2015). In Lerida and Tarragona, the levels are higher than in Barcelona and Gerona (Belmonte et al. 2017). In Toledo (Perez-Badia et al. 2010) and Guadalajara (Rojo et al. 2016), the maximum values are in the range of those found in Cartagena and Murcia. In Vigo (Rodríguez-Rajo et al. 2004), it shows low pollen concentrations, with a maximum below 50 grains/m³. It appears in the air between March and April, and July and August, depending on the location. Similar intensities to those of Cádiz are found in Thessaloniki (Gioulekas et al. 2004) and in the mountain range of Cordoba in Trento (Cristofori et al. 2010). It is absent in Uşak (Uğuz et al. 2018).

4.1.14 *Zygophyllum*

This pollen type was first identified in the air by Moreno-Grau et al. (1995), defined as an allergen by Belchí-Hernández et al. (1997, 1998), and its amphotrophic character was shown by Castells et al. (1999). It is present in all three cities from the middle of spring

to the middle of summer. The maximum intensity is in the city of Murcia.

4.1.15 Myrtaceae (*Eucalyptus*)

Airborne Myrtaceae pollen is only significant in the city of Lorca, from the end of spring to the beginning of summer. The extract from this pollen does not trigger an intense response in respiratory allergic patients (Gill et al. 2016). In Vigo (Rodríguez-Rajo et al. 2004), it is present in the calendar with a low concentration all year round, reaching its highest concentration in April. In Cadiz, Huelva, Málaga, and Sevilla (Martínez-Bracero et al. 2015), it is present with higher intensity than in Vigo. In Barcelona, Gerona, Lérida, and Tarragona (Belmonte et al. 2017), it is scarce, as well as in Lorca. In Uşak, *E. camaldulensis* is present with a very low concentration in May and June (Uğuz et al. 2018).

4.1.16 *Artemisia*

According to the report Alergológica 2015 (SEAIC 2017), *Artemisia* is a relevant allergic pollen type which occupies the eighth position in patients affected by rhinoconjunctivitis and the seventh for patients with asthma. It has shown a reduction in sensitization from previous reports, from 8% in 1992 and 6.8% in 2005, to 5% in 2015, in contrast with other pollen types mentioned previously. Waisel et al. (2004), reported that 4 or 5 grains/m³ are enough to trigger allergic symptoms. This pollen type is present in all the Region of Murcia, especially in the city of Lorca. It appears in the last month of summer, with a first peak at the beginning of winter and a second in midwinter, remaining in the air until the end of winter. The same behavior is found in Almeria (Martínez-Bracero et al. 2015). In Guadalajara, *Artemisia* pollen is present in the air in August and September (Rojo et al. 2016), while in Toledo (Perez-Badia et al. 2010) it has two periods, August and September, and November and December. In Uşak (Uğuz et al. 2018), it is present from June to December with low concentrations. It is also found in the pollen calendar of Trento (Cristofori et al. 2010) from August to November.

In the Region of Murcia, *Artemisia bearrelieri* Besser (Vallès-Xirau 1987) is endemic and blossoms during the winter. It is responsible for the presence of this pollen type in the air during January and February.

It is a taxon to consider for allergic patients with symptoms during those winter months.

4.1.17 *Casuarina*

As indicated above, *Casuarina* pollen is only significant in the city of Murcia, where it reaches high pollen concentrations. During its maximum period, it is the major pollen type in Murcia, where it is ornamentally used in parks and gardens. It is present from late summer to the beginning of winter, showing its maximum levels in autumn. It is a taxon that appears as allergenic in the literature (García et al. 1997). Its abundance at this time of the year makes this pollen type a possible etiology agent for sensitizations (de Weger et al. 2013). In Almeria, it shows similar behavior to that of Murcia, but in Huelva and Málaga it has lower intensity and a shorter time span (Martínez-Bracero et al. 2015). In El-Hadjar, it is present from August to February.

4.1.18 Total pollen

From the observation of the total pollen graphs, it can be concluded that in Cartagena there are two clearly defined peaks, the first in spring and the second at the end of summer, both reaching the same intensity. In Lorca, there is a first peak in winter and the second, which is the most intense peak, in spring, while in summer and autumn, a weak upturn in total pollen concentrations can be observed. In Murcia, the behavior is closer to that of Cartagena, but the spring peak takes place earlier, and it is followed by an upturn in late summer, concluding in the autumn peak.

Among the factors that influence the pollen concentrations are (1) the abundance of pollen-productive species, (2) the proximity of those species, and (3) external factors like climatic variables or orography (Edmonds 1979; Dahl et al. 2013). The bioclimatic belts propitiate certain types of vegetation (Alcaraz Ariza 2013), and the pollen types in the bioaerosol depend on the anemophilous plants, which, in turn, can be autochthonous or allochthonous.

The presence of pollen from different species in a pollen type explains the occurrence of more than one peak throughout the year, as in the case of Amaranthaceae (Fernández-Illescas et al. 2010) or Poaceae (León-Ruiz et al. 2011). Meanwhile, other pollen types present two different modes throughout the year

due to medium- or long-distance transport phenomena, for example, *Olea europaea* in Cartagena (Moreno-Grau et al. 2016). The vicinity of mountains (Meso- and supra-Mediterranean belts) results in higher pollen concentrations of tree species like *Quercus* in Lorca or *Pinus* both in Lorca and in Murcia. On the other hand, a rise in humidity reduces pollen concentrations (Rojo et al. 2015), and Cartagena is a coastal city with higher humidity than Murcia or Lorca. This accounts for the lower pollen concentrations found in Cartagena.

4.1.19 Correlation analysis (pollen)

The appearance of pollen in the air depends both on intrinsic, species-related factors (Cariñanos et al. 2014) and extrinsic factors, such as weather variables and other environmental factors (Flo et al. 2018). When it comes to the correlation among each pollen type's APIn and city (Table 4), there is no statistical significance for Amaranthaceae, *Zygophyllum*, Palmae, and *Platanus*. These are interpreted as autochthonous plant populations. On the other hand, high statistical significance, above 99%, among APIn of Urticaceae, *Plantago*, Poaceae, *Quercus*, and Cupressaceae pollen types, is found. This means that the factors governing these pollen types affect the pollen concentrations in the same way in all three cities, enabling an increase or decrease in the total pollen grains collected in the three cities simultaneously. When comparisons are made, Lorca and Murcia show statistical significance, ranging from 95 to 99% among *Artemisia*, *Morus*, *Olea*, and *Pinus* pollen types. A statistical significance above 99% is found for APIn *Pinus* between Cartagena and Murcia and APIn *Olea* between Cartagena and Lorca. Further research is necessary to check the effect of long-distance pollen transportation on these important correlations for these pollen types, especially arboreal plants.

4.2 Fungal spores

4.2.1 *Cladosporium*

Cladosporium is among the most common fungal types (Aira et al. 2012). There is interest in knowing its concentration in the air due to the losses it causes in agricultural crops, due to the fact that it is a parasitic fungus on vegetables, and because it has been evoked

as an allergenic fungal type (Yew et al. 2016). In aerobiological samples, the presence of two mitospore types, which belong to the *Cladosporium* genus, is common. They are easy to identify under an optical microscope (Mediavilla-Molina et al. 1998; Aira et al. 2012; Schubert et al. 2007; Bensch et al. 2010, 2012), which allows them to be classified into two groups, *Cladosporium herbarum* type or *C. cladosporioides* type.

Cladosporium herbarum is the most abundant type in the Region of Murcia. The same presence is found in descending order in Madrid, Lugo, and Mérida, while in Seville, Santiago, Orense Vigo, and Alcalá de Henares, the most abundant type is *Cladosporium cladosporioides* (Aira et al. 2012). In this study, Cartagena is the city with the lowest ASIn mean values for both types and Murcia shows the highest. *Cladosporium herbarum* shows its maximum intensities in spring and summer and its minimum in winter. In Lorca, *Cladosporium cladosporioides* shows a higher intensity during the spring, even though it has a lower ASIn than in the city of Murcia.

4.2.2 *Alternaria*

Alternaria is a cosmopolitan fungal type which is considered to be an emergent pathogen for both plants and humans, and is known for its sensitization characteristics (Aira et al. 2013). In the Region of Murcia, it is in Lorca where it shows the highest ASIn. In Cartagena and Murcia, the levels of this fungal type are clearly lower in winter. In all three cities, there is an increase in *Alternaria* spore concentrations in spring, with special significance during the summer in Lorca. It is present all year round in the Region of Murcia and exhibits the bimodal behavior previously stated in the literature (Aira et al. 2013; De Linares et al. 2010).

4.2.3 Correlation analysis (fungal spores)

Cladosporium herbarum's ASIn correlation among the three cities does not show any statistical significance. It is a cosmopolitan fungus and has been isolated from air, soil, foodstuffs, paints, textiles, and numerous other materials (Schubert et al. 2007).

Its ubiquity and ease of growth in this area (Elvira-Rendueles et al. 2013) cause this fungus to behave differently in each city, which explains why no

correlation has been found. On the contrary, *Alternaria* shows above 99% statistical significance among all three cities, as does *Cladosporium cladosporioides* between Lorca and Murcia, as well as Cartagena and Murcia. This implies that the intrinsic (species-related) and extrinsic factors (substratum availability, meteorological factors) which affect the presence and production of these fungus types have the same influence in all three cities. *Cladosporium cladosporioides* is a very common, cosmopolitan, saprobic species. It often occurs as a secondary invader on necrotic parts of many different host plants. A common endophytic has been isolated from air, soil, textiles, and several other substrates (Bensch et al. 2010).

Even though the concentration of *Cladosporium* spores in the bioaerosols of the 3 cities is much higher than the concentration of *Alternaria*, the impact of rhinoconjunctivitis and allergic asthma of *Alternaria* is much higher. According to the report Alergológica 2015, *Alternaria alternata* is the main cause of fungus allergies, with a sensitization of 10% for allergic rhinoconjunctivitis and 13.1% for allergic asthma. There is no case of sensitization to *Cladosporium* for the year 2015 in this study. Several authors state that 3000 spores/m³ of *Cladosporium* are necessary to cause allergic symptoms and 100 spores/m³ of *Alternaria* (Gravesen 1981; O’Gorman and Fuller 2008).

5 Conclusions

1. The pollen calendars of Cartagena, Lorca, and Murcia show quantitative and qualitative differences that advise the maintenance of aerobiological surveillance in these three cities.
2. The concentrations of pollen grains in each biogeographic zone depend both on the vegetation near the sampling points and on medium- and long-distance transport.
3. The profile of the pollen calendar from the city of Lorca shows the agricultural nature of the city. In Murcia, the importance of ornamental plants is remarkable. Cartagena presents intermediate behavior with lower pollen concentrations in many pollen types due to its proximity to the sea.
4. In relation to allergic diseases, the following must be pointed out. In Cartagena, there is an important presence of Amaranthaceae at the end of summer, when it is the dominant taxon. In Lorca, there is a winter peak of *Artemisia*, and in Murcia, a great intensity of the pollen type *Casuarina* exists during the autumn.
5. The abundance of fungal types *Cladosporium herbarum*, *C. cladosporioides*, and *Alternaria* suggests further research on their responsibility when it comes to health effects.

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