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Cannabis, an emerging aeroallergen in southeastern Spain (Region of Murcia)

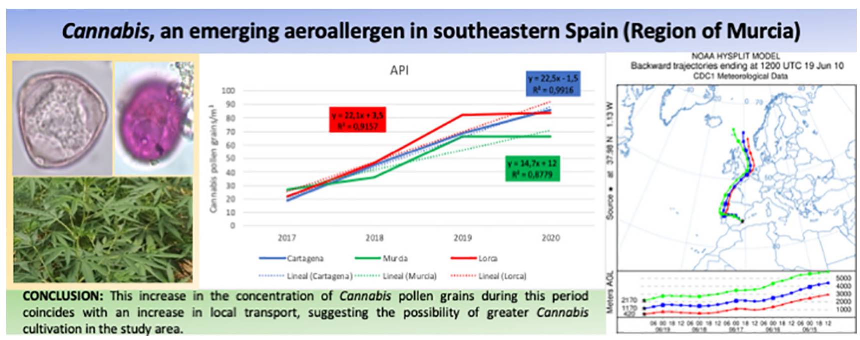
F. Aznar, L. Negral, S. Moreno-Grau, B. Elvira-Rendueles, I. Costa-Gómez, J.M. Moreno *

Department of Chemical and Environmental Engineering, Technical University of Cartagena, Cartagena, Spain

HIGHLIGHTS

- *Cannabis* concentrations increased significantly over the period 2017–2020.
- June, July and August have been established as the *Cannabis* pollen season.
- The back trajectories showed *Cannabis* pollen grains with a local origin.
- Local transport may be due to an increase in *Cannabis* cultivation in the study area.

GRAPHICAL ABSTRACT



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ABSTRACT

The evolution of the behaviour of the *Cannabis* taxon in the Region of Murcia, Spain, has been analysed (in the cities of Cartagena, 1993–2020; Murcia, 2010–2020; and Lorca, 2010–2020). An attempt has been made to establish the origin of *Cannabis* pollen in this region to determine whether it is transported locally or from long distances based on air mass origins. *Cannabis* is an herbaceous, normally dioecious and anemophilous plant, which produces large quantities of pollen grains. It has been widely used for fibre (hemp), bird food (hempseed), essential oils and narcotics. The origin of *Cannabis* pollen grains has been established by calculating back trajectories at the altitudes of: 750, 1500 and 2500 m above mean sea level (m amsl); 350, 500 and 650 m amsl; and 10, 100 and 250 m amsl, using the HYSPLIT model. Considering this data, 29 days of *Cannabis* pollen potentially originating in Africa were identified in Cartagena, 19 days in Murcia and 15 days in Lorca. Of the remaining days, the air mass back trajectories showed local or regional pollen origins. These were 83 days in Cartagena, 61 days in Murcia and 57 days in Lorca. The presence of *Cannabis* in the bioaerosol of the Region of Murcia is irregular, and it is considered a minority pollen type. However, from 2017 to 2020, concentrations increased, with a positive and significant trend of 90% in the Annual Pollen Integral. The pollen season can be defined between June and August. This increase in the concentration of *Cannabis* pollen grains during this period coincides with an increase in local transport, suggesting the possibility of increased *Cannabis* cultivation in the study area.

1. Introduction

Aerobiological monitoring of pollen grain concentrations in the atmosphere is useful for detecting anomalies in the biodiversity of anemophilous species and the climate (Fernández-Llamazares et al., 2014). Sufficiently extensive records of airborne pollen data can therefore be considered suitable bioindicators to assess the behaviour, conservation and pollination disturbances of vegetation (Alba-Sánchez et al., 2010; Ruiz-Valenzuela and Aguilera, 2018).

Long-term pollen databases provide excellent means for studying the effects of climate change on pollen-producing plants (Ruiz-Valenzuela and Aguilera, 2018). In addition, they offer the possibility of establishing forecasting tools such as regression models, time series or the use of artificial

* Corresponding author.
E-mail addresses: francisco.aznar@edu.upct.es (F. Aznar), luis.negral@upct.es (L. Negral), stella.moreno@upct.es (S. Moreno-Grau), belen.elvira@upct.es (B. Elvira-Rendueles), isabel.costa@upct.es (I. Costa-Gómez), sele.moreno@upct.es (J.M. Moreno).

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intelligence (Scheifinger et al., 2013). These tools are essential for many specific applications (García-Mozo, 2011), such as helping people avoid allergenic elements.

The *Cannabis* plant is native to Central Asia. It is an herbaceous, usually dioecious plant, although it can also be monoecious. It has been widely used to produce fibre (hemp), bird food (hempseed), essential oils and narcotics (Castroviejo Bolibar, 2005). Some controversy about its taxonomy exits, but it is classified as a single *Cannabis* species, *C. sativa* (Koren et al., 2020). Some of its varieties are cultivated to produce marijuana or hash from the resin found in the stalks, young leaves and flowers, and it is one of the oldest known psychoactive substances (Cabezudo et al., 1997). Industrially grown hemp must contain less than 0.2% tetrahydrocannabinol (THC), and its cultivation from EU-certified seeds does not require a licence. In the 1961 Single Convention on Narcotic Drugs, *Cannabis* is described as the flowering or fruited tops of the *Cannabis* plant from which the resin has not been extracted (World Health Organization -WHO-, 2019). Its cultivation requires authorisation from the Spanish Agency for Medicines and Medical Devices. In 2020, the WHO removed *Cannabis* from Schedule IV of the Convention, thereby recognising its potential medicinal properties. However, its recreational use is prohibited in Spain. *Cannabis* also produces large amounts of pollen (Small and Antle, 2003). A single flower can release more than 350,000 pollen grains into the environment (Aboulaich et al., 2013). This pollen is dispersed by wind, meaning it can be transported over long distances (Estève et al., 2018).

The presence of *Cannabis* pollen in southern Spain has been reported as a result of transport from northern Africa (Cabezudo et al., 1997; Cariñanos et al., 2004). For instance, *Cannabis* pollen levels increased in the city of Málaga between 1992 and 2015 (Aboulaich et al., 2013; Gharbi, 2018). This pollen type does not appear in the work by Fernández Rodríguez (2012) in Extremadura, a region located in the central-western part of Spain, but it does appear in a study by Maya Manzano (2015) of the same region. This increase in *Cannabis* pollen in recent years may be a consequence of illegal *Cannabis* cultivation in cities, resulting in local or regional transport of *Cannabis* air masses.

An interesting question to consider is whether the presence of this pollen type corresponds to transport from distant areas, like northern Africa, or whether it is a consequence of increased cultivation in areas close to the sampling points. One of the most commonly used atmospheric transport and dispersion models in the scientific community is HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory), provided by the Air Resources Laboratory of the National Oceanic and Atmospheric Administration (NOAA) (Stein et al., 2015). This model displays weather forecasts and reproduces (also retrospectively) the trajectories of an air parcel and the results of its dispersion model through a series of interactive web pages (Rolph et al., 2017). It is a hybrid between the Lagrangian approach, which tracks air parcels moving from their initial locations, and the Eulerian method, which uses a fixed three-dimensional grid to observe the movement of air masses (Escudero et al., 2006; Rolph et al., 2017). HYSPLIT back trajectories allow users to trace air mass origins and their paths at different times, helping to identify particle transport at varying altitudes. This model has been used for many applications, such as the description of atmospheric transport, dispersion and deposition of airborne dust, allergens or atmospheric pollutants, smokes, volcanic ash or radionuclides, among others (Stein et al., 2015).

Air masses from African deserts transport large amounts of biological particles, such as pollen grains, fungal spores, bacteria and viruses, as well as different protein or lipid components (Cariñanos et al., 2004; Kanatani et al., 2010; Kellogg and Griffin, 2006; Zhang et al., 2016). The incidence of these air masses over the southeastern Iberian Peninsula is relatively high compared to other peninsular enclaves. For example, about 30% of the days in 2004 coincided with North African air masses (Negral et al., 2008).

The aim of this work is to analyse the behaviour of *Cannabis* taxon concentration time series in Cartagena (1993–2020), Murcia (2010–2020) and Lorca (2010–2020), the three most populated cities in the Region of Murcia. We study the relationship these concentrations have to the meteorology to establish the origin of *Cannabis* pollen in the Region of Murcia by analysing back trajectories generated with the HYSPLIT model. We determine whether the transport has been local or long-distance from air mass origins.

2. Material and methods

2.1. Study area

This study was carried out in the Region of Murcia, specifically in the cities of Cartagena (37°36′00″ N, 0°59′00″ W), Murcia (37°58′57″ N, 1°07′16″ W) and Lorca (37°38′42″ N, 1°39′55″ W). These cities are in southeastern Spain, and Cartagena is on the Mediterranean coast. The climatic profile of this region is warm, arid or sub-arid Mediterranean, and it is one of the driest regions in Spain, with very hot, dry summers and mild winters. It has an average temperature of 18.8 °C, and rainfall is low, with an annual average between 300 and 350 L/m^2 in the territory studied (Elvira-Rendueles et al., 2019).

Cartagena is a maritime city located in the southeastern part of the region, with an area of 558.1 km^2 and an altitude of 10 metres above mean sea level (m amsl). Murcia is the capital and is located in the eastern part of the region, with an area of 881.9 km^2 and an altitude of 42 m amsl. Lorca, the third-largest city in the region, is located in the southwestern part of the region, with an area of 1675 km^2 and an altitude of 353 m amsl.

In Cartagena, the sampling station is located on the roof of the railway station, 10 metres above ground level (m agl). In Murcia, the trap is located on top of the Reina Sofía University Hospital, at 25 m agl, and in Lorca, it is located on the roof of the Rafael Méndez Hospital, at 15 m agl.

The maximum, mean and minimum temperatures, mean daily wind speed and rainfall data for Cartagena, Lorca and Murcia were obtained from the State Meteorological Agency (AEMET), provided by the Cartagena, Murcia and Lorca stations. In addition, data on minimum and maximum atmospheric pressure were also available for Cartagena and Murcia, and data on hours of sunlight and maximum wind gusts were obtained for Murcia.

2.2. Airborne pollen

Aerobiological samples were collected using a Hirst-type trap, model VPPS 2000, from Lanzoni S.R.L (Galán et al., 2007). The trap is equipped with a slit for air intake. The air is suctioned by a motor and intercepted by a rotating drum fitted with a belt made of Melinex, coated with adhesive silicone. The airborne particles hit the adhesive tape and are retained. The tape is cut into daily segments weekly and mounted on slides with glycerogelatin and fuchsin, protected with coverslips and, after a rest period, observed under an optical microscope for analysis. In this study, four longitudinal transects were read with an immersion 50× optical zoom lens. The surface area read was more than 10% of the total sampling area, allowing us to identify the different pollen types and carry out the corresponding count (EN 16868:2019).

The *Cannabis* pollen grain is a medium-sized monad, 20–30 μm in diameter, spheroidal, isopolar and trizonoporate. The pores have an annulus, and the intine forms an oncus under the pore. Under an optical microscope, the ornamentation of the exine is psilate (Halbritter and Heigl, 2020).

2.3. Calculation and use of back trajectories for aerobiological purposes

One of the most common uses of back trajectories is to study aerovagant pollen grains (Negral et al., 2017). In this work, back trajectories were used to determine the origin of the *Cannabis* pollen type. To define the origin of air masses, the HYSPLIT model from the NOAA (https://www.ready.noaa.gov/HYSPLIT.php) was used to identify pollen grain transport over long distances, following the methodology described by Negral et al. (2021). Further details about HYSPLIT and the characteristics of the meteorological databases can be consulted elsewhere (Rolph et al., 2017; Stein et al., 2015).

On the days that *Cannabis* was recorded, air mass back trajectories were calculated from 1993 to 2020 for Cartagena and from 2010 to 2020 for Murcia and Lorca. The selected meteorological database was NCEP/NCAR REANALYSIS (National Centre for Environmental Prediction/National Centre for Atmospheric Research): 1948/01/01-present; global domain, 2.5° latitude-longitude, 17 vertical levels, with the top level at 10 hPa, four analyses per day (more information about this meteorological database can be found at https://www.ready.noaa.gov/gbl_reanalysis.php, https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html). The starting time for the trajectory calculation was 12 h UTC, which is common practice when working with daily atmospheric pollutants (Ashrafi et al., 2014; Cerro et al., 2020; Sánchez-Ccoyllo et al., 2006). This starting time has also been used to study daily airborne pollen concentrations (Belmonte et al., 2008; Moreno-Grau et al., 2016). In addition, three simultaneous trajectories were calculated at different heights. Back trajectories were calculated at 750, 1500 and 2500 m amsl. These altitudes are suitable for observing African dust particles travelling long distances over the Iberian Peninsula (Negral et al., 2012). For better visualisation of local transport, back trajectories were calculated at lower altitudes: 350, 500 and 650 m amsl, and 10, 100 and 250 m amsl. This has been useful in cases where higher altitude plots were inconclusive, and local transport was suspected (Robayo-Avedaño and Galindo-Mendoza, 2014). These low altitude back trajectories show a clearer distinction between local or regional transport and that from northern Africa (Negral et al., 2017).

The back trajectories were used to classify the air masses according to their origin, following the proposal for the Iberian Peninsula by Font Tullot (2000) and incorporating the regional origin, which is of particular importance in the southeastern Iberian Peninsula (Negral et al., 2008). The sectors defined for these air masses are: North Atlantic (AN), Northwest Atlantic (ANW), West Atlantic (AW), Southwest Atlantic (ASW), North African (NAF), Mediterranean (ME), European (EU) and Regional (RE).

2.4. African dust outbreaks

Data on days with an intrusion of African air masses in Spain have been obtained from the Spanish Ministry of Ecological Transition and Demographic Challenge (MITECO, 2021). Information about African dust outbreaks reaching the Iberian Peninsula is relevant to associate African *Cannabis* pollen with northwards air masses from Africa.

The methodology used to identify these episodes is available in the document "Establishing guidelines for the demonstration and subtraction of exceedances attributable to natural sources under Directive 2008/50/EC on ambient air quality and cleaner air for Europe" (European Commission, 2011). Daily meteorological situations were identified, and air mass back trajectories were obtained with HYSPLIT. The results were then validated by studying the synoptic maps of the European Centre for Medium-Range Weather Forecasts, Aerosol Index Maps reflecting the Ozone Monitoring Instrument indirect measurement and daily results from SKIRON, the Barcelona Supercomputing Centre and the Navy Aerosol Analysis and Prediction System (NAAPs).

This work has used MITECO reports available from 2009 to 2020. For the period 2004 to 2008, the African dust intrusion data were taken from Negral Álvarez (2010), and for the years 2002 and 2003, the NAAPs aerosol maps were consulted. No NAAPs maps were available for 1999, so the arrival of African dust intrusions was estimated using the back trajectories obtained with HYSPLIT.

2.5. Data treatment and statistical analysis

Our dataset contained daily pollen grains/m^3. These concentrations were used to define the *Cannabis* Main Pollen Season (MPS). The MPS was established considering the beginning to be the first day of the Gregorian year with a record of the *Cannabis* pollen type and the end, the last day of the year on which the bioaerosol appeared. It was calculated between 2017 and 2020. The Annual Pollen Integral (APIn) was calculated according to Galán et al. (2017): the sum of daily pollen concentrations throughout the *Cannabis* MPS.

Statistical analysis was developed using IBM SPSS (version 26.0). The Kruskal-Wallis test was used to determine whether significant differences were detected comparing the APIn of different years in every city. This non-parametric test was used after rejecting the hypothesis of the normal distribution of *Cannabis* pollen concentrations with the Kolmogorov-Smirnov test. Regression equations were calculated from the APIn between 2017 and 2020, providing the *p*-value of the slope of the linear equation. The non-parametric Spearman correlation coefficient was used to assess the impact of meteorological variables on the daily pollen concentrations in all three cities between 2017 and 2020.

3. Results

3.1. Cannabis aerobiology and meteorology in Cartagena, Murcia and Lorca (Region of Murcia)

In the aerobiological registers of Cartagena established with the Hirst method since March 1993, *Cannabis* has an irregular presence. Fig. 1a) shows the APIn for Cartagena from 1993 to 2020. Fig. S1 (Supplementary material) shows the daily values of *Cannabis* for the years it has been present in the bioaerosol of this city. Table 1a) shows the quantitative APIn value, the maximum annual value, and the days of occurrence for Cartagena. Aerobiological quantification in the city of Murcia began in June 2009 and in Lorca in February 2010, so the results of *Cannabis* since 2010 are included in this work. Fig. 1b) shows the APIn of this taxon during the period studied, and Fig. S2 (Supplementary material), the daily concentrations of *Cannabis* for the years it has been present in the bioaerosol of Murcia. Table 1b) shows the APIn, the maximum annual value and the days they occurred in Murcia. Fig. 1c) shows the APIn during the period studied, and Fig. S3 (Supplementary material) shows the daily concentrations of *Cannabis* for the years it has been part of the atmospheric bioaerosol of Lorca. Table 1c) shows the APIn, the maximum value and the days they occurred in Lorca.

The decision to calculate the MPS with 100% of the days with *Cannabis* pollen was based on the need to take into account both the local and long-distance transport of *Cannabis* pollen grains. This is because the probability of differentiating non-local origin increases at the tails of the MPS. The years before 2017, the tendency of the APIn was not included in the study since the concentration was reported to be 0 grains/m^3 or *Cannabis* pollen grains were only detected on one or two days (Figs. S1, S2 and S3). Table 2 shows the starting date, the first day of the year, the end date, the last day of the year and the duration of the MPS in days.

Since the variables did not fit the normal distribution hypothesis according to the Kolmogorov-Smirnov test, the non-parametric Kruskal-Wallis test was performed for the APIn in the three cities from 2017 to 2020. There were statistically significant differences for Cartagena (p-value = 0.000) and Murcia (p-value = 0.005). For Lorca, the significance level was 90% (p-value = 0.091). Fig. 2 shows the APIns for each of the cities with the regression lines and the respective coefficients of determination. The significance levels of the slopes are: p-value = 0.004 for Cartagena; p-value = 0.063 for Murcia; and p-value = 0.043 for Lorca.

The non-parametric correlation (Spearman) between the daily *Cannabis* pollen concentrations from 2017 to 2020 and the meteorological variables available in each of the three cities is presented in Table 3.

3.2. Origin of Cannabis pollen grains in the Region of Murcia

The calculated back trajectories indicated a local/regional *Cannabis* pollen origin in the Region of Murcia on most days: 74.1% (83 days) in Cartagena, 76.2% (61 days) in Murcia, and 79.2% (57 days) in Lorca (Table 4). That is, no long-distance transport from Africa was detected, as shown in Fig. 3 for Cartagena, Murcia, and Lorca on 07/26/2010, 06/19/2010 and 07/24/2011, respectively. A daily list with the proposed origin of *Cannabis* pollen can be consulted in Table S1 (Supplementary material).

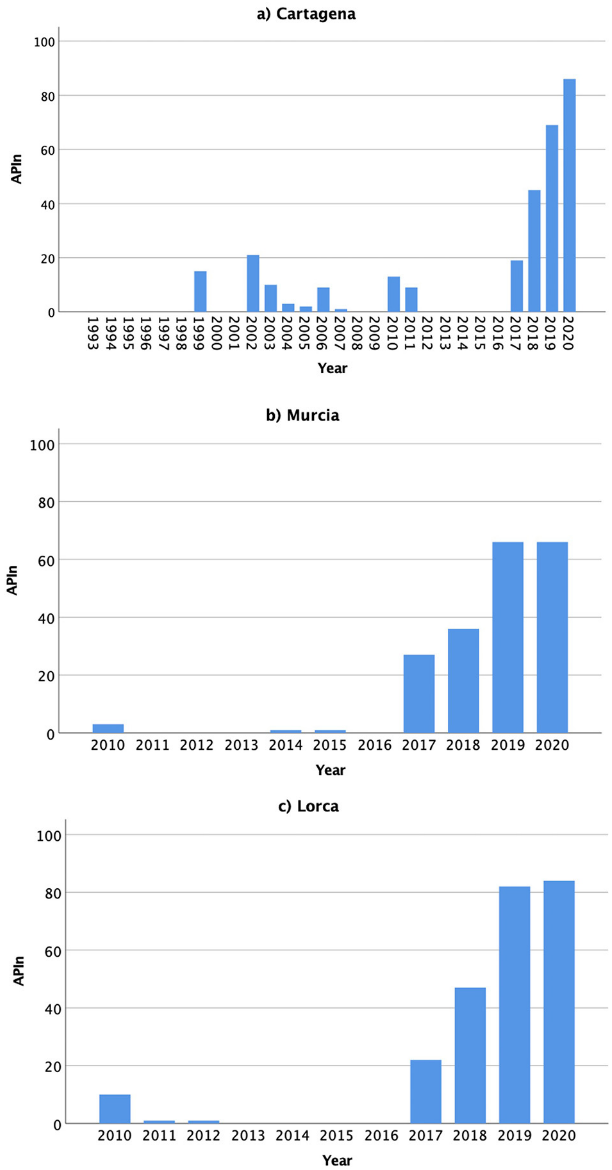

Fig. 1. Annual Pollen Integral (APIn, pollen grains/m^3) for *Cannabis* pollen in the city of a) Cartagena from 1993 to 2020, b) Murcia from 2010 to 2020, and c) Lorca from 2010 to 2020.

The days with local/regional *Cannabis* pollen occurred with the eight types of air masses: AN, ANW, AW, ASW, NAF, ME, EU and RE.

The days when *Cannabis* pollen originated in Africa were much less frequent (Table 4). All these days corresponded to NAF air masses, except for 07/01/2018, when the air mass was catalogued as ASW (Table S2, Supplementary material). Fig. 4 represents the calculated back trajectories for Cartagena on 07/23/2017. These trajectories pointed to African origin on the same day long-transported *Cannabis* pollen also reached Murcia and Lorca.

It should be noted that the peak days in 2020 occurred in August in all three cities, so the origin of the air masses could not be verified due to limited REANALYSIS data. For Cartagena, among the peak days of 1999–2010, only two years coincided with air masses of African origin: 2003 and 2017. For the other years, the pollen grains of the *Cannabis* peak day had a local or regional origin. For Murcia, among the peak days of 2010–2019, only one year, 2017, coincided with air masses from Africa. Finally, for Lorca, the peak days from 2010 to 2019 did not coincide with air masses of African origin, so the *Cannabis* pollen grains were local or regional.

Table 1
Annual pollen integral (APIn), maximum daily concentrations and date of occurrence for every year *Cannabis* pollen appears in the Region of Murcia.

Year	APIn	Maximum	mm/dd	Year	APIn	Maximum	mm/dd
	Pollen grains/m^3				Pollen grains/m^3		
a) Cartagena							
1999	15	4	04/14	2010	13	5	07/26
2002	21	10	04/26	2011	9	9	07/30
2003	10	3	06/08	2017	19	3	07/23
2004	3	2	06/05				08/01
2005	2	2	03/11	2018	45	7	07/15
2006	9	5	07/04	2019	69	9	08/06
2007	1	1	06/19	2020	86	14	08/14
b) Murcia							
2010	3	2	06/18	2017	27	5	08/01
2014	1	1	07/27	2018	36	6	07/14
2015	1	1	06/26	2019	66	6	08/07
				2020	66	8	08/14
c) Lorca							
2010	10	6	06/07	2017	22	4	06/26
2011	1	1	07/24	2018	47	9	08/27
2012	1	1	07/31	2019	82	8	06/10
				2020	84	27	08/15

4. Discussion

4.1. Aerobiology

The presence of *Cannabis* pollen in the bioaerosol of the Region of Murcia was sporadic until 2017. Up to that time, it was considered a minority pollen type in our region and was not a part of the pollen calendar (Elvira-Rendueles et al., 2019). Although up to 21 pollen grains/m^3 (2002) could be found in the air of Cartagena before 2017, almost half of it was collected on a single day, and its presence was concentrated on specific days. As an example, the peak day in 2002, 04/26/2002, was of local/regional origin (Table S1). However, we have verified that since 2017, a systematic count that could be due to autochthonous flowering has occurred in Cartagena, Murcia and Lorca. This asseveration is supported by the dismantling of illegal *Cannabis* crops in the Region of Murcia over the last five years. Alvarez et al. (2016) warned about changes in *Cannabis* consumption in Spain, where “the rise of large-scale *Cannabis* plantations in the Spanish Mediterranean coast has been increasingly replacing Moroccan hashish imports.” Likewise, the expansion of small-scale cultivation in Spain is assumed to be taken place (Amado et al., 2020). In this context, the control of *Cannabis* pollen broadens the scope of Aerobiology with a new application for public health/law professionals.

Table 2
Main Pollen Season (MPS) in Cartagena, Murcia and Lorca from 2017 to 2020.

	Start date (mm/dd)	Day of the year	End date (mm/dd)	Day of the year	Duration MPS, days
Cartagena					
2017	06/09	160	08/26	238	79
2018	06/24	175	08/09	251	77
2019	06/05	156	08/27	239	84
2020	06/19	171	08/28	241	71
Murcia					
2017	06/09	160	08/26	238	79
2018	06/06	157	09/01	244	88
2019	06/04	155	08/25	237	83
2020	06/18	170	08/28	241	72
Lorca					
2017	06/10	161	08/01	213	53
2018	06/07	158	08/27	239	82
2019	06/04	154	08/27	239	85
2020	06/26	178	08/29	242	65

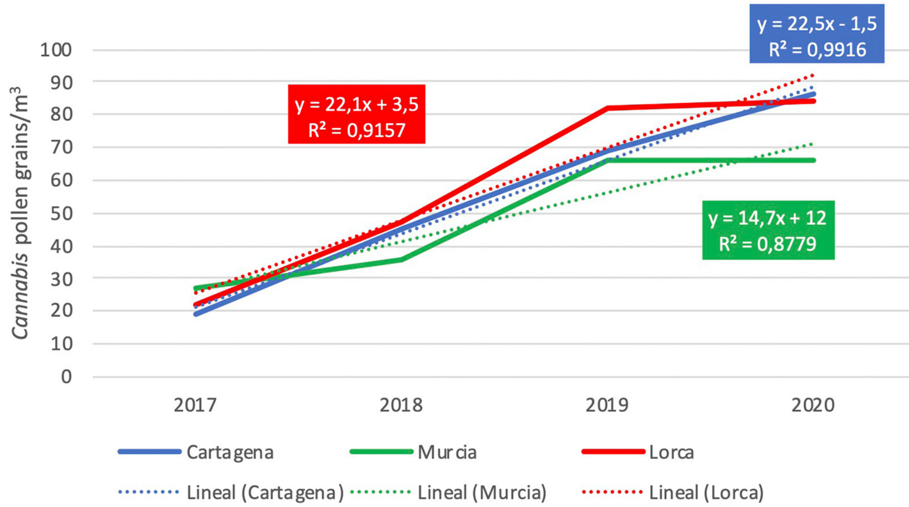

Fig. 2. *Cannabis* APIn values from 2017 to 2020 in Cartagena, Murcia and Lorca. The regression line and the coefficients of determination are shown.

These professionals could be interested in the *Cannabis* MPS. Depending on the year, it can start at any time from the beginning to the end of June and last until the first days of August or even September, with a variation of 13 days in Cartagena, 16 days in Murcia and 32 days in Lorca (Table 2). Although our MPS is not the standard definition in which 95% of the population is retained, discarding the 5% at the tails (Andersen, 1991), Jato et al. (2006) argued that the MPS should be defined according to the purpose of the research. The purpose of our research was to identify the origin of the *Cannabis* pollen grains, regardless of the concentrations. Nevertheless, the option to work with the standard MPS (95%) was assessed. This idea was discarded because it would mean leaving out high concentration days, even the peak day, e.g., in Lorca in 2018. This behaviour is not expected for plants spread naturally in the area of study.

The duration of the MPS in the Region of Murcia is much shorter than that defined for areas where there is widespread cultivation of this plant, like Tetouan. There, the duration of the MPS (95%) is in the range of 127 to 172 days, and it constitutes a major pollen type (Aboulaich et al., 2013). In Islamabad, Pakistan, it is the most important allergen from July to September (Abbas et al., 2012).

The concentrations registered in the three cities of the Region of Murcia increased from 2017 to 2020, with differences among the mean values and a positive trend in the evolution of the APIn (Fig. 2). In terms of the consequences for allergy sufferers, the APIn was probably not high enough to cause problems for the general population during the years of the study. Conversely, those directly exposed to *Cannabis* crops or living around them could experience some effects (Nayak et al., 2017). If the tendency continues rising, *Cannabis* aeroallergens could become a matter of concern, requiring more intense monitoring. Although allergic symptoms have already been found in a woman working with *Cannabis* pollen in Spain (Mayoral et al., 2008), public health concerns are more related to drug use at this point.

The positive and significant correlation with temperature (daily minimum, mean and maximum) was expected, as *Cannabis* is a plant that flowers in spring-summer. This explains the duration of the MPS in surrounding countries, like northern Morocco between April and August (Boullayali et al., 2021), or the south of France between the end of July and the middle of August (Anselme et al., 2011). Aboulaich et al. (2013) found a positive and significant correlation with mean wind velocity and a negative correlation with precipitation. This coincides with what we found in our study for some years. Behaviour related to wind velocity can be explained by the fact that cultivation sites must be a certain distance from cities, where the traps are located. If the sources of pollen grains are close to the collector, greater wind velocities have a scattering effect, whereas for sources far from the trap, greater wind velocities allow the pollen grains to arrive. This is why we have analysed air masses analysis in our research. While air masses catalogued as AN, ANW, AW, ASW, NAF, ME and EU would point to possibly distant sources, an RE air mass would indicate surrounding sources. As expected, RE is the most frequent air mass origin with local/regional sources of *Cannabis* pollen in all the cities (Table S1). The effect of precipitation has been reported for other pollen types. Precipitation is directly related to atmospheric washing (Pérez et al., 2009). We have also found a negative correlation with atmospheric pressure, which may be due to the subsidence caused by anticyclonic situations, limiting pollen grain dispersion capacity. The latter has also been observed for *Olea* pollen grains in the Region of Murcia (Negral et al., 2022).

4.2. Back trajectories and the origin of Cannabis pollen grains

As indicated above, back trajectories have been calculated for days when at least 1 *Cannabis* pollen grain/m^3 was present in the atmosphere of the three cities. Recently, back trajectories have been used with concentrations of 1 *Betula* pollen grain/m^3 in northeastern Spain (Alarcón et al., 2022). These authors identified Central Europe as the origin, providing another example of using back trajectories to monitor the long-distance transport of very low airborne pollen concentrations.

The day 07/26/2010 is an example of *Cannabis* pollen with a local or regional origin in Cartagena on the peak day (Fig. 3, Table S1). The back trajectories at 750, 1500 and 2500 m amsl originated in the Atlantic Ocean, slowing down considerably when reaching the Iberian Peninsula. In this case, no air mass contacted the ground. The back trajectories at 350, 500 and 650 m amsl, also showed air masses originating in the North Atlantic. However, the air mass at 350 m amsl contacted the ground over the Iberian Peninsula from 00 h to 12 h the previous day. Finally, the back trajectories at 10, 100 and 250 m amsl also had their origin in the North Atlantic, and all the air masses had contacted the ground of the Iberian Peninsula from 00 h until 18 h the previous day. This is evidence of regional or local *Cannabis* pollen grain transport. The absence of *Cannabis* pollen grains that day in Murcia and Lorca points to local transport as a reason for the presence of this pollen type in Cartagena. Moreover, there was no intrusion of African dust in the study area on this day, and the air mass was classified as AN. Another example of local/regional transport was in Murcia on 06/19/2010, a day after the peak day (Fig. 3, Table S1). The back trajectories at 750, 1500 and 2500 m amsl originated in the North Atlantic, slowing down as they reached their destination. All the air masses approached the ground as they reached Murcia. The back trajectories at 350, 500 and 650 m amsl slowed down over the Iberian Peninsula, staying very close to the ground two days before the day in question. The back trajectories at 10, 100 and 250 m amsl showed the same North Atlantic origin, slowing

Table 3
P-value (left) and Spearman correlation coefficient (right) between the daily *Cannabis* pollen concentrations and the meteorological variables in Cartagena, Murcia and Lorca, from 2017 to 2020.

	Cartagena	Murcia	Lorca
2017			
Daily maximum temperature	0.000| 0.204	0.000| 0.287	0.000| 0.281
Daily mean temperature	0.000| 0.217	0.000| 0.291	0.000| 0.277
Daily minimum temperature	0.000| 0.217	0.000| 0.282	0.000| 0.246
Daily sunlight	n.a.	0.003| 0.159	n.a.
Daily mean wind velocity		0.005| 0.151	
Daily maximum wind gust		0.046| 0.106	
Daily rainfall			
Daily maximum atmospheric pressure	−0.014| 0.128	−0.002| 0.163	n.a.
Daily minimum atmospheric pressure	−0.031| 0.113	−0.018| 0.126	n.a.
2018			
Daily maximum temperature	0.000| 0.222	0.000| 0.285	0.000| 0.272
Daily mean temperature	0.000| 0.240	0.000| 0.299	0.000| 0.283
Daily minimum temperature	0.000| 0.268	0.000| 0.298	0.000| 0.277
Daily sunlight	n.a.	0.001| 0.185	n.a.
Daily mean wind velocity			0.004| 0.163
Daily maximum wind gust			
Daily rainfall			
Daily maximum atmospheric pressure	−0.016| 0.130	−0.004| 0.162	n.a.
Daily minimum atmospheric pressure			n.a.
2019			
Daily maximum temperature	0.000| 0.339	0.000| 0.394	0.000| 0.381
Daily mean temperature	0.000| 0.352	0.000| 0.383	0.000| 0.385
Daily minimum temperature	0.000| 0.358	0.000| 0.363	0.000| 0.371
Daily sunlight	n.a.	0.000| 0.316	n.a.
Daily mean wind velocity	0.003| 0.154	0.002| 0.166	0.008| 0.144
Daily maximum wind gust	0.039| 0.108	0.017| 0.128	0.040| 0.111
Daily rainfall		−0.034| 0.116	
Daily maximum atmospheric pressure	−0.000| 0.223	−0.000| 0.262	n.a.
Daily minimum atmospheric pressure	−0.002| 0.164	−0.000| 0.218	n.a.
2020			
Daily maximum temperature	0.000| 0.427	0.000| 0.426	0.000| 0.390
Daily mean temperature	0.000| 0.451	0.000| 0.433	0.000| 0.388
Daily minimum temperature	0.000| 0.461	0.000| 0.419	0.000| 0.379
Daily sunlight	n.a.	0.000| 0.260	n.a.
Daily mean wind velocity	0.002| 0.165	0.025| 0.117	0.005| 0.150
Daily maximum wind gust			0.013| 0.134
Daily rainfall			−0.033| 0.115
Daily maximum atmospheric pressure	−0.000| 0.224	−0.000| 0.244	n.a.
Daily minimum atmospheric pressure	−0.001| 0.166	−0.001| 0.178	n.a.

n.a. = not available.

Table 4
Origin of *Cannabis* pollen in Cartagena (1993–2020), Murcia (2010–2020) and Lorca (2010–2020).

City	Local/regional (days| %)	Africa (days| %)	Total (days| % of the total)
Cartagena	83| 74.1%	29| 25.9%	112| 100%
1999	6| 100%	0| 0%	6| 5.4%
2002	6| 60%	4| 40%	10| 8.9%
2003	7| 87.5%	1| 12.5%	8| 7.1%
2004	2| 100%	0| 0%	2| 1.8%
2005	1| 100%	0| 0%	1| 0.9%
2006	3| 75%	1| 25%	4| 3.6%
2007	1| 100%	0| 0%	1| 0.9%
2010	4| 100%	0| 0%	4| 3.6%
2011	1| 100%	0| 0%	1| 0.9%
2017	7| 53.8%	6| 46.2%	13| 11.6%
2018	11| 84.6%	2| 15.4%	13| 11.6%
2019	21| 67.7%	10| 32.3%	31| 27.7%
2020	13| 72.2%	5| 27.8%	18| 16.1%
Murcia	61| 76.2%	19| 23.8%	80| 100%
2010	2| 100%	0| 0%	2| 2.5%
2014	1| 100%	0| 0%	1| 1.25%
2015	1| 100%	0| 0%	1| 1.25%
2017	10| 62.5%	6| 37.5%	16| 20%
2018	12| 80%	3| 20%	15| 18.8%
2019	25| 80.6%	6| 19.4%	31| 38.8%
2020	10| 71.4%	4| 28.6%	14| 17.5%
Lorca	57| 79.2%	15| 20.8%	72| 100%
2010	2| 100%	0| 0%	2| 2.8%
2011	1| 100%	0| 0%	1| 1.4%
2012	1| 100%	0| 0%	1| 1.4%
2017	11| 84.6%	2| 15.4%	13| 18.1%
2018	14| 87.5%	2| 12.5%	16| 22.2%
2019	24| 77.4%	7| 22.6%	31| 43.1%
2020	4| 50%	4| 50%	8| 11.1%

down over the Iberian Peninsula and approaching the ground as they reached their destination. African dust intrusion was not reported on this day, and the air mass was classified as AN, which is evidence of local or regional *Cannabis* pollen grain transport. The presence of this pollen type on this date only in Murcia indicates a local origin. This day can be contextualised with the day before, the peak day, with an air mass classified as EU. Air masses from AN and EU are geographically incompatible with any drag bringing *Cannabis* pollen from Africa. Local/regional *Cannabis* pollen transport was also evident in Lorca on 07/24/2011 (Fig. 3, Table S1). The air mass at 2500 m amsl had its origin in the Northwest Atlantic, although it slowed down considerably as it reached the Iberian Peninsula. The air masses at 750 and 1500 m amsl recirculated over the Iberian Peninsula, looping and contacting the ground three days before the day in question. The back trajectories at 350, 500 and 650 m amsl recirculated over the Iberian Peninsula, looping several times and contacting the ground at various points along their way, indicating regional or local transport. Finally, the back trajectories at 10, 100 and 250 m amsl showed air masses originating in the Iberian Peninsula, recirculating along their path. They touched the ground four days before and on the same day from 00 h onwards. During this day, there was no intrusion of African dust. The air mass was classified as RE. In addition, on this day, only *Cannabis* pollen grains were observed in Lorca, pointing to local pollen transport. Overall, the different back trajectories point to local pollen grains. The previous examples of local/regional sources in each city should be contextualised with the frequency of origin (Table 4). The days with local/regional origin were three times higher than the number of days with African origin (Table 4). As pollen displacement drops exponentially with distance from the flower (Solomon, 2002), the idea of an increase in illegal *Cannabis* crops surrounding the sampling points is reinforced.

Fig. 4 shows that *Cannabis* pollen grains originated in Africa on 07/23/2017. Back trajectories at 750, 1500 and 2500 m amsl showed recirculation of all the air masses over North Africa. The air mass at 2500 m amsl contacted the ground over Africa during the three days preceding the day in question, and the air mass at 750 m amsl did so from 12 h to 18 h on the previous day. This explains the transport of particles from northern Africa to the Iberian Peninsula and, specifically, to the Region of Murcia. At 18 h the previous day, with back trajectories at 350, 500 and 650 m amsl, air masses originated over the Atlantic Ocean but travelled across Africa before arriving to their destination. All the air masses had approached the ground between 6 h and 18 h the previous day and slowed down when they reached the Region of Murcia. A similar situation occurred for the back trajectories at 10, 100 and 250 m amsl. All the air masses originated over the Atlantic Ocean, but they travelled across Africa, coming into contact with the ground from 6 h to 12 h the previous day and slowing down when they reached the Region of Murcia. Although the back trajectories in Fig. 4 correspond to the coordinates of Cartagena, the analysis was comparable to the back trajectories of Murcia and Lorca. Another aspect that points to the African origin of *Cannabis* is the detection of African

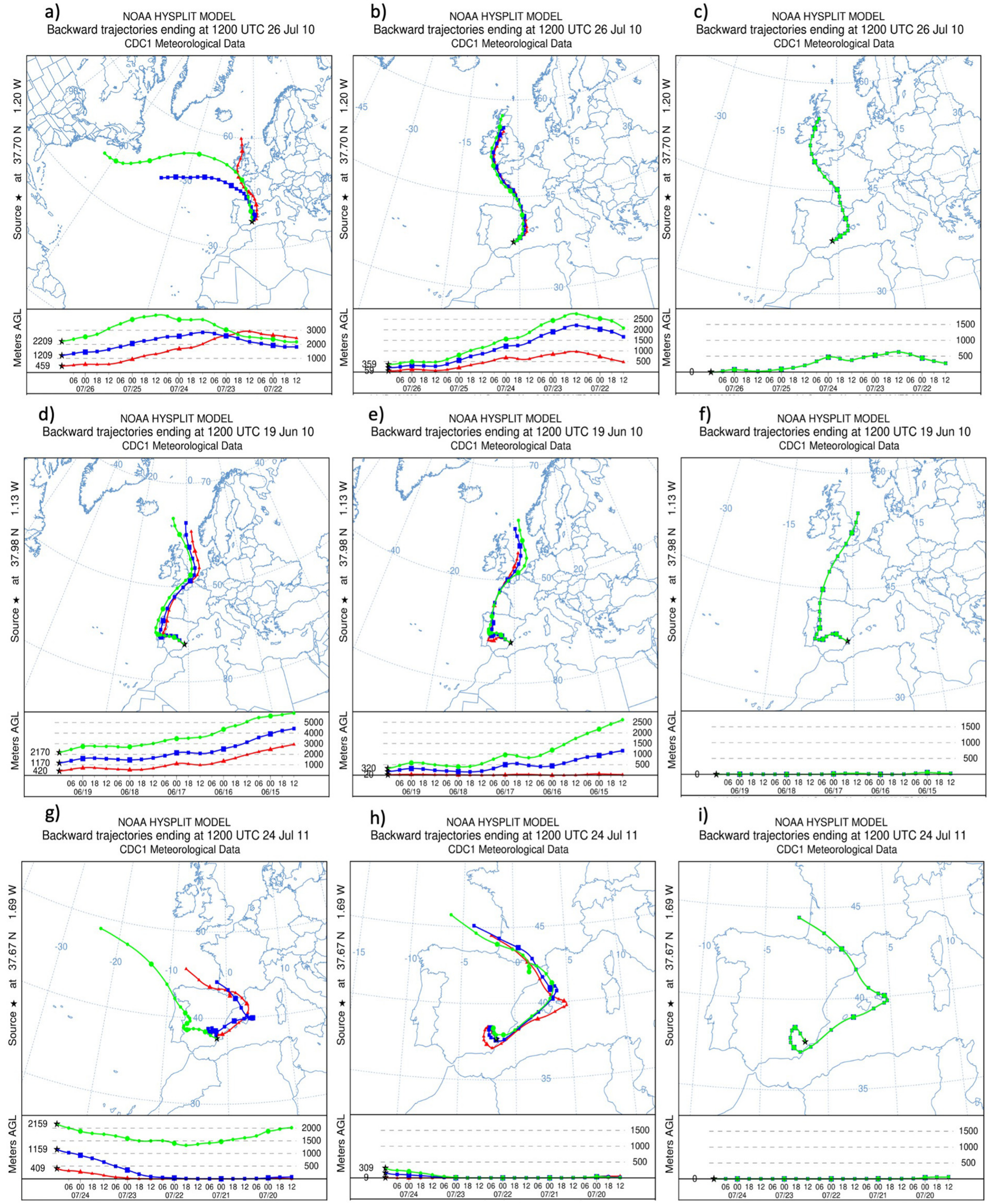

Fig. 3. Back trajectories with local/regional origin on: 07/26/2010 in Cartagena at a) 750, 1500, 2500 m amsl; b) 350, 500, 650 m amsl; and c) 10, 100, 250 m amsl. 06/19/2020 in Murcia at d) 750, 1500, 2500 m amsl; e) 350, 500, 650 m amsl; and f) 10, 100, 250 m amsl. 07/24/2011 in Lorca at g) 750, 1500, 2500 m amsl; h) 350, 500, 650 m amsl; and i) 10, 100, 250 m amsl.

dust intrusions in the area of the three cities, with the peak day in Cartagena. The concomitance in the three cities is congruent with long-distance particle transport. In the presence of an NAF air mass, these results coincide with those published by Cabezudo et al. (1997) and Cariñanos et al. (2004), showing *Cannabis* transport from northern Africa to southern Spain. In spite of the infrequency of African *Cannabis* pollen in Cartagena, attention should be paid to the allergenic effects of African dust outbreaks. If local/regional *Cannabis* crops continue to increase, sensitisation will become more of a problem. As African pollen grains had to be expelled to high altitudes before they could reach their destination overseas (Escudero et al., 2005), variety of meteorological conditions were present in their path: different temperatures due to the environmental height gradient; consequent relative humidity fluctuation; the acquired marine nature of the air mass, with chemical exposition to sea salt; barometric pressure; and contact with abiotic particulate matter from dust deserts. Concerning the interactions among solids, Visez et al. (2015) proved how birch pollen

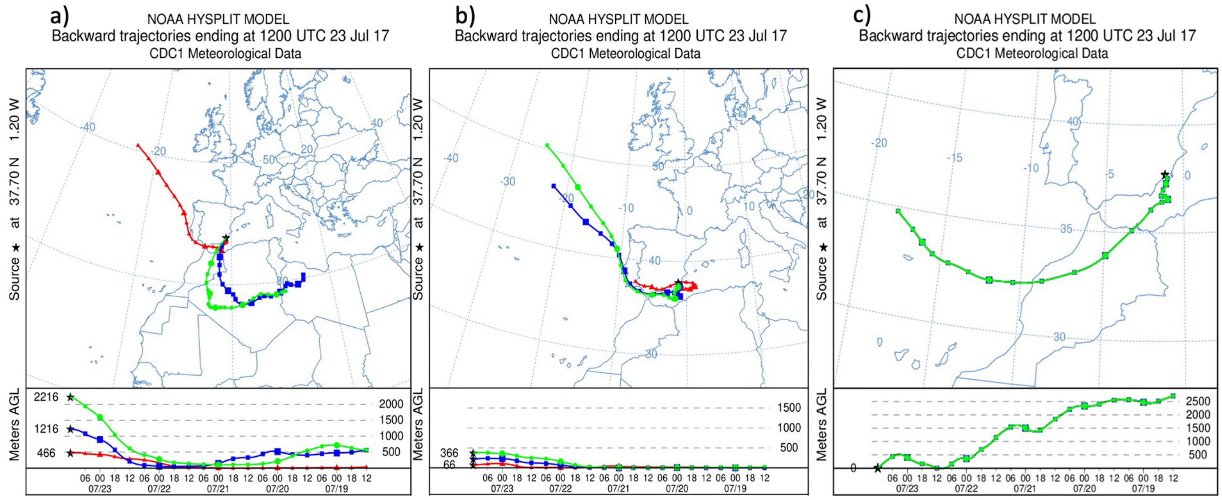

Fig. 4. Back trajectories of African origin on 07/23/2017 in Cartagena at a) 750, 1500 and 2500 m amsl; b) 350, 500 and 650 m amsl; and c) 10, 100 and 250 m amsl.

grains can rupture when they impact solid surfaces in light breezes. The release of paucimicronic particles caused by a hypothetical rupture of *Cannabis* pollen, either from Africa or local/regional sources, could affect those previously sensitised.

5. Conclusions

Due to the lack of or low *Cannabis* pollen concentrations, a pollen season could not be defined in Cartagena, Murcia and Lorca until 2017. From 2017 to 2020, the *Cannabis* pollen season occurred between June and August, with a duration ranging from 53 to 88 days. The *Cannabis* pollen concentrations recorded in the three cities increased from 2017 to 2020, with a positive and significant tendency of over 90% in the evolution of the APIns. This tendency has been ascribed to the spread of illegal crops in the regional sphere. A positive and significant correlation was found with daily temperatures. The correlation with the mean daily wind velocity explained that greater wind velocities allowed pollen grains from sources far from the traps to arrive. The negative correlation with atmospheric pressure may reflect the subsidence caused by anticyclonic situations, limiting pollen grain dispersion capacity.

Back trajectory analysis has allowed us to show the local or regional origin of *Cannabis* pollen on 75% of the days. Long-distance transport from Africa was infrequent. These findings pointed to local transport coinciding with an increase in the concentration of *Cannabis* pollen grains. Local transport, which has increased in recent years, points to the possibility of an escalation in *Cannabis* cultivation in the study area. In relation to surrounding *Cannabis* crops, an emerging area of the research is the use of aerobiology for forensic science.

CRediT authorship contribution statement

F. Aznar: Conceptualisation, methodology, data curation, original draft preparation, review and editing and supervision. **L. Negral:** Conceptualisation, methodology, software, investigation and supervision. **S. Moreno-Grau:** Conceptualisation, validation, data curation, review and editing, project administration and supervision. **B. Elvira-Rendueles:** Validation, investigation and supervision. **I. Costa-Gómez:** Formal analysis, investigation and supervision. **J.M. Moreno:** Methodology, project administration, software, formal analysis and supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2022.155156.

References

Abbas, S., Katelaris, C.H., Singh, A.B., Raza, S.M., Khan, M.A., Rashid, M., Abbas, M., Ismail, M., 2012. World Allergy Organization study on aerobiology for creating first pollen and mold calendar with clinical significance in Islamabad, Pakistan; a project of World Allergy Organization and Pakistan Allergy, Asthma & Clinical Immunology Centre of Islamabad. World Allergy Organ.J. 5 (9), 103–110. https://doi.org/10.1097/WOX.0b013e31826421c8.

Aboulaich, N., Trigo, M.M., Bouziane, H., Cabezudo, B., Recio, M., El Kadiri, M., Ater, M., 2013. Variations and origin of the atmospheric pollen of Cannabis detected in the province of Tetouan (NW Morocco): 2008–2010. Sci. Total Environ. 443, 413–419. https://doi.org/10.1016/j.scitotenv.2012.10.075.

Alba-Sánchez, F., Sabriego-Ruíz, S., Díaz de la Guardia, C., Nieto-Lugilde, D., De Linares, C., 2010. Aerobiological behaviour of six anemophilous taxa in semi-arid environments of southern Europe (Almería, SE Spain). J. Arid Environ. 74, 1381–1391. https://doi.org/10.1016/j.jaridenv.2010.06.005.

Alarcón, M., Periago, C., Pino, D., Mazón, J., Casas-Castillo, M.C., Ho-Zhang, J.J., De Linares, C., Rodríguez-Solà, R., Belmonte, J., 2022. Potential contribution of distant sources to airborne Betula pollen levels in Northeastern Iberian Peninsula. Sci. Total Environ. 818, 151827. https://doi.org/10.1016/j.scitotenv.2021.151827.

Alvarez, A., Gamella, J.F., Parra, I., 2016. Cannabis cultivation in Spain: a profile of plantations, growers and production systems. Int. J. Drug Policy 37, 70–81. https://doi.org/10.1016/j.drugpo.2016.08.003.

Amado, B.G., Villanueva, V.J., Vidal-Infer, A., Isorna, M., 2020. Gender differences among Cannabis self-cultivators in Spain. Adicciones 32 (3), 181. https://doi.org/10.20882/adicciones.1142.

Andersen, T.B., 1991. A model to predict the beginning of the pollen season. Grana 30, 269–275. https://doi.org/10.1080/00173139109427810.

Anselme, A., Metz-Favre, C., de Blay, F., 2011. Allergie aux stupéfiants. Rev. Fr. Allergol. 51 (6), 548–552. https://doi.org/10.1016/j.reval.2011.01.006.

Ashrafi, K., Shafiepour-Motlagh, M., Aslemand, A., Ghader, S., 2014. Dust storm simulation over Iran using HYSPLIT. J. Environ. Health Sci. Eng. 12 (1), 9. https://doi.org/10.1186/2052-336X-12-9.

Belmonte, J., Alarcón, M., Avila, A., Scialabba, E., Pino, D., 2008. Long-range transport of beech (Fagus sylvatica L.) pollen to Catalonia (north-eastern Spain). Int. J. Biometeorol. 52 (7), 675–687. https://doi.org/10.1007/s00484-008-0160-9.

Boullayali, A., Elhassani, L., Janati, A., Achmakh, L., Bouziane, H., 2021. Airborne pollen trends in Tétouan (NW of Morocco). Aerobiologia 37 (3), 479–505. https://doi.org/10.1007/s10453-021-09700-z.

Cabezudo, B., Recio, M., Sánchez-Laulhé, J., Trigo, M.D.M., Toro, F.J., Polvorinos, F., 1997. Atmospheric transportation of marihuana pollen from North Africa to the Southwest of Europe. Atmos. Environ. 31 (20), 3323–3328. https://doi.org/10.1016/S1352-2310(97)00161-1.

Cariñanos, P., Galan, C., Alcazar, P., Domınguez, E., 2004. Analysis of the particles transported with dust-clouds reaching Cordoba, southwestern Spain. Arch. Environ. Contam. Toxicol. 46, 141–146. https://doi.org/10.1007/s00244-003-2273-9.

Castroviejo Bolibar, S., 2005. Flora ibérica. Plantas vasculares de la Península Ibérica e Islas Baleares. Vol. III (2a).

Cerro, J.C., Cerdà, V., Caballero, S., Bujosa, C., Alastuey, A., Querol, X., Pey, J., 2020. Chemistry of dry and wet atmospheric deposition over the Balearic Islands, NW Mediterranean: source apportionment and African dust areas. Sci. Total Environ. 747, 141187. https://doi.org/10.1016/j.scitotenv.2020.141187.

Elvira-Rendueles, B., Moreno, J.M., Costa, I., Bañón, D., Martínez-García, M.J., Moreno-Grau, S., 2019. Pollen calendars of Cartagena, Lorca, and Murcia (Region of Murcia), southeastern Iberian Peninsula: 2010–2017. Aerobiologia 35 (3), 477–496. https://doi.org/10.1007/s10453-019-09578-y.

Escudero, M., Castillo, S., Querol, X., Avila, A., Alarc, M., Viana, M.M., Alastuey, A., Cuevas, E., Rodriguez, S., 2005. Wet and dry African dust episodes over eastern Spain. J. Geophys. Res. 110, D18S08. https://doi.org/10.1029/2004JD004731.

Escudero, M., Stein, A., Draxler, R.R., Querol, X., Alastuey, A., Castillo, S., Avila, A., 2006. Determination of the contribution of northern Africa dust source areas to PM10 concentrations over the central Iberian Peninsula using the Hybrid Single-Particle Lagrangian Integrated Trajectory Model (HYSPLIT) model. J. Geophys. Res. 111 (D6), D06210. https://doi.org/10.1029/2005JD006395.

Estève, R.S., Baisnée, D., Guinot, B., Petit, J.-E., Sodeau, J., O'Connor, D., Besancenot, J.-P., Thibaudon, M., Gros, V., 2018. Temporal variability and geographical origins of airborne pollen grains concentrations from 2015 to 2018 at Saclay,France. Remote Sens. 10 (12), 1–23. https://doi.org/10.3390/rs10121932.

European Commission, 2011. Establishing guidelines for demonstration and subtraction of exceedances attributable to natural sources under the Directive 2008/50/EC on ambient air quality and cleaner air for Europe. 38. Council of the European Union.

Fernández Rodríguez, S., 2012. Estudio comparativo en altura y distancia en el muestreo aerobiológico. [Doctoral thesis, Universidad de Extremadura]Institutional repository – Dehesa, Universidad de Extremadura http://hdl.handle.net/10662/317.

Fernández-Llamazares, Á., Belmonte, J., Boada, M., Fraixedas, S., 2014. Airborne pollen records and their potential applications to the conservation of biodiversity. Aerobiologia 30 (2), 111–122. https://doi.org/10.1007/s10453-013-9320-4.

Font Tullot, I., 2000. Climatología de España y Portugal (2a). Ediciones Universidad de Salamanca.

Galán, C., Ariatti, A., Bonini, M., Clot, B., Crouzy, B., Dahl, A., Fernandez-González, D., Frenguelli, G., Gehrig, R., Isard, S., Levetin, E., Li, D.W., Mandrioli, P., Rogers, C.A., Thibaudon, M., Sauliene, I., Skjoth, C., Smith, M., Sofiev, M., 2017. Recommended terminology for aerobiological studies. Aerobiologia 33 (3), 293–295. https://doi.org/10.1007/s10453-017-9496-0.

Galán, C., Cariñanos, P., Alcázar, P., Domínguez-Vilches, E., 2007. Spanish Aerobiology Network (REA): management and quality manual. Servicio de Publicaciones Universidad de Córdoba. http://www.uco.es/raa/infor_raa/manual_eng.pdf.

García-Mozo, H., 2011. The use of aerobiological data on agronomical studies. Ann. Agric. Environ. Med. 18, 1–6.

Gharbi, D., 2018. Evolución del comportamiento de los diferentes tipos polínicos en la atmósfera de Málaga (1991-2015): Su relación con los parámetros meteorológicos y cambio climático. [Doctoral thesis, Universidad de Málaga]Institutional repository – Universidad de Málaga https://hdl.handle.net/10630/17239.

Halbritter, H., Heigl, H., 2020. Cannabis sativa. PalDat. A palynological database. https://www.paldat.org/pub/Cannabis_sativa/303779;jsessionid=503ª1175ADB946A1D5A9CEE1C54CAD00;consultado%202021-07-13.

Jato, V., Rodríguez-Rajo, F.J., Alcázar, P., De Nuntiis, P., Galán, C., Mandrioli, P., 2006. May the definition of pollen season influence aerobiological results?. Data setAerobiologia 22 (1), 13–25. https://doi.org/10.1007/s10453-005-9011-x.

Kanatani, K.T., Ito, I., Al-Delaimy, W.K., Adachi, Y., Mathews, W.C., Ramsdell, J.W., 2010. Desert dust exposure is associated with increased risk of asthma hospitalization in children. Am. J. Respir. Crit. Care Med. 182 (12), 1475–1481. https://doi.org/10.1164/rccm.201002-0296OC.

Kellogg, C.A., Griffin, D.W., 2006. Aerobiology and the global transport of desert dust. Trends Ecol. Evol. 21 (11), 638–644. https://doi.org/10.1016/j.tree.2006.07.004.

Koren, A., Sikora, V., Kiprovski, B., Brdar-Jokanovic, M., Acimovic, M., Konstantinovic, B., Latkovic, D., 2020. Controversial taxonomy of hemp. Genetika 52 (1), 1–13. https://doi.org/10.2298/GENSR2001001K.

Maya Manzano, J.M., 2015. Estudio comparativo de la concentración de polen y esporas de Alternaria en el aire de tres ciudades de Extremadura. [Doctoral thesis, Universidad de Extremadura]Institutional repository – Dehesa, Universidad de Extremadura http://hdl.handle.net/10662/3192.

Mayoral, M., Calderón, H., Carno, R., Lombardero, M., 2008. Allergic rhinoconjunctivitis caused by Cannabis sativa pollen. J. Investig. Allergol. Clin. Immunol. 18 (1), 73–74.

MITECO, 2021. Histórico de Informes de Episodios Naturales. Ministry of Ecological Transition and Demographic Challenge. Spanish Government. https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/atmosfera-y-calidad-del-aire/calidad-del-aire/evaluacion-datos/fuentes-naturales/anuales.aspx.

Moreno-Grau, S., Aira, M.J., Elvira-Rendueles, B., Fernández-González, M., Fernández-González, D., García-Sánchez, A., Martínez-García, M.J., Moreno, J.M., Negral, L., Vara, A., Rodríguez-Rajo, F.J., 2016. Assessment of the Olea pollen and its major allergen Ole e 1 concentrations in the bioearosol of two biogeographical areas. Atmos. Environ. 145, 264–271. https://doi.org/10.1016/j.atmosenv.2016.09.040.

Nayak, A.P., Green, B.J., Sussman, G., Beezhold, D.H., 2017. Allergenicity to Cannabis sativa L. and methods to assess personal exposure. In: Chandra, S., Lata, H., ElSohly, M.A. (Eds.), Cannabis sativa L. - Botany And Biotechnology. Springer International Publishing, pp. 263–284 https://doi.org/10.1007/978-3-319-54564-6_12.

Negral, L., Aznar, F., Galera, M.D., Costa-Gómez, I., Moreno-Grau, S., Moreno, J.M., 2022. Phenological and seismological impacts on airborne pollen types: a case study of Olea pollen in the Region of Murcia, Mediterranean Spanish climate. Sci. Total Environ. 815, 152686. https://doi.org/10.1016/j.scitotenv.2021.152686.

Negral, L., Elvira-Rendueles, B., Moreno, J.M., García-Sánchez, A., Moreno-Grau, S., 2017. Aplicación del análisis de retrotrayectorias en Aerobiología. Rev.Salud Ambiental 17, 39–49.

Negral, L., Moreno-Grau, S., Galera, M.D., Elvira-Rendueles, B., Costa-Gómez, I., Aznar, F., Pérez-Badia, R., Moreno, J.M., 2021. The effects of continentality, marine nature and the recirculation of air masses on pollen concentration: Olea in a Mediterranean coastal enclave. Sci. Total Environ. 790, 147999. https://doi.org/10.1016/j.scitotenv.2021.147999.

Negral, L., Moreno-Grau, S., Moreno, J., Querol, X., Viana, M.M., Alastuey, A., 2008. Natural and anthropogenic contributions to PM10 and PM2.5 in an urban area in the western Mediterranean coast. Water Air Soil Pollut. 192 (1–4), 227–238. https://doi.org/10.1007/s11270-008-9650-y.

Negral, L., Moreno-Grau, S., Querol, X., Moreno, J., Viana, M., García-Sánchez, A., Alastuey, A., Moreno-Clavel, J., 2012. Weak pressure gradient over the Iberian Peninsula and African dust outbreaks: a new dust long-transport scenario. Bull. Am. Meteorol. Soc. 93 (8), 1125–1132. https://doi.org/10.1175/BAMS-D-10-05000.1.

Negral Álvarez, L., 2010. Variability of Levels And Composition in Airborne Particulate Matter in the Southeast of the Iberian Peninsula. Institutional repository – Universidad Politécnica de Cartagena.

Pérez, C.F., Gassmann, M.I., Covi, M., 2009. An evaluation of the airborne pollen–precipitation relationship with the superposed epoch method. Aerobiologia 25 (4), 313–320. https://doi.org/10.1007/s10453-009-9135-5.

Robayo-Avedaño, A., Galindo-Mendoza, M., 2014. Analysis of dispersal probability of genetically modified maize pollen using the HYSPLIT model. Agrociencia 48, 511–523.

Rolph, G., Stein, A., Stunder, B., 2017. Real-time Environmental Applications and Display sYstem: READY. Environ. Model Softw. 95, 210–228. https://doi.org/10.1016/j.envsoft.2017.06.025.

Ruiz-Valenzuela, L., Aguilera, F., 2018. Trends in airborne pollen and pollen-season-related features of anemophilous species in Jaen (south Spain): a 23-year perspective. Atmos. Environ. 180, 234–243. https://doi.org/10.1016/j.atmosenv.2018.03.012.

Scheifinger, H., Belmonte, J., Buters, J., Celenk, S., Damialis, A., Dechamp, C., García-Mozo, H., Gehrig, R., Grewling, L., Halley, J.M., Hogda, K.-A., Jäger, S., Karatzas, K., Karlsen, S.-R., Koch, E., Pauling, A., Peel, R., Sikoparija, B., Smith, M., de Weger, L.A., 2013. Monitoring, modelling and forecasting of the pollen season. In: Sofiev, M., Bergmann, K.-C. (Eds.), Allergenic Pollen. Springer, Netherlands, pp. 71–126 https://doi.org/10.1007/978-94-007-4881-1_4.

Sánchez-Ccoyllo, O.R., Silva Dias, P.L., de Fátima Andrade, M., Freitas, S.R., 2006. Determination of O3-, CO- and PM10-transport in the metropolitan area of São Paulo, Brazil through synoptic-scale analysis of back trajectories. Meteorog. Atmos. Phys. 92 (1–2), 83–93. https://doi.org/10.1007/s00703-005-0139-6.

Small, E., Antle, T., 2003. A preliminary study of pollen dispersal in Cannabis sativa in relation to wind direction. J.Ind.Hemp 8 (2), 37–50. https://doi.org/10.1300/J237v08n02_03.

Solomon, W.R., 2002. Airborne pollen: a brief life. J. Allergy Clin. Immunol. 109 (6), 895–900. https://doi.org/10.1067/mai.2002.125556.

Stein, A.F., Draxler, R.R., Rolph, G.D., Stunder, B.J.B., Cohen, M.D., Ngan, F., 2015. NOAA's HYSPLIT atmospheric transport and dispersion modeling system. Bull. Am. Meteorol. Soc. 96 (12), 2059–2077. https://doi.org/10.1175/BAMS-D-14-00110.1.

UNE EN 16868:2019, 2019. AENOR. Ambient Air—Sampling And Analysis of Airborne Pollen Grains And Fungal Spores for Networks Related to Allergy—Volumetric Hirst Method. UNE.

World Health Organization, 2019. WHO Expert Committee on Drug Dependence: Forty-first Report.

Visez, N., Chassard, G., Azarkan, N., Naas, O., Sénéchal, H., Sutra, J.P., Poncet, P., Choël, M., 2015. Wind-induced mechanical rupture of birch pollen: potential implications for allergen dispersal. J. Aerosol Sci. 89, 77–84. https://doi.org/10.1016/j.jaerosci.2015.07.005.

Zhang, X., Zhao, L., Tong, D., Wu, G., Dan, M., Teng, B., 2016. A systematic review of global desert dust and associated human health effects. Atmosphere 7 (12), 158. https://doi.org/10.3390/atmos7120158.