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Characterization of Allergen Emission Sources in Urban Areas

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Abstract

Pollen released by urban flora—a major contributor to airborne allergen content during the pollen season—has a considerable adverse impact on human health. Using aerobiological techniques to sample and characterize airborne biological particulate matter (BPM), we can identify the main species contributing to the pollen spectrum and chart variations in counts and overall pollen dynamics throughout the year. However, given the exponential increase in the number of pollen allergy sufferers in built-up areas, new strategies are required to improve the biological quality of urban air. This paper reports on a novel characterization of the potential allergenicity of the tree species most commonly used as ornamentals in Mediterranean cities. Values were assigned to each species based on a number of intrinsic features including pollination strategy, pollen season duration, and allergenic capacity as reported in the specialist literature. Findings were used to generate a database in which groups of conifers, broadleaves, and palm trees were assigned a value of between 0 and 36, enabling their allergenicity to be rated as nil, low, moderate, high, or very high. The case study presented here focuses on the city of Granada in southern Spain. The major airborne-pollen-producing species were identified and the allergenicity of species growing in urban green zones was estimated. Corrective measures are proposed to prevent high allergen levels and thus improve biological air quality.

Core Ideas

- Pollen emissions by urban flora are the chief source of airborne allergens.
- A novel characterization of the potential allergenicity of urban trees is presented.
- Wind-pollinated species are associated with higher allergenicity values.
- Assigning an allergenic value to each tree species will help to improve air quality.

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URBAN TREES play a major role in generating ecosystem services relating to air quality by removing gaseous pollutants and particulate matter (Nowak et al., 2006; Bealey et al., 2007) and are directly involved in the sequestration and storage of CO_2 and other greenhouse gases (Nowak and Crane, 2002). Tree canopy cover also affects local microclimate, mitigates heat stress, and creates better conditions for thermal comfort than open spaces (Lafortezza et al., 2009; Yan et al., 2012). Moreover, urban tree diversity plays a key aesthetic and landscape role with a socioeconomic impact on the environment (Smardon, 1988; Lohr et al., 2004).

However, some urban tree species have been found to cause episodes of air pollution, that is, ecosystem disservices (Escobedo et al., 2011; Lyytimäki and Sipilä, 2009). A number of authors have noted that ozone and aerosol formation in the urban atmosphere is largely attributable to biogenic volatile organic compound emissions by local urban vegetation (Calfapietra et al., 2013). Pollen released during the flowering period has also been identified as a major airborne allergen in urban environments (Cariñanos and Casares-Porcel, 2011; Lohr et al., 2004; Seitz and Escobedo, 2012; Staffolani et al., 2011), exerting an adverse impact on public health and on biological air quality (Cariñanos et al., 2001, 2007). The allergenic potential of pollen from certain common ornamental tree species is widely recognized (Ribeiro et al., 2009; Celik et al., 2005; Velasco-Jiménez et al., 2014; Díaz de la Guardia et al., 2006), and, in urban areas, pollen may interact with other air pollutants such as CO_2 (Ziska and Caulfield, 2000), thus leading to a greater risk of allergic sensitization than in rural areas (Bosch-Cano et al., 2011; Bousquet et al., 2008; Gonzalo-Garijo et al., 2006; Jianan et al., 2007; Thompson and Thompson, 2003). The situation is particularly serious in the Mediterranean region, where climate and topography favor the growth of numerous tree species whose flowering period is longer than in other bioclimatic zones, leading to the world's highest incidence of pollen allergies (Asher et al., 2006; D'Amato et al., 2007).

The installation of Hirst-type aerobiological sampling units is currently among the most widely used measures for

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Abbreviations: BPM, biological particulate matter; I_{UGZA}, allergenicity index; PAV, potential allergenic value; PI, pollen index.

monitoring airborne allergenic pollen levels in urban areas since continuous monitoring enables characterization of biological particulate matter (BPM), identification of emission sources, estimation of threshold levels for the onset of allergy symptoms, and measurement of the duration of pollen in the air as a function of weather-related variables (Wilson et al., 2011; Galán et al., 2007). Analysis of the pollen spectrum in urban environments has highlighted the major involvement of pollen from green-space trees in the sensitization of the local population (D'Amato et al., 2007; Dales et al., 2008; Harberle et al., 2014; Liu et al., 2010; Lovasi et al., 2013; Seitz and Escobedo, 2012; White and Bernstein, 2003).

Given the progressively rising incidence of pollen-related hay fever in urban areas over recent decades (Cariñanos and Casares-Porcel, 2011) and the likelihood of further increases due to climate change (Shea et al., 2008), new strategies are required to minimize the impact of plant allergens on public health. This paper reports on a novel characterization of the potential allergenicity of tree species most commonly used as ornamentals in Mediterranean cities. The assignment of a potential allergenic value (PAV) to each species will enable mitigation strategies to be adopted in existing populations and will help to guide the design of future green spaces by enabling the selection of the most appropriate species. Practical application of this approach is illustrated in a case study performed in Granada (southern Spain) where PAVs were assigned to tree species in the city's 10 largest green spaces with a view to establishing the overall allergenicity of these spaces and proposing the appropriate corrective measures in each case.

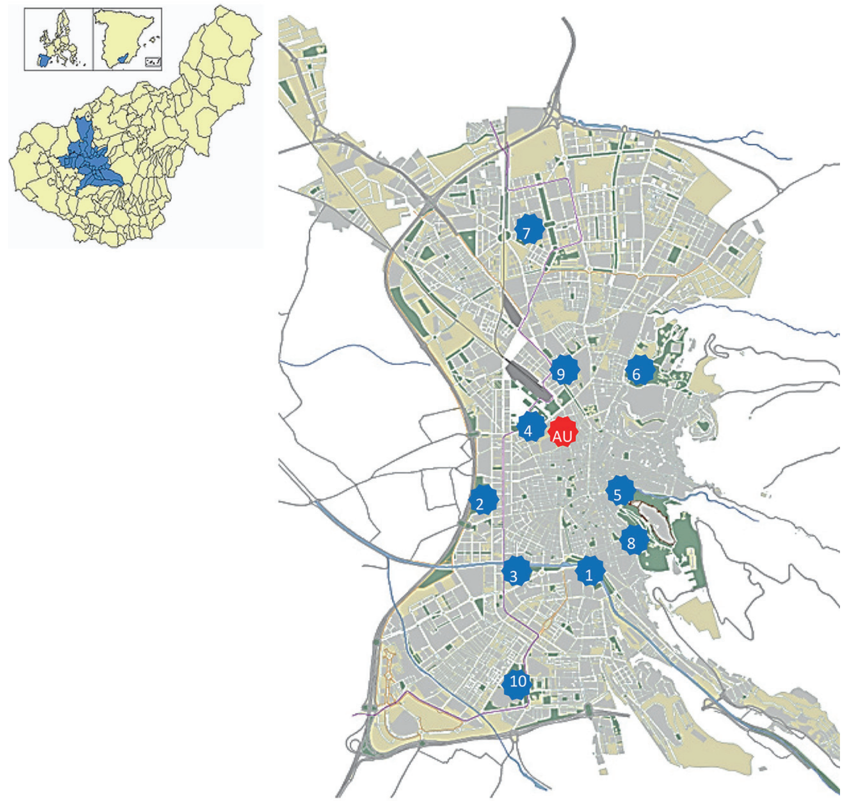

Fig. 1. Location of the city of Granada, Spain (top) and of different green spaces featured in this study in the metropolitan area of Granada (below). 1, Paseo del Salón y de la Bomba Boulevard; 2, Garcia Lorca Park; 3, Tico Medina Park; 4, Fuentenueva Garden; 5, Gomérez Periurban Forest; 6, Garden of the Faculty of Theology; 7, Almunia de Aynadamar Park; 8, Carmen de los Mártires Gardens; 9, Triunfo Gardens; 10, Zaidin Park; AU, aerobiological sampling unit at the University of Granada.

Material and Methods

Description of the Study Area

The area selected to illustrate the application of this tool for characterizing allergenic pollen release from urban trees was the city of Granada (37°10′ N, 3°35′ W), in the southeastern Iberian Peninsula (Fig. 1). The city, located in the intrabaetic basin in the foothills of the Sierra Nevada, covers a surface area of 88.02 km^2. Climate conditions are typical of the Mediterranean area, with a certain degree of continentality. The annual average temperature is 15°C, and total average annual rainfall is 375 mm (data provided by the Spanish Meteorology Agency [www.aemet.es], as measured at a weather station located at Granada Airport, for the period 1973–2000). The city's main environmental indicators are shown in Table 1. Granada boasts 363 green spaces, yielding a total green surface area of over 1.0×10^3 m^2, and an average of 4.74 m^2 of green surface per resident. The ratio of 160 trees per 1000 inhabitant is slightly higher than the European average (Pauleit et al., 2002). The most abundant genera in these green areas are, in decreasing order, *Platanus*, *Ulmus*, *Acer*, *Cupressus*, *Citrus*, and *Populus*, some species of which contribute considerably to the city's high pollen index (PI). The PI, defined as the annual sum of daily values, is estimated at over 55×10^3 pollen grains yr^{-1} (Table 2), according to the findings of 22 yr continuous monitoring by the aerobiological monitoring unit located at the University of Granada Science Faculty (Fig. 1) operating in accordance with the standardized Spanish Aerobiology Network procedure (Galán et al., 2007). Analysis of the local pollen spectrum reveals that the highest contributions come from species in urban and periurban forests. Pollen allergy is reported by almost 30% of the city's population, the highest rate of sensitization being recorded for *Olea* and Poaceae—the major causes of pollen allergy in the Mediterranean area—followed by other widely planted urban tree species: *Cupressus* spp., *Platanus* spp., *Populus* spp., *Fraxinus* spp. (D'Amato, 1998; Díaz de la Guardia et al., 2006).

Database of Urban Tree Potential Allergenic Values

Species included for testing this application were selected by direct observation or by using bibliographical references with a view to focusing particularly on those compatible with Mediterranean climate characteristics, that is, those included in USDA hardiness categories 8 through 10 (able to live at temperatures between −7 and +4°C), but also—given local climatic variability—some species in categories 7 (−17 to −11°C) and 11 (+4 to 11°C) (Magarey et al., 2008; Roloff et al., 2009).

To facilitate data management, selected species were assigned to one of three categories traditionally used in urban landscape gardening: conifers, broadleaves, and palms (Nagendra and

Table 1. Environmental indicators for the city of Granada.

Environmental indicators	Value
No. of trees†	39,035
No. trees per 1000 inhabitants	160
Main tree species (no. specimens)	
Platanus × *hispanica* Mill. ex Münchh.	4,392
Ulmus spp.	2,879
Acer spp.	2,541
Cupressus spp.	2,474
Citrus aurantium L.	2,305
Populus spp.	2,069
Phoenix spp; *Washingtonia filifera*	1,152
Robinia pseudoacacia L.	995
Melia azederach L.	680
Ligustrum spp.	620
Total green surface area (m^2)	$1,060 \times 10^3$
Surface green area per inhabitant (m^2)	4.74
No. of green areas	
>5.000 m^2	63
<5.000 m^2	300
Total	363
Average surface of green areas (m^2)	3,145.7
Daily annual mean PM_{10}, $PM_{2.5}$ ($\mu g\ m^{-3}$)‡	29, 16
Daily annual mean BPM§ (pollen grains m^{-3})	152
Average days per month with poor air quality¶	8
Average days per month with poor biological air quality§	10#

† Data from the Department of Parks and Gardens of Granada City Hall, 2013.

‡ Data from ambient (outdoor) air pollution database, World Health Org., 2014.

§ Data from the aerobiological sampling unit, University of Granada.

¶ Data from the Surveillance and Environmental Monitoring Network, Department of the Environment, Regional Government of Andalusia, Spain.

These data represent a monthly average estimated taking into account the total number of days with poor biological air quality in the city. However, this figure may be exceeded in the periods in which major contributory species with pollen emissions are in bloom: Cupressaceae, *Olea*, *Platanus*, Poaceae, and *Parietaria*.

Gopal, 2011). Wherever possible, subspecies levels were used (i.e., subspecies, hybrid, variety, or cultivar) since some ornamentals are single-sex clones or sterile plants, which may be relevant when establishing their allergenic capacity. Each record included the following general taxon information: scientific name, common name, bioclimatic zone, and whether monoecious or dioecious, since in the latter case only male trees are relevant for establishing PAVs.

The following variables directly affecting PAV linked to biological pollen-release features, were recorded: type of pollination (tp), duration of pollination period (dpp) (Navés-Viñas et al., 2003), and allergenic potential (ap) as noted in published reports and specific databases (Cariñanos and Casares-Porcel, 2011; Frenz, 1995; Mari et al., 2009; Ogren, 2000, 2003; Spieksma et al., 1992; Radauer et al., 2014) providing full information on plant allergens. Taken in conjunction, data for these three variables yielded the PAV for urban trees in the Mediterranean area:

$$\mathrm{PAV} = \mathrm{tp} \times \mathrm{dpp} \times \mathrm{ap}$$

Variables and values used to determine PAVs are detailed in Table 3. Once PAVs had been assigned to each species, the allergenicity of that species was classed as nil, low, moderate, high, or very high using the ranges shown in Table 4.

Allergenicity Index for Urban Green Areas

The allergenicity index (I_{UGZA}), as outlined by Cariñanos et al. (2014), was calculated by combining PAVs for trees in urban green spaces with data on tree size, surface area occupied by each tree, and number of individuals in the green space. This index, which reflects the composition, development, and abundance of allergenic and nonallergenic species in any given area, takes the form of an overall value between 0 and 1. Ten of the city's main green areas were selected to ensure a variety of types: boulevard (Paseo del Salón and Paseo de la Bomba), modern park (García Lorca, Zaidín, and Tico Medina), gardens dating from the 1970s and 1980s (Fuentenueva, Triunfo, and Faculty of Theology), historic gardens (Carmen de los Mártires), and periurban forest (Bosque de Gomérez). These green areas are located in different districts of the city (Fig. 1) and vary considerably in terms of surface area, design, and number and distribution of trees. Species diversity for each green area was also calculated using the Shannon–Weaver index (Shannon and Weaver, 1949).

To identify the factors most influencing this index, overall values and certain specific features for each green area were subjected to a Pearson correlation test.

Biological Air Quality

Biological air quality levels, that is, varying airborne pollen counts from one or more species of varying allergenicity (Galán

Table 2. Aerobiological indicators of the city of Granada (average data for the period 1992–2013).

Annual pollen index†	Main taxa contributing to the aerobiological spectrum	Main sources of emission of biological particulate matter	Pollen allergy prevalence in the population of Granada
	%	%	%
55.502	*Olea*, 35.5 *Cupressus*, 29 *Parietaria*, 10.5 *Quercus*, 6.05 *Platanus*, 5.2 Poaceae, 5.0 *Populus*, 2.5 *Pinus*, 1.70 *Artemisia*, 1.62 Amaranthaceae, 1.5 *Acer*, 1.43	Natural vegetation, 9.9 Urban and periurban forests (included expontaneous vegetation), 49.1 Crops, 41	*Olea*, 77.2 Poaceae, 54.6 Amaranthaceae, 31.5 *Cupressus*, 29.5 *Plantago*, 23.4 *Artemisia*, 19.6 *Platanus*, 17.0 *Parietaria*, 15.9 *Populus*, 7 Other *Oleaceae* (*Fraxinus*, *Ligustrum*), 7

† Annual sum of daily pollen grain counts averaged over 1992 through 2013.

Table 3. Parameters and values to be assigned for obtaining the potential allergenicity value (PAV) of urban Mediterranean trees.

Parameter	Value	Description
Type of pollination	0	Plants that do not emit pollen because they are sterile (varieties, hybrids, cultivars), cleistogamous, or are female only
	1	Plants of primarily or exclusively biotic pollination with low pollen emission
	2	Mixed pollination system plants (amphiphilic), none of which prevails over others, and which display moderate-high pollen emission
	3	Wind-pollinated plant species that produce and release large amounts of pollen.
Duration of pollination even	1	Pollen emissions last 1 to 3 wk
	2	Pollen emissions last 4 to 6 wk
	3	Pollen emissions last more than 6 wk or all the Genus or species share the same pollen type and pollination occurs successively
Allergenic potential	0	Nonallergenic or not reported as allergenic
	1	Low allergenicity
	2	Moderate allergenicity, with moderate effect on population
	3	High allergenicity, with marked effect on population
	4	Major allergens in the Mediterranean region, broad distribution and presence, very marked effect on population

et al., 2007), are shown in Table 5. These levels are used to alert the population to pollen counts sufficient to prompt moderate, unhealthy, or hazardous allergy symptoms (Cariñanos et al., 2007).

Results

On the basis of direct observation and identification of the species growing in the study areas coupled with bibliographical data on compatibility with local climate, a list of 100 representative species was compiled for Granada; a simplified version is provided in Table 6. Of the 100 taxa, 83% were broadleaves, 13% conifers, and 4% palms. A total of 49% displayed PAVs in the range 1 to 6 (low allergenicity), while 15% were classed as moderately allergenic (range 8–12); allergenicity was rated as high (16–24) or very high (27–36) for 34% of taxa. The very high values were recorded by wind-pollinated trees and particularly by members of the Cupressaceae family [*Chamaecyparis lawsoniana* (A. Murray) Parl., *Cupressus* spp., *Juniperus phoenicea* L., *Platycladus orientalis* (L.) Franco, and *Taxus baccata* L.], all of which displayed maximum PAVs.

Species were rated as moderately allergenic (PAV 8–12) for a variety of reasons: in some cases, despite abundant pollen production and wide dispersal, their pollen is regarded in the specialist literature as a very minor cause of allergies (*Castanea sativa* Mill., *Cedrus* spp., *Celtis australis* L., *Phoenix* spp., and *Pinus* spp.); in other cases, despite high reported allergenicity, they are entomophilous and displayed low pollen-release levels [*Ligustrum* spp., *Pistacia* spp., *Tamarix* spp., and *Trachycarpus fortunei* (Hook.) H. Wendl.].

The PAVs obtained for tree species growing in Granada's urban green areas were used to calculate I_{UGZA} of these areas: values for this index ranged from a minimum of 0.1 for Zaidín Park to a maximum of 0.78 for the Bosque de Gomérez, one of the city's periurban forests (Supplemental Table S1). Attention is also drawn to marked differences in both tree numbers and species diversity in these areas: 134 different tree species were recorded in the Paseo del Salón boulevard compared with only 15 in the Triunfo Gardens. The highest tree density was recorded for the Paseo del Salón boulevard (>1686 trees ha^{-1}), and the lowest was in Tico Medina Park and the Triunfo Gardens (barely 100 trees ha^{-1}). High biodiversity values were obtained using the Shannon–Weaver index for most green areas studied, with the exception of the periurban Bosque de Gomérez, which yielded an index value of <3. All study areas contained at least some of the species recording the highest potential allergenicity (*Cupressus*, *Platanus*, and *Olea europaea* L.), although numbers and proportions varied.

Application of Pearson's correlation test to I_{UGZA} and certain features of the study areas (Table 7) revealed a significant positive correlation between I_{UGZA} and total number of trees per green space (0.923, $p < 0.01$), and a nonsignificant negative correlation between I_{UGZA} and Shannon–Weaver biodiversity score (H′; −0.298, $p = 0.064$). However, no correlation was observed between I_{UGZA} scores and species richness (i.e., number of species), since I_{UGZA} reflects the number of trees of each species in a given space rather than the number of different species in that space.

Analysis of the involvement of pollen from the recorded species in adverse biological air quality episodes, using the categories shown in Table 5, revealed that some of the most common urban trees in Granada—and by extension in the Mediterranean area as a whole—belonged to Groups 3 (*Platanus*, *Ginkgo biloba* L., *Populus*, *Tilia* spp., *Morus alba* 'Pendula', *Acer* spp., *Ulmus* spp., *Ligustrum* spp.) and 4 (*Cupressus*, *Olea*, *Fraxinus*, *Carpinus betulus* L., *Betula pendula* Roth); during their flowering season, therefore, BPM levels may cause biological air quality to be classed often as unhealthy and, relatively, often as hazardous.

Table 4. Ranks of potential allergenicity value (PAV) applicable to urban tree species in the Mediterranean region.

PAV (rank)	Allergenicity
0	Nil
1–6	Low
8–12	Moderate
16–24	High
27–36	Very high

Discussion

Generation of a database characterizing major urban tree species in terms of their potential allergenicity is a novel tool aimed at minimizing the impact of plant allergens on the local population, and is thus of considerable public health interest (Lovasi et al., 2013). One of its chief advantages is that it enables different tree species to be rated as sources of

Table 5. Categories of biological air quality based on the presence of different allergenic taxa and allergenicity groups. Modified from Management and Quality Manual, Spanish Aerobiology Network (*Galán et al., 2007*).

Level	Definition	Group	Definition
Good	Airborne pollen counts remain at low levels (1–25 pollen grains m^{-3})	Group 1	Anemophilous or entomophilous herbaceous species with low to moderate presence in the air and variable allergenicity
Moderate	Airborne pollen counts for most pollen types are low, but pollen types Group 4 are present and counts for Group 1 are at ~25 pollen grains m^{-3}.	Group 2	Anemophilous and entomophilous herbaceous or shrub species with moderate-high presence in the air and moderate-high allergenicity
Unhealthy	Airborne pollen counts for Groups 2, 3, and 4 are moderate (25 pollen grains m^{-3}), or high for Group 1 (<25 pollen grains m^{-3}), or two or more main allergenic taxa in the area are present simultaneously in moderate levels.	Group 3	Anemophilous and entomophilous tree species with moderate (high) presence in the air and moderate (high) allergenicity
Hazardous	Airborne pollen counts are high (<25 pollen grains m^{-3}) for any Group, or two or more highly allergenic pollen types are recorded simultaneously.	Group 4	Mainly anemophilous tree species with high presence in the air and high to very high allergenicity

allergy-causing pollen, taking into account not only the allergenic risk of the pollen but also the amount of pollen released. Moreover, unlike in other suggested approaches (Hruska, 2003; Ogren 2000, 2003; Matyasovszky and Makra, 2012), the quantitative score generated for each species can be fine-tuned as a function of the importance of that species as a major allergen in a given area. This resource helps to unify and standardize the abundant yet scattered information available on the allergenicity of urban ornamental flora (Ciferri et al., 2006; Hruska, 2003; Ianovici, 2007; Lorenzoni-Chiesura et al., 2000; Matyasovszky and Makra, 2012; Staffolani et al., 2011; Velasco Jiménez et al., 2014) and may, thus, be useful in any other area in which bioclimatic conditions lead to similar plant phenological and reproductive behavior (Raven, 1973). Finally, unlike other complex approaches to modeling airborne BPM levels (e.g., Helbig et al., 2004), the system outlined here is readily applicable, even by the layman.

To illustrate the utility of the database, the system was tested in the city of Granada, whose boulevards and green spaces—owing to its geographical location and typically Mediterranean climate—boast a wide diversity of tree species, some of which are associated with maximum PAVs (16–27) and are major causes of pollen allergy in the local population (Alba, 1997). The incidence of sensitization to *Cupressus*—a historically symbolic species in the city (Casares-Porcel, 2010) and one widespread in certain urban areas—has increased to three times the national average (Díaz de la Guardia et al., 2006). The method used to calculate PAV enables species like this to be assigned a value to the allergenic potential variable of 4, thus increasing their importance as local allergens, with a PAV of between 24 and 36. The same is true of the London plane (*Platanus*), whose abundance as a shade tree in parks, gardens, and boulevards has prompted a considerable increase in the incidence of pollen allergy in the local population (Alcázar et al., 2011) and is therefore assigned a value of 4.

Particular mention should be made of *Olea*. Despite its intermediate entomophilous and anemophilous nature, its great abundance in periurban areas as a commercial crop has led to its becoming the chief contributor to the local pollen spectrum and the leading cause of pollen allergy not only in Granada but across the whole of the Mediterranean area (D'Amato, 1998; De Linares et al., 2007). Moreover, its growing use as an ornamental in some of the city's green areas (Velasco-Jiménez et al., 2014) has prompted increased sensitization to other Oleaceae because of cross-reactivity (Lombardero et al., 2002).

Some taxa, though classed as moderately allergenic in terms of their PAV, are rated as 3 in terms of allergenic potential. This is the case of *Aesculus* spp., *Eleagnus angustifolia* L., *Lagunaria patersonii* (Andrews) G.Don., *Ligustrum* spp., *Pistacia*, *Schinus* spp., *Tamarix*, and *Zelkova serrata* (Thunb.) Makino, which—though entomophilous, or having a short pollen season—may give rise to proximity allergies in the immediate vicinity of the tree in question (De Larramendi and Abujeta, 2005), or may be cross-reactive with other major panallergens (Weber, 2003). Also, male trees of monoecious or dioecious hermaphrodite species may have positive PAVs, while females of those species bearing pistillate non-pollen-producing flowers have a PAV of nil (Freeman et al., 1976). Of the species listed for Granada, this would be the case of *Acer negundo* L., *Ginkgo biloba*, *Laurus nobilis* L., *Morus alba*, *Populus* spp., *Rhus typhina* L., *Schinus molle* L., and *Salix alba* L.

When designing urban green areas, it important to choose the right cultivar for those taxa with a large number of ornamental varieties, since this may directly affect the amount of allergenic pollen released. A good example is *Populus*, a genus widely used in Granada for screening purposes, whose numerous varieties and hybrids include some male-only (*P. alba* 'Pyramidalis', *P. ×canadensis*, *P. nigra* 'Italica') and other female-only cultivars (*P. alba* 'Nívea', *P. canadensis* 'Incrassata', *P. tremuloides*) (Ogren, 2000, 2003); greater abundance of one or the other may increase or decrease the allergenicity score for this taxon (Celik et al., 2005).

One major application of this tool for establishing the PAV of the species in a given green space is in the calculation of I_{UGZA} of that area (Cariñanos et al., 2014). Here, the I_{UGZA} obtained for 10 of Granada's main green areas highlighted considerable differences between them, linked largely to the ratio of highly allergenic species to the total number of trees in the green area. Although all 10 areas studied here contained trees belonging to the species classed as highly allergenic (*Cupressus*, *Platanus*, *Olea*, *Ligustrum*, *Fraxinus*, and *Morus*), the highest I_{UGZA} values were recorded for those green areas where wind-pollinated allergenic species predominated (Bosque de Gomérez and Carmen de los Mártires). Although statistical tests revealed no significant correlation between the biodiversity (H') and the I_{UGZA} of any green area, maintaining and even increasing biodiversity may be a useful strategy for controlling allergenicity, since there is evidence that loss of biodiversity may be in part responsible for the increasing incidence of allergies over the last few years (Hanski et al., 2012; Haahtela et al., 2013).

Table 6. Potential allergenicity values (PAVs) and allergenic category of the 100 most common urban trees in the city of Granada.

Tree	PAV†	Allergenicity	Tree	PAV	Allergenicity	Tree	PAV	Allergenicity	Tree	PAV	Allergenicity
Abies spp.	3×2×1 = 6	Low	*Cercis siliquastrum*	1×2×2 = 4	Low	*Lagerstroemia indica*	1×2×1 = 2	Low	*Populus alba* 'Pyramidalis'	3×2×3 = 18	High
Acacia spp.	1×3×2 = 6	Low	*Chamaerops humilis*	3×2×3 = 18	High	*Lagunaria patersonii*	1×1×3 = 3	Low	*Populus* × *canadensis*	3×2×1 = 6 (mainly female)	Low
Acer negundo	3×2×3 = 18 (dioecious)	High	*Chamaecyparis lawsoniana*	3×3×3 = 27	Very high	*Laurus nobilis*	1×3×2 = 6 (dioecious)	Low	*Populus nigra* 'Italica'	3×2×3 = 18	High
Acer spp.	2×2×2 = 8	Moderate	*Citrus* spp.	1×3×1 = 3	Low	*Ligustrum* spp.	2×2×3 = 12	Moderate	*Prunus* spp.	1×1×1 = 1	Low
Aesculus spp.	2×2×3 = 12	Moderate	*Corylus* spp.	1×1×1 = 1	Low	*Liquidambar styraciflua*	3×2×3 = 18	High	*Punica granatum*	1×1×1 = 1	Low
Ailanthus altissima	2×3×3 = 18	High	*Cupressus* spp.	3×3×3 = 27	Very high	*Liriodendron tulipifera*	1×1×2 = 2	Low	*Pyrus* spp.	1×1×1 = 1	Low
Albizia julibrissin	1×1×2 = 2	Low	*Diospyros kaki*	3×3×4 = 36	Very high	*Magnolia* spp.	1×2×2 = 4	Low	*Quercus* spp.	3×3×2 = 18	High
Alnus glutinosa	3×2×3 = 18	High	*Dracena drago*	1×1×1 = 1	Low	*Malus* spp.	1×1×1 = 1	Low	*Rhus typhina*	1×1×3 = 3 (dioecious)	Low
Araucaria spp.	3×3×2 = 18	High	*Eleagnus angustifolia*	1×1×0 = 0	Null	*Melia azederach*	1×2×1 = 2	Low	*Robinia* spp.	1×2×2 = 4	Low
Arbutus unedo	1×1×2 = 2	Low	*Eryobotria japonica*	2×1×3 = 6	Low	*Morus alba* 'Pendula'	3×2×3 = 18	High	*Salix alba*	3×2×3 = 18 (dioecious)	High
Bahuinia spp.	1×1×2 = 2	Low	*Erythrina* spp	1×2×1 = 2	Low	*Morus nigra*	3×3×3 = 27	Very high	*Salix purpurea*	3×2×3 = 18	High
Betula pendula	3×3×3 = 27	Very high	*Eucalyptus* spp.	1×1×2 = 2	Low	*Mussa* spp.	1×2×2 = 4	Low	*Schinus* spp.	1×1×3 = 3	Low
Brachychiton spp	1×1×2 = 2	Low	*Fagus* spp.	3×2×2 = 12	Moderate	*Olea europaea*	2×3×4 = 24	Very high	*Sophora japonica*	2×1×2 = 4	Low
Broussonetia papyrifera	3×3×3 = 27	Very high	*Feijoa sellowiana*	1×1×1 = 1	Low	*Parkinsonia aculeata*	1×2×2 = 4	Low	*Sorbus* spp.	1×2×2 = 2	Low
Callistemum spp.	1×3×3 = 9	Moderate	*Ficus* spp.	1×2×1 = 2	Low	*Pawlonia tomentosa*	1×1×2 = 2	Low	*Tamarix* spp.	2×2×3 = 12	Moderate
Calocedrus decurrens	3×3×1 = 9	Moderate	*Fraxinus angustifolia*	3×2×2 = 12	Moderate	*Persea gratissima*	1×1×1 = 1	Low	*Taxodium distichum*	3×3×3 = 27	High
Carpinus betulus	3×3×3 = 27	Very high	*F. excelsior, F. ornus*	3×2×3 = 18	High	*Phoenix* spp.	3×2×2 = 12	Moderate	*Taxus baccata*	3×2×3 = 18	High
Carya spp	3×2×3 = 18	High	*Ginkgo biloba*	3×2×3 = 18 (dioecious)	High	*Photinia serrulata*	1×2×1 = 2	Low	*Thuja plicata*	3×3×3 = 27	Very high
Castanea sativa	3×2×2 = 12	Moderate	*Gleditsia triacanthos*	1×2×2 = 4	Low	*Phytolaca dioica*	1×1×2 = 2	Low	*Tilia* spp.	2×1×2 = 4	Low
Casuarina equisetifolia	3×3×3 = 27	Very high	*Grevillea robusta*	1×1×2 = 2	Low	*Picea* spp.	3×2×1 = 6	Low	*Tipuana tipu*	1×1×1 = 1	Low
Catalpa bignonioides	1×1×3 = 3	Low	*Hibiscus syriacus*	1×2×2 = 4	Low	*Pinus* spp.	3×2×2 = 12	Moderate	*Trachycarpus fortunei*	2×2×3 = 12	Moderate
Cedrus spp.	3×3×1/2 = 9/18	Moderate/high	*Jacaranda mimosifolia*	1×1×2 = 2	Low	*Pistacia atlantica*	3×1×3 = 9	Moderate	*Ulmus* spp.	3×2×3 = 18	High
Ceiba insignis	1×1×1 = 1	Low	*Juglans* spp.	3×3×2 = 18	High	*Pittosporum tobira*	1×3×1 = 3	Low	*Washingtonia* spp.	2×2×1 = 4	Low
Celtis australis	3×2×2 = 12	Moderate	*Juniperus phoenicea*	3×3×3 = 27	Very high	*Platanus hispanica; Platanus* spp.	3×2×3 = 18	High	*Yucca* spp.	1×1×2 = 2	Low
Ceratonia siliqua	1×2×2 = 4	Low	*Koelreuteria paniculata*	1×1×2 = 2	Low	*Platycladus orientalis*	3×3×3 = 27	Very high	*Zelkova serrata*	2×2×3 = 12	Moderate

† PAV = tp × dpp × ap; tp, type of pollination; dpp, duration of pollination event; ap, allergenic potential.

Table 7. Pearson's correlation between index of allergenicity (I_{UGZA}) and characteristics of the green spaces in this study.

	Surface of the green space	Density of trees	Number of trees	Number of species	Index of biodiversity
I_{UGZA}	0.520	0.178	0.923**	0.152	−0.298
p values	0.123	0.623	0.623	0.676	0.064

** Significant at the 0.01 probability level.

A further consideration is that by estimating the I_{UGZA} of urban green spaces we can identify the main sources of allergenic BPMs in the metropolitan area, with a view to focusing biological air quality interventions. Once released into the air, BPMs behave in much the same way as chemical or abiotic pollutants (Cariñanos et al., 2001), and their dispersal is strongly influenced both by the city's town-planning structure and by its microclimate. A vital step when planning a new urban green space should be the thorough analysis of the structural nature of the area surrounding the intended site, examining all potential factors likely to favor the build-up of biotic and abiotic pollutants, including the architectural layout of the designated area itself (Cariñanos et al., 2000; Rodriguez-Rajo et al., 2010), and the effects of the urban climate (Shea et al., 2008; Nazridoust and Ahmadi, 2006). Analysis should also take into account the incorporation of particulate matter originating in periurban areas, which may increase the existing airborne allergen load (Burge and Rogers, 2000). When deciding on the specific green-space design, key planning measures should reflect prevailing wind patterns, the selection of species with low-to-moderate PAVs, and the use of elements facilitating pollen uptake, such as water features and nonallergenic lawns (Cariñanos and Casares-Porcel, 2011; Cariñanos et al., 2014).

In existing green areas, measures should be aimed at progressively reducing sources of allergenic pollen. Given that it is not feasible to eradicate all allergy-causing trees (Lorenzoni-Chiesura et al., 2000), detailed awareness of the problem may enable a progressive reduction in the proportion of species in Groups 3 and 4 by replacing them on their death; in this context, it should be remembered that the lifespan of urban trees may up to 40% lower than that of wild trees in light of stress factors (Sklar and Ames, 1985). Another useful measure might be to diversify single-species populations, since these are major allergen sources (Gonzalo-Garijo et al., 2006). For this purpose, selective replacement—for example, of one in every three trees with a high PAV—could reduce local pollen emission by up to 30%. The list of urban species generated here is divided into three broad categories widely used in landscape gardening: conifers, broadleaves, and palms; these categories could be maintained, but replacing trees in each group by less allergenic species. The selection of replacement species could be fine-tuned by taking into account additional information, including sex-related allergenicity in dioecious species and cultivar sterility (Ogren, 2000), thus ensuring that the replacement of one species by another has no marked effect on the landscape.

Finally, it should be stressed that the construction of this preliminary database was prompted by the urgent need to identify additional measures for controlling airborne allergens in urban environments; the aim is to expand the number of records. Given that the incidence of respiratory disorders linked to high pollen counts is expected to rise over the next few years as a result not only of climate change (McMichael et al., 2006) but also of the increasing proportion of the population living in urban areas (United Nations, 2008), any tool aimed at minimizing the impact of allergenic pollen should be heavily publicized and made available to the general public. This is one way of ensuring that urban green spaces, and the plants they contain, can continue to play a key role in sustainable, healthy cities (Haq, 2011), providing a variety of benefits and enhancing the well-being of local residents without endangering their health (Pataki et al., 2011; Lafortezza et al., 2009; Adinolfi et al., 2014).

Conclusions

This database, providing potential allergenicity values for tree species widely found in the Mediterranean region, is a novel tool to help identify allergen sources in urban environments. It offers a number of advantages:

- It enables species to be classified in terms of their role in affecting pollen allergies in urban environments.
- It aids quantification of the allergenicity index of urban green spaces.
- It helps to improve biological air quality by focusing on BPM levels.
- It can be used as a basis for measures aimed at mitigating overall allergen loads in any given area.
- It helps shape the design strategy for new urban green spaces by ensuring low allergenic impact.
- It lays the foundations for appropriate corrective measures in existing green areas.

Our findings also complement the information provided by aerobiological monitoring units already operating in some areas. Above all, the PAVs provide a rough estimation of the potential allergenicity of areas where no allergenic BPM monitoring measures have yet been implemented.

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