Title: Allergenicity of the urban green areas in the city of Córdoba (Spain)

Abstract:

Gardens provide from the antiquity a place of easing and leisure for the human being. The development of gardens in cities carries the creation of a green space that serves as support to the oxygenation of the air in these and participate in the mitigation of pollution. However, sometimes these parks and gardens can generate health problems in residents due to the presence of species that release high concentrations of allergenic pollen grains into the atmosphere. This work presents a study of potential allergenicity of urban green areas in the city of Córdoba (Spain) to observe if these spaces could be considered as a problem for public health due to its poor air quality. The results obtained suggest that some study spaces present a moderate allergenic potential and could represent a risk to the citizens. The main causes of this high rate in these areas have been the abundance of individuals of allergenic species, concentrated in a small area.

Key words: Urban green areas, Allergenic flora, Ornamental flora, Index of alergenicity; Airborne pollen.

Introduction

Gardens and parks of the cities are perceived by the inhabitants as beneficial for society due to the numerous contributions of them for the health of the human being: direct contact with nature, habitat of numerous plant and animal species, place of meeting and recreation, etc. (Chiesura et al., 2004; Latinopoulus et al., 2016). Even, urban green areas can be managed to impact the urban water, heat, carbon, and pollution cycles (Livesley et al., 2016).

At the same time, they present some inconveniences to the population due, among other causes, to the increasing incidence of pollen allergy symptoms. Recently, an increment of airborne pollen in urban areas has been observed, becoming one of the main public health problems, with incidence figures in the population above 30% (Pawankar, 2014). This may have been due to the rapid urbanization in recent years, trying to meet the aesthetic and recreational needs of local residents (United Nations, 2007). Among the causes that have increased the allergenic behavior of the ornamental flora are the low biodiversity, the massive use of a few species (Díaz de la Guardia et al., 2006), the incorporation of new species of unknown allergenicity (García et al., 1997; Trigo et al., 1999) and, above all, the interaction with atmospheric pollutants present in the urban environment (Bosh-Cano et al., 2011; Beck et al., 2013). In addition to the above, it must be added the incorporation of pollen emissions from forest or extensive crops in the peri-urban environment, i.e. olive pollen in Córdoba (Velasco-Jiménez et al., 2013; Galán et al 2016).

Respiratory diseases, linked to the presence of pollen in the air, have also been pointed out as some of the problems with greater predictions of increasing in the coming decades as a result of climate change (McMichael et al., 2006) and the deterioration of quality of the urban air (Cariñanos et al., 2001 and 2008).

The challenges that cities must do in the face of the expectations of population growth, and the effects of climate change, further reaffirm their essential role in the context of a sustainable and healthy city (Grimm et al., 2008; Leichenko, 2011; Baker, 2012). However, it is also necessary to review some of the negative effects associated with this ornamental flora, among them the costs derived from the allergic reactions caused by pollen emissions during flowering (Weis et al., 2001).

The ornamental flora has a clear influence on the pollen concentration in the air that affects the population suffering from pollinosis (Staffolani et al., 2011, Velasco-Jiménez et al., 2014; Cariñanos et al., 2017). An analytical study of the presence of potentially allergenic species, their biological characteristics and the factors involved in their activity, as sources of pollen emission, would be very useful when creating and designing new gardens or urban parks, and a solution to redesign those already existing (Cariñanos and Casares-Porcel, 2011). On the other hand, not all pollen grains have proteins that cause allergy and, among those pollen grains with allergenic proteins, not all have the same allergy potency (Behrendt & Becker, 2001), so it is very convenient to know these characteristics of pollen grains.

This study focused on the most important parks and gardens in the city of Córdoba (Spain) to study the allergenic potential of these areas, to know which trees species have the most influence on this allergenic potential. On the other hand, it is intended to update the pollen calendar of the city of Córdoba to know the periods of maximum concentration of pollen from these allergenic species and contribute to better management and minimize the impact on the resident population.

Material and methods

Study area

Córdoba (37º 50’ N, 4º 45’W) is located in Andalusia, south Spain, at 111 m above sea level (Figure 1); it is a medium-sized city with a population of around 325,708 inhabitants (according to the last census of 2018) and a surface of 1254.91 km^2. It is characterized by a Mediterranean climate with some continental features, cold, rainy winters and hot, dry summers. The annual average temperature is 18.2ºC, mean annual rainfall is 605 mm (data from 1981-2010, AEMET – State weather agency).

Inside the city, the 8 most important public parks and gardens, with a suitable surface to apply the Allergenicity Index detailed below have been studied. The antiquity, architecture and surface characteristics, as well as the typology, according to the classification of Rall et al. (2015), are detailed in Table 1.

Ornamental flora data

Complete lists of trees and palms growing in the urban green area were compiled by the Parks and Gardens Services of the Town Councils (https://infraestructuras.cordoba.es/sec-parqujard/especieszv/listadoszv) and checked by the authors with *in situ* observation.

Shrubs or herbaceous species have not been taken into account due to the frequent pruning carried out by maintenance personnel. This work causes that the flowering of these species is minimal since much flowers are eliminated in these actions

Estimating the Index of Allergenicity of urban green areas.

The potential allergenicity of urban parks was calculated using the index of allergenicity of urban green zones (IUGZA) developed by Cariñanos et al. (2014), which takes into account a number of biological and biometric parameters for tree and palm species growing in green spaces. Analysis of biological parameters enables a potential allergenic value (VPA) to be assigned to each species, while the biometric parameters enable estimation of their actual behaviour as a source of allergen emissions. VPA itself results from combining three natural variables: type of pollination, duration of the pollen season and intrinsic allergenicity of pollen grains, (Database of parameters for the calculation of the IUGZA, registered in Safe Creative platform, Nº IPR-684). A list of biological parameters for the 100 most common tree species in Mediterranean cities is provided in

Cariñanos et al. (2016). This value can range between 27 (highly allergenic species) and 1 (non-allergenic species)

Biometric parameters were based on crown diameter and height; this facilitates calculation of allergen emission volumes by assimilating treetops to a geometric figure of similar shape (Cariñanos et al., 2014).

Finally, in order to determine the relative value of allergen emissions in a given area or space, the values obtained were compared with those of a space with the same features and surface area, in which all trees planted had maximum values for all parameters, according to the following formula (Cariñanos et al., 2014):

$$IUGZA = \frac{1}{maxVPAxST} \sum_{i=1}^{k} VPAxSixHi$$

Where:

VPA= Potential Allergenicity Value for each species.

ST= Surface area of the urban park.

k= number of species in the park.

Si= Area occupied by each species in the park.

Hi= maximum height reachable by mature tree.

Application of the index yields a value between 0 (null allergenicity) and 1 (maximum allergenicity). An urban green space will have a low IUGZA value when it is below 0.2, moderate between 0.2-0.3 and high above 0.3 (Cariñanos et al., 2019).

Airborne pollen

Airborne pollen databases were obtained from sampling station located in the University Campus of Rabanales (Córdoba), which belongs to the Spanish Aerobiology Network

(REA). Sampling was performed during the last 10 years (2009-2018), using volumetric suction samplers based on the impact principle, i.e. Hirst-type spore traps (Hirst 1952). The methodology designed by the REA (Galán et al. 2007), in compliance with the minimum requirements set out by the European Aerobiology Society (EAS) (Galán et al., 2014), was used for sampling and for calculating average daily airborne pollen concentration (pollen grains/m^3).

For the representation of the pollen calendar, the 10-day average daily pollen count (Julian calendar) was taken as a single value corresponding to the arithmetic mean for a period of ten consecutive days; for 31-day months, the last group contained 11 days, as recommended by Gutierrez et al. (2016) and Martínez-Bracero et al. (2015), while February was taken as a 29-day month, the last group comprising 9 days. The airborne pollen classification recommended by Stix & Ferratti (1974) and Martínez-Bracero et al. (2015) has been the following: 1–2 pollen grains/ m^3 of air; then 3–5, 6–11, 12–24, 25–49, 50–99, 100–199, 200–399, 400–799, 800–1600, and finally over 1600 pollen grains/m^3 of air.

Results

The major findings are shown in Table 2. The proportion of highly allergenic species, expressed as a percentage of the total number of trees, ranged from 28.13% for "Paseo de la Victoria" to 43.75% for the "Parque de la Asomadilla". The number of trees per ha have also varied considerably, from less than 100 trees/ha ("Parque de la Asomadilla" and "Parque de Elena Fortú"), to over 200 trees/ha ("Parque de Cruz-Conde", "Parque Juan Carlos I" and "Jardines de la Merced"). The green areas with the most species richness have been "Parque Cruz-Conde", "Jardines del Alcázar" and "Jardines de Agricultura".

The origin of the species found in each urban green area, expressed in percentage, has been represented in Figure 2. In 5 parks, most of the species have been of Asian origin (“Parque Elena Fortú”, “Jardines del Alcázar”, “Parque Cruz-Conde”, “Jardines de Agricultura” and “Jardines de la Merced”); in 2 parks, most of the species have been of Mediterranean origin (“Parque de la Asomadilla” and “Paseo de la Victoria”); in “Juan Carlos I” Park, most species have been of American origin. Species of European and Australian origin have also been found but to a lesser extent.

In order to estimate the allergenicity index, the VPA of all tree species was calculated. The highest values were found for those taxa with the following natural features: wind pollination, pollen season lasting longer than six weeks, and allergenic pollen grains. The genera and species recording maximum VPA (27) have been: paper mulberry (*Broussonetia papyrifera*), australian pine (*Casuarina equisetifolia)*, cypress (*Cupressus* sp.), juniper (*Juniperus* sp.), mulberry (*Morus* sp.), bald cypress (*Taxodium* sp.) and thuja (*Thuja* sp.). Other species with a high VPA value (18) have been: olive (*Olea europaea)*, plane tree (*Platanus hispanica*), poplar (*Populus alba*) and elm (*Ulmus minor*). In the case of juniper, bald cypress and thuja species, they have not been found in all the parks and, in those that appear, the number of trees is very low (between 1 and 3).

The results obtained by applying potential allergenicity index to the study areas are shown in Fig. 3. Values ranged from a minimum of 0.04 for the “Parque de la Asomadilla” to a maximum of 0.6 for “Jardines de la Merced”. Since an index value of 0.3 was taken as the threshold considered sufficient to trigger allergy symptoms in the sensitive population, only 2 of the spaces analyzed here, with high values, may be regarded as unhealthy for pollen-allergy sufferers. “Jardines de Agricultura” recorded a moderate value and the others green areas can be classed as low or very low allergenic.

Pollen calendar of the principal ornamental pollen types observed in the city of Córdoba during the period 2009-2018 have been represented in Figure 4. During winter, the most important pollen types are Cupressaceae and *Populus* and, to a lesser extent, *Fraxinus*, *Ulmus* and *Alnus;* in early spring are *Platanus*, *Morus*, *Pinus* and *Quercus*; in late spring are *Olea* and, to a lesser extent, Arecaceae and Myrtaceae; finally, *Casuarina* pollen type appears in autumn but with low concentrations.

Discussion

In the present study, 8 green areas have been analyzed, with a total area of 529,350 m2. Taking into account that the total green area estimated by the Council of Córdoba is 5,132,956.72 m2, about 10% has been sampled. The green areas studied correspond to the parks and gardens of greater area of the city, although there are numerous smaller landscaped areas without trees in most of the streets. On the other hand, the most abundant species found in the studied parks (*Citrus aurantium*, *Celtis australis*, *Platanus hispanica*, *Melia azederach*, *Ulmus minor* and *Robinia pseudoacacia*) are also cited in the list of the Council of Córdoba among the most abundant in the city.

The study of the ornamental flora carried out in Cordoba city has shown the diversity of species used, both taxonomic groups and diverse origins, which contributes to enrich the urban landscape of the city.

The majority of the species present in the studied parks and gardens are of Asian origin. These species are common in the city of Córdoba from the Muslim period (Ubera, 1996). The second group of most abundant species is the one of Mediterranean origin. These species have recently been incorporated, trying to present the residents of the city with the great richness of our natural flora. However, some Mediterranean species have a high allergenic pollen, such as *Cupressus sempervirens* and *Olea europaea* (Cariñanos et al., 2017). On the other hand, Cordoba is characterized by a climate with a certain degree of continentally, with frequent nights of frost in winter, which could explain the presence of some European species, and a lower percentage of tropical species than coastal cities, such as Malaga (Velasco et al. 2014). The results confirmed that both native and allochthonous taxa contributed to the allergenicity index. Thus, there is no justification for replacing non-native species by native flora (Jianan et al., 2007; Cariñanos et al., 2017).

Among the most represented species most used in the studied parks and gardens are several listed as highly allergenic (Cariñanos et al., 2017), with a VPA value of 27, as is the case of: cypress in the “Jardines de la Merced” and the “Jardines del Alcázar” or paper mulberry in the “Jardines del Alcázar”. Allergenic species are also frequent, with a VPA value of 18, such as: plane tree in the “Paseo de la Victoria”, “Jardines de la Merced”, “Parque de Cruz-Conde” and “Jardines de Agricultura”; olive in the “Parque de la Asomadilla” or elm and poplar in the “Parque Juan Carlos I”.

On the other hand, numerous individuals of species with a low VPA index have also been found, i.e orange tree (*Citrus aurantium*), indian bean tree (*Catalpa bignonioides*) and pomegranate (*Punica granatum*), among others. However, although these species have a low index, they could cause problems for the local population in those streets or avenues where the number of individuals is high (Cariñanos et al., 2002; Alcázar et al., 2016).

It is interesting to note how in the “Parque de la Asomadilla”, of very recent construction, with more than 500 olive trees, despite the proven negative effect of its pollen on the population (Cariñanos et al., 2002; Sánchez- Mesa et al., 2005; D'Amato et al., 2007; Cebrino et al., 2017). In addition, the cultivation of olive trees is widespread in the province of Córdoba, reaching to occupy about 25,600 ha (data from the Government of

Andalusia, 2017). The fact of including specimen of this tree in the city only worsens the effects that already exert extensive crops (Velasco- Jiménez et al., 2014). For future management, entomophilic autochthonous species, with a very low VPA value, could be used, as carob tree (*Ceratonia silicua*). Nonetheless, this park has the lowest IUGZA index of all the studied ones, due to the large area it occupies, which gives rise to the lower density of tree population.

On the two urban green spaces with an IUGZA index greater than 0.3, and therefore susceptible to trigger allergy symptoms to the local population, comment that both have a high density of trees and also highly allergenic species predominate, as above. In the study carried out by Cariñanos et al. (2017) the relation existing between a high value of the IUGZA index and the density of trees was already exposed. However, in this study we have found parks, such as Juan Carlos I, with a high density of trees but low IUGZA index. We have checked that the predominant species in this park is *Citrus aurantium*, with a VPA value of only 3. Therefore, although the density of trees is important for the IUGZA index, as much or more is the choice of the species used and the number of individuals of these. It is also true that the following species, in order of abundance in this park, *Ulmus minor* and *Populus alba*, are considered allergenic and have a VPA of 18, similar to olive or plane tree. But the pollen concentrations in the air of these species reach are much lower than *Olea* and *Platanus*.

For some years it has been observed that the massive use of individuals of the same species is causing a significant increase in pollen concentrations in the air (Velasco-Jiménez et al., 2014). This fact has already been discussed for some cases of trees especially allergenic, and also of allochthonous origin, such as the plane tree (Alcázar et al., 2004 and 2011), cypress (Cariñanos et al., 2016) or the casuarina (García et al., 1997; Trigo et al., 1999). And yet, the most recent urban green areas (Parque de la Asomadilla, Parque de Cruz-Conde and Parque Juan Carlos I) are the ones that have presented the highest percentage of allergenic species. This makes us see that there is still a lot to be done in this issue to raise awareness among city managers of the need to have expert advice on this subject.

Another aspect to keep in mind is that the parks and gardens do not present a continuous allergenicity over time, so that its effect will be greater only during the flowering season of the allergenic species. According to the latest pollen calendar published for the cities in Andalusia (Martínez-Bracero et al., 2015). In Córdoba, most study species bloom in spring, which makes it the most adverse time for allergic people who often cross these gardens or spend time in them. Nevertheless some species bloom during other times, like winter (cypress) or autumn (Australian pine). So the population sensitive to these pollen types should take special care also on these dates.

Conclusion

The urban green areas studied in the city of Córdoba have a moderate-low allergenicity index. Only two of the parks analyzed have exceeded the value of 0.3, considered as susceptible to trigger allergy symptoms to the local population.

The most allergenic species that have been found in these parks and gardens have been paper mulberry, australian pine, cypress, olive, plane tree, poplar and elm.

The factors that have contributed most to the allergenicity index of each urban green area have been the abundance of individuals of allergenic species and the surface of the park. Although it is also important to take into account the final amount of pollen that is released into the atmosphere by each species.

Since some of these spaces are of recent construction, this makes us see that there is still a lot to be done in this issue to raise awareness among city managers of the need to have expert advice on this subject.

It would be convenient to complete this initial study with other garden areas of the city and even extend it to other locations in the province.

Acknowledgement

The study was supported by the proyect “CGL2014-54731-R- FENOMED-Estudio de tendencias fenológicas en plantas del Mediterráneo Occidental y su relación con el cambio climático”. Ministerio de Economía y Competitividad. Spain Goverment.

In addition, this work has been part of different Final Degree Projects by the following students: Patricia Cosano Pérez, Blanca Rodríguez Linares, María Sánchez Olmo, Eva Mª Olalla Reyes, Norberto Sabina López y Gemma Vivo Baeza.

References.

Alcázar, P., Cariñanos, P., De Castro, C., Guerra, F., Moreno, C., Domínguez-Vilches, E., & Galán, C. (2004). Airbone plane-tree (Platanus hispanica) pollen distribution in the city of Cordoba, South-western Spain, and possible implications on pollen allergy. *Journal of Investigational Allergology and Clinical Immunology*, 14, 238-243.

Alcázar, P., García-Mozo, H., del Mar Trigo, M., Ruiz, L., González-Minero, F. J., Hidalgo, P., ... & Galán, C. (2011). Platanus pollen season in Andalusia (southern Spain): trends and modeling. *Journal of Environmental Monitoring*, 13(9), 2502-2510.

Alcázar, P., Velasco-Jiménez, M. J., Domínguez-Vilches, E., Galán, C. (2016). A contribution to the study of airborne Citrus pollen in Córdoba, southern Spain. *Urban forestry & urban greening*, 16, 9-12.

Baker, J. L. (Ed.). (2012). *Climate change, disaster risk, and the urban poor: cities building resilience for a changing world*. The World Bank.

Beck, I., Jochner, S., Gilles, S., McIntyre, M., Buters, J. T., Schmidt-Weber, C., ... & Traidl-Hoffmann, C. (2013). High environmental ozone levels lead to enhanced allergenicity of birch pollen. PloS one, 8(11), e80147.

Behrendt. H., Becker W.M. (2001). Localization. release and bioavailability of pollen allergens: the influence of environmental factors. *Current opinion in immunology*. 13(6). 709-715.

Bosch-Cano, F., Bernard, N., Sudre, B., Gillet, F., Thibaudon, M., Richard, H., ... & Ruffaldi, P. (2011). Human exposure to allergenic pollens: A comparison between urban and rural areas. *Environmental research*, 111(5), 619-625.

Carinanos, P., Sánchez-Mesa, J. A., Prieto-Baena, J. C., Lopez, A., Guerra, F., Moreno, C., ... & Galan, C. (2002). Pollen allergy related to the area of residence in the city of Córdoba, south-west Spain. *Journal of Environmental Monitoring*, 4(5), 734-738.

Cariñanos, P., Adinolfi, C., Díaz de la Guardia, C., De Linares, C., Casares-Porcel, M. (2016). Characterization of allergen emission sources in urban areas. *Journal of environmental quality*, 45(1), 244-252.

Cariñanos P., Galán C., Alcázar P., Domínguez E. (2008). Classification. analysis and interaction of solid airbone particles in urban environments. In A. G. Kungolos. C. A. Brebbia. & M. Zamorano (Eds.). *Environmental Toxicology II* (317-325).

Cariñanos P., Prieto J.C., Galán C., Domínguez E. (2001). Solid suspended particles affecting the quality of air in urban environments. *Bull. Environ. Contam. Toxicol*; 67:385-91.

Cariñanos, P., Alcázar, P., Galán, C., Domínguez, E. (2002). Privet pollen (Ligustrum sp.) as potential cause of pollinosis in the city of Cordoba, south-west Spain. *Allergy*, 57(2), 92-97.

Cariñanos, P., Casares-Porcel, M., & Quesada-Rubio, J. M. (2014). Estimating the allergenic potential of urban green spaces: A case-study in Granada, Spain. *Landscape and urban planning*, 123, 134-144.

Cariñanos, P., Casares-Porcel, M., de la Guardia, C. D., Aira, M. J., Belmonte, J., Boi, M., ... & Pérez-Badía, R. (2017). Assessing allergenicity in urban parks: A nature-based solution to reduce the impact on public health. *Environmental research*, 155, 219-227.

Cariñanos, P., Grilo, F., Pinho, P., Casares-Porcel, M., Branquinho, C., Acil, N., ... & Calaza-Martínez, P. (2019). Estimation of the Allergenic Potential of Urban Trees and Urban Parks: Towards the Healthy Design of Urban Green Spaces of the Future. *International journal of environmental research and public health*, 16(8), 1357.

Cariñaos P. & Casares M. (2011): Urban Green zones and related pollen allergy: A review. Guidelines for designing spaces of low allergy impact. *Landscape and Urban Planning*. 101. 205-214.

Cebrino, J., de la Cruz, S. P., Barasona, M. J., Alcázar, P., Moreno, C., Domínguez-Vilches, E., & Galán, C. (2017). Airborne pollen in Córdoba City (Spain) and its implications for pollen allergy. *Aerobiologia*, 33(2), 281-291.

Chiesura A. (2004). The role of urban parks for the sustainable city. *Landscape and Urban Planning*. 68:129-138.

D'Amato, G., Cecchi, L., Bonini, S., Nunes, C., Annesi-Maesano, I., Behrendt, H., ... & Van Cauwenberge, P. (2007). Allergenic pollen and pollen allergy in Europe. *Allergy*, 62(9), 976-990.

Díaz de la Guardia, C., Alba-Sánchez, F., Linares Fernández, C. D., Nieto-Lugilde, D., López Caballero, J. (2006). Aerobiological and allergenic analysis of Cupressaceae pollen in Granada (Southern Spain). *J Investig Allergol Clin Immunol*, 16(1): 24-33

Galán C, Smith M, Thibaudon M, Frenguelli G, Oteros J, Gehrig R & EAS QC Working Group. (2014). Pollen monitoring: minimum requirements and reproducibility of analysis. *Aerobiologia*, 30(4), 385-395.

Galán C., Alcázar P., Oteros J., García-Mozo H., Aira M. J., Belmonte J., ... & Pérez-Badía R. (2016). Airborne pollen trends in the Iberian Peninsula. *Science of the Total Environment*, 550, 53-59.

Galán C., Cariñanos P., Alcázar P., Domínguez E. (2007). *Quality and management manual of the Spanish aerobiology network*. Servicio de Publicaciones de la Universidad de Córdoba. Spain.

García, J. J., Trigo, M. M., Cabezudo, B., Recio, M., Vega, J. M., Barber, D., ... & Miranda, A. (1997). Pollinosis due to Australian pine (Casuarina): an aerobiologic and clinical study in southern Spain. *Allergy*, 52(1), 11-17.

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., Briggs, J. M. (2008). *Global change and the ecology of cities. science*, 319(5864), 756-760.

Gutiérrez, M., Sabariego, S., Cervigón, P. (2006). Calendario polínico de Madrid (Ciudad Universitaria). Periodo 1994-2004. *Lazaroa*, 27, 21.

Hirst, J. (1952). An automatic volumetric spore trap. *Annals of applied Biology*, 39(2), 257-265.

Jianan, X., Zhiyun, O., Hua, Z., Xiaoke, W., Hong, M. (2007). Allergenic pollen plants and their influential factors in urban areas. *Acta Ecologica Sinica*, 27(9), 3820-3827.

Latinopoulos, D., Mallios, Z., Latinopoulos, P. (2016). Valuing the benefits of an urban park project: A contingent valuation study in Thessaloniki, Greece. *Land Use Policy*, 55, 130-141.

Leichenko, R. (2011). Climate change and urban resilience. *Current opinion in environmental sustainability*, 3(3), 164-168.

Livesley, S. J., McPherson, E. G., Calfapietra, C. (2016). The urban forest and ecosystem services: impacts on urban water, heat, and pollution cycles at the tree, street, and city scale. *Journal of environmental quality*, 45(1), 119-124.

Martínez-Bracero M., Alcázar P., de la Guardia C. González-Minero F.J., Ruiz L., Pérez M. T., Galán C. (2015). Pollen calendars: a guide to common airborne pollen in Andalusia. *Aerobiologia*, 31(4), 549-557.

McMichael A.J., Woodruff R.E., Hales S. (2006). Climate change and human health: Present and future risks. *Lancet*. 367: 859-869.

Oteros, J., García-Mozo, H., Alcázar, P., Belmonte, J., Bermejo, D., Boi, M., ... & Gutiérrez-Bustillo, A. M. (2015). A new method for determining the sources of airborne particles. *Journal of environmental management*, 155, 212-218.

Pawankar, R. (2014). Allergic diseases and asthma: a global public health concern and a call to action. *World Allergy Organ. J.* 7, 12.

Rall, L., Niemela, J., Pauleit, S., Pintar, M., Lafortezza, R., Santos, A., ... & Železnikar, Š. (2015). A typology of urban green spaces, eco-system services provisioning services and demands. Report D3, 1.

Sánchez-Mesa, J. A., Serrano, P., Cariñanos, P., Prieto-Baena, J. C., Moreno, C., Guerra, F., Galan, C. (2005). Pollen allergy in Cordoba city: frequency of sensitization and relation with antihistamine sales. *Journal of Investigational Allergology and Clinical Immunology*, 15(1), 50-56.

Staffolani L., Velasco-Jiménez M.J., Galán C., Hruska K. (2011). Allergenicity of the ornamental urban flora: ecological and aerobiological analyses in Córdoba (Spain) and Ascoli Piceno (Italy). *Aerobiologia*. 27. 239–246.

Stix, E., & Ferretti, M. L. (1974). Pollen calendars of three locations in Western Germany. *Atlas European des Pollens Allergisants*, 85-94.

Trigo, M. M., Recio, M., Toro Gil, F. J., Cano, M., Dopazo, M. A., García, H., ... & Cabezudo, B. (1999). Annual variations of Airbone Casuarina pollen in the Iberian Península. *Polen*. 10:67-73.

Ubera, J. L. (1996). Palynology of the historical period at the Madinat al-Zahra archaeological site, Spain. *Journal of archaeological science*, 23(2), 249-261.

United Nations. World urbanization prospects: The 2007 revision. Executive summary. New York: United Nations. Dep. Econ. Social Affairs. 2008.

Velasco-Jiménez M. J., Alcázar P., Domínguez-Vilches E., Galán C. (2013). Comparative study of airborne pollen counts located in different areas of the city of Córdoba (south-western Spain). *Aerobiologia*, 29(1), 113-120.

Velasco-Jiménez M.J., Alcázar P., Valle A., Trigo M.M., Minero F., Domínguez E., Galán C. (2014). Aerobiological and ecological study of the potentially allergenic ornamental plants in south Spain. *Aerobiologia*. 30(1). 91-101.

Weiss, K. B., & Sullivan, S. D. (2001). The health economics of asthma and rhinitis. I. Assessing the economic impact. *Journal of Allergy and Clinical Immunology*, 107(1), 3-8.

Figures:

Figure 1. Location of Córdoba city.

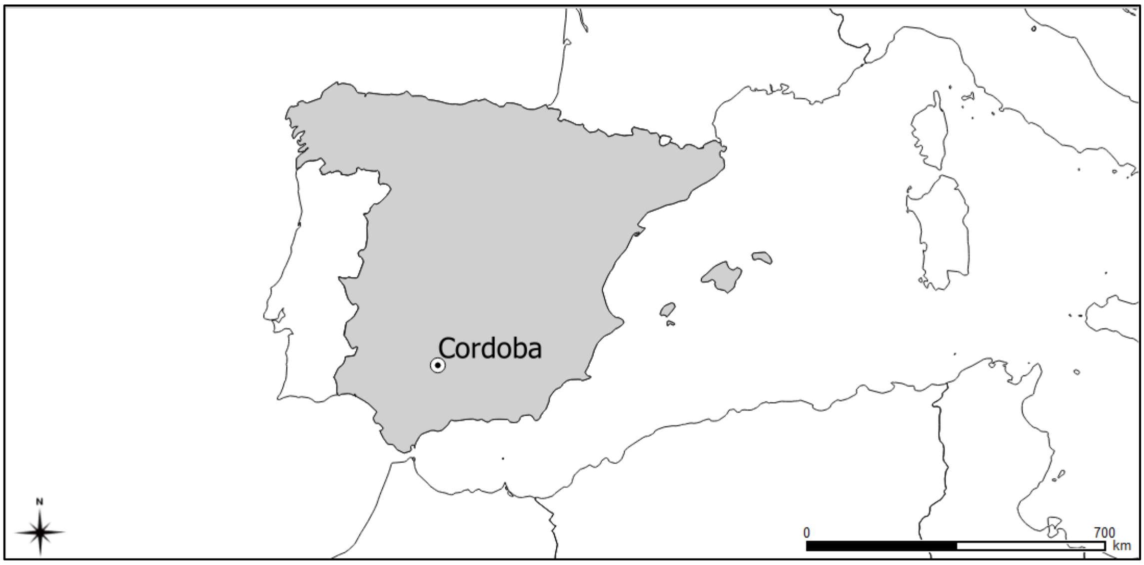


Figure 2. Origin for ornamental flora in the studied gardens, expressed in percentage.

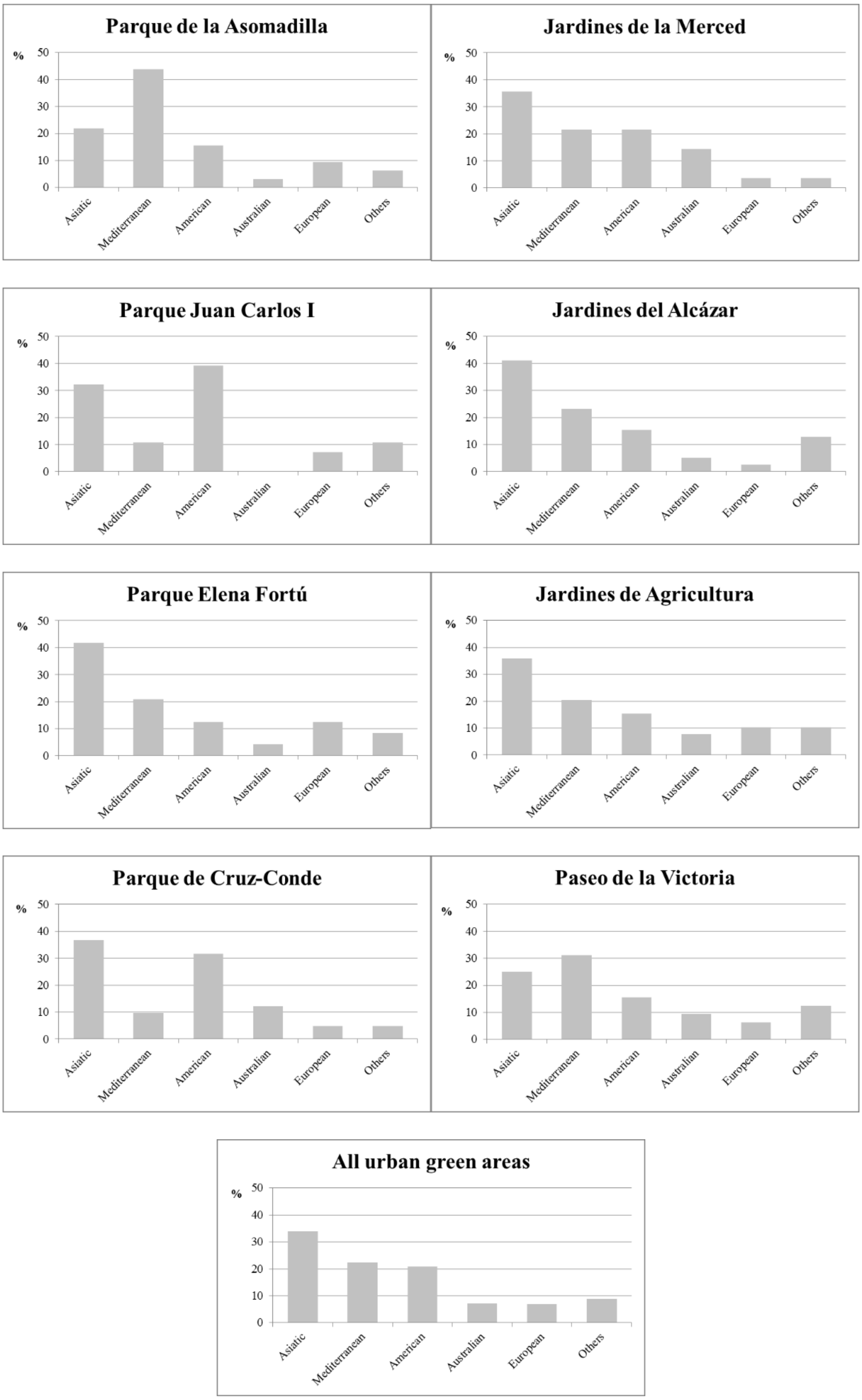
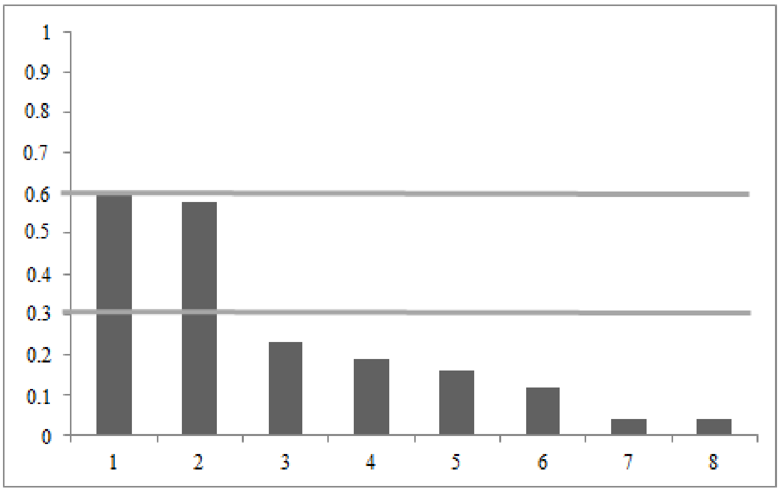
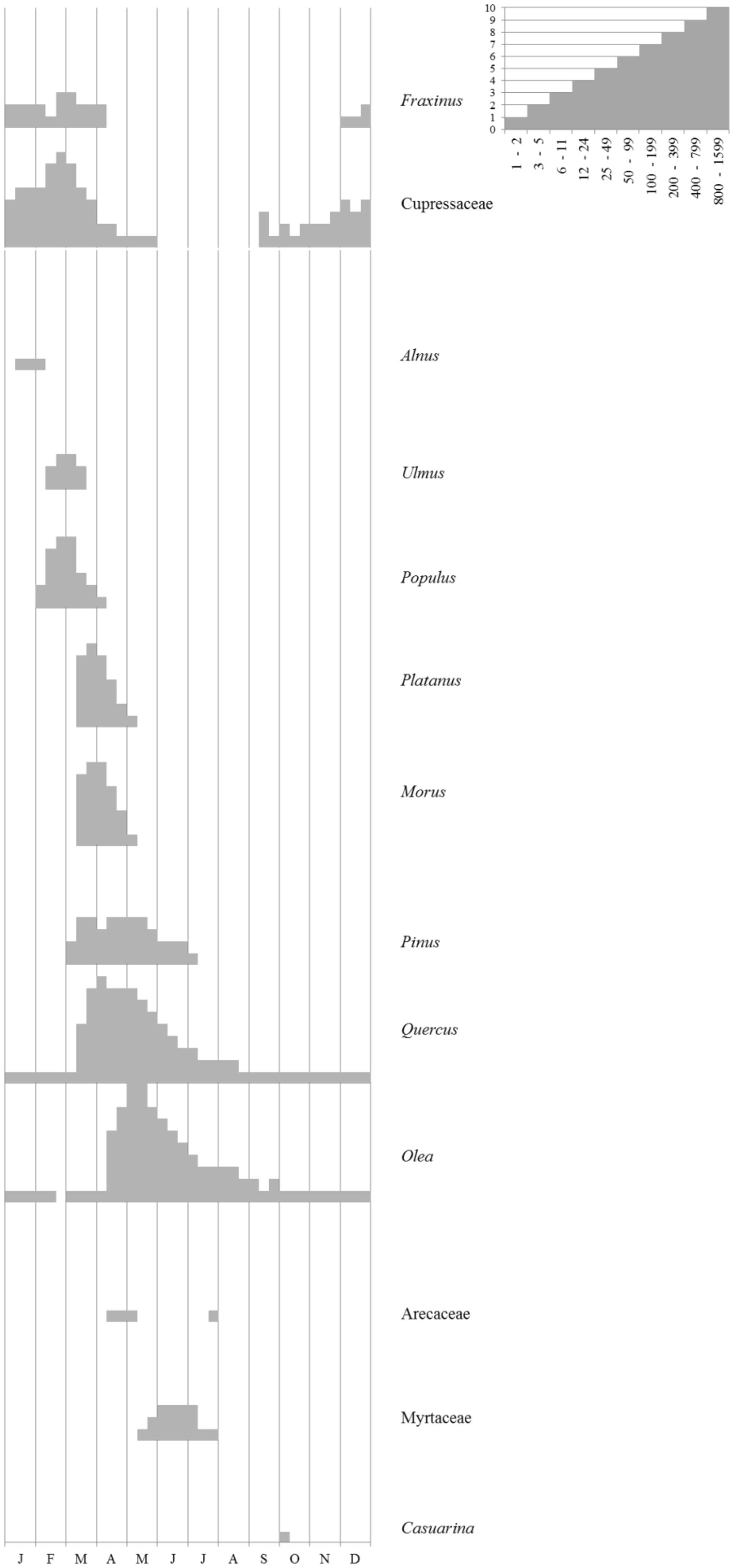


Figure 3. IUGZA of the urban parks considered in this study, according to the Index proposed by Cariñanos et al. (2014).



1. Jardines de la Merced
2. Parque de Cruz-Conde
3. Jardines de Agricultura
4. Paseo de la Victoria
5. Parque Juan Carlos I
6. Parque Elena Fortú
7. Jardines del Alcázar
8. Parque de la Asomadilla

Figure 4. Pollen Calendar of Córdoba during 2009-2018, related to ornamental flora.


Fraxinus
Cupressaceae
Alnus
Ulmus
Populus
Platanus
Morus
Pinus
Quercus
Olea
Arecaceae
Myrtaceae
Casuarina
J F M A M J J A S O N D
10
9
8
7
6
5
4
3
2
1
0
1 - 2
3 - 5
6 - 11
12 - 24
25 - 49
50 - 99
100 - 199
200 - 399
400 - 799
800 - 1599

Tables:

Table 1. General characteristics of the green areas considered in this study.

Name	Year	Tipology	Surface (m^2)	Nº trees	Geographic location
Parque de la Asomadilla	2007	Large urban park	270,000	1,372	37°54'16.32"N 4°46'38.60"O
Jardines del Alcázar	1328	Historical garden	55,000	619	37°52'30.37"N 4°46'59.22"O
Paseo de la Victoria	1776	Large urban park	52,000	576	37°53'1.54"N 4°47'8.08"O
Parque Cruz-Conde	1950	Large urban park	50,000	1,364	37°52'20.36"N 4°47'24.43"O
Parque Elena Fortú	1990	Pocket park	40,000	396	37°52'38.18"N 4°47'58.83"O
Jardines de Agricultura	1811	Pocket park	30,550	351	37°53'16.66"N 4°47'8.54"O
Jardines de la Merced	1905	Pocket park	19,300	461	37°53′24″N 4°46′42″O
Parque Juan Carlos I	1999	Pocket park	12,500	316	37°52'59.08"N 4°47'20.43"O

Table 2
Percentage of highly-allergenic species, density of trees, Species richness, and species of the 8 urban spaces considered in this study.

Name	Allergenic species (%)	Density (Trees/ha)	Species richness	Species (N° individuals)			
Parque de la Asomadilla	43.75	51	32	*Olea europaea* (505)	*Ceratonia siliqua* (46)	*Populus nigra* (7)	*Arbutus unedo* (2)
				Punica granatun (157)	*Quercus suber* (33)	*Melia azedarach* (7)	*Cupressus glabra* (1)
				Celtis australis (119)	*Cupressus sempervirens* (29)	*Ficus carica* (5)	*Juniperus phoenicea* (1)
				Pinus pinea (90)	*Cupressus macrocarpa* (23)	*Ulmus pumila* (2)	*Morus alba* (1)
				Crataegus monogyna (79)	*Acer negundo* (22)	*Phoenix dactylifera* (2)	*Ulmus glabra* (1)
				Ulmus minor (78)	*Fraxinus angustifolia* (11)	*Phoenix canariensis* (2)	*Chamaeropus humillis* (1)
				Quercus ilex (71)	*Sophora japonica* (10)	*Tamarix gallica* (2)	*Washingtonia filifera* (1)
				Quercus faginea (54)	*Ailanthus altissima* (7)	*Yucca elephantipes* (2)	*Brachychiton populneus* (1)
Jardines de la Merced	39.29	239	28	*Cupressus sempervirens* (107)	*Morus alba* (7)	*Olea europaea* (3)	*Jacaranda mimosifolia* (2)
				Platanus hispanica (97)	*Sophora japonica* (7)	*Pinus pinea* (3)	*Acer negundo* (1)
				Phoenix dactylifera (88)	*Laurus nobilis* (5)	*Photinia serrulata* (3)	*Quercus suber* (1)
				Citrus aurantium (62)	*Casuarina equisetifolia* (4)	*Grevillea robusta* (3)	*Euonymus japonicus* (1)
				Washingtonia sp. (17)	*Ulmus minor* (4)	*Ginkgo biloba* (2)	*Gleditsia triacanthos* (1)
				Yucca elephantipes (17)	*Eleagnus angustifolia* (4)	*Trachycarpus fortunei* (2)	*Magnolia grandiflora* (1)
				Lagerstroemia indica (13)	*Chamaerops humilis* (3)	*Eucalyptus camaldulensis* (2)	*Brachychiton populneus* (1)
Parque Juan Carlos I	39.29	253	28	*Citrus aurantium* (53)	*Prunus cerasifera pisardii* (20)	*Washingtonia spp.* (5)	*Olea europea* (2)
				Ulmus minor (39)	*Magnolia grandiflora* (13)	*Schinus molle* (4)	*Euonymus japonicus* (2)
				Populus alba (29)	*Cercis siliquastrum* (12)	*Albizia julibrissin* (4)	*Washingtonia filifera* (2)
				Catalpa bignonioides (23)	*Thuja occidentalis* (11)	*Morus nigra* (3)	*Ailanthus altissima* (1)
				Sophora japonica (22)	*Cupressus sempervirens* (7)	*Ginkgo biloba* (3)	*Phoenix canariensis* (1)
				Jacaranda mimosifolia (21)	*Phoenix dactylifera* (6)	*Robinia pseudoacacia* (3)	*Cedrus atlántica* (1)
				Washingtonia robusta (20)	*Melia azedarach* (6)	*Cupressus arizonica* (2)	*Yucca elephantipes* (1)
Jardines del Alcázar	38.46	113	39	*Citrus aurantium* (291)	*Tamarindus indica* (4)	*Juglans regia* (1)	*Cedrus atlantica* (1)
				Cupressus sempervirens (206)	*Laurus nobilis* (3)	*Carya illinoensis* (1)	*Euonymus japonicus* (1)
				Citrus limon (19)	*Citrus maxima* (3)	*Salix erythroflexuosa* (1)	*Washingtonia filifera* (1)
				Broussonetia papyrifera (15)	*Prunus triloba* (3)	*Platanus x hispanica* (1)	*Syringa vulgaris* (1)
				Cupressus arizonica (11)	*Morus alba* (2)	*Quercus ilex* (1)	*Ceratonia siliqua* (1)
				Ligustrum lucidum (11)	*Pistacia terebinthus* (2)	*Phoenix dactylifera* (1)	*Cercis siliquastrum* (1)
				Punica granatum (11)	*Pittosporum tobira* (2)	*Eucalyptus camaldulensis* (1)	*Ziziphus jujuba* (1)
				Casuarina equisetifolia (4)	*Photinia glabra* (2)	*Phoenix canariensis* (1)	*Eriobotrya japonica* (1)
				Ulmus americana (4)	*Ficus carica* (2)	*Celtis australis* (1)	*Lagerstroemia indica* (1)
				Ailanthus altissima (4)	*Platycladus orientalis* (1)	*Tamarix gallica* (1)	
Parque Elena Fortú	37.50	99	24	*Sophora japonica* (62)	*Pittosporum tobira* (24)	*Ligustrum lucidum* (12)	*Laurus nobilis* (6)
				Citrus aurantium (37)	*Populus tremula* (18)	*Photinia serratifolia* (10)	*Punica granatum* (6)
				Robinia pseudoacacia (33)	*Cupressus sempervirens* (16)	*Olea europea* (9)	*Salix babylonica* (4)
				Ulmus minor (32)	*Koelreuteria paniculata* (15)	*Crataegus monogyna* (9)	*Celtis australis* (4)
				Platanus x hispánica (28)	*Jacaranda mimosifolia* (13)	*Morus alba* (8)	*Quercus ilex* (3)
				Brachychiton populneus (25)	*Melia azedarach* (13)	*Catalpa bignonioides* (8)	*Prunus cerasifera* (1)
Jardines de Agricultura	35.90	115	39	*Citrus aurantium* (112)	*Morus alba* (5)	*Chamaerops humilis* (2)	*Pinus pinea* (1)
				Phoenix canariensis (60)	*Magnolia grandiflora* (5)	*Phoenix roebelenii* (2)	*Butia yatay* (1)
				Platanus hispanica (54)	*Lagunaria patersonii* (5)	*Aesculus hippocastanum* (2)	*Sophora japónica* (1)
				Washingtonia robusta (20)	*Taxus baccata* (4)	*Koelreuteria paniculata* (2)	*Magnolia x soulangeana* (1)
				Trachycarpus fortunei (18)	*Cedrus deodara* (4)	*Ailanthus altissima* (1)	*Ceratonia siliqua* (1)
				Washingtonia filifera (11)	*Tilia x europea* (4)	*Ginkgo biloba* (1)	*Ziziphus jujuba* (1)
				Cercis siliquastrum (9)	*Taxodium distichum* (3)	*Araucaria excelsa* (1)	*Jacaranda mimosifolia* (1)
				Casuarina equisetifolia (7)	*Olea europea* (3)	*Quercus suber* (1)	*Arbutus unedo* (1)
				Cupressus sempervirens (6)	*Pinus canariensis* (3)	*Pinus halepensis* (1)	*Punica granatum* (1)
				Ligustrum japonicum (6)	*Lagerstroemia indica* (3)	*Castanea sativa* (1)	
Parque Cruz-Conde	31.71	273	41	*Pinus pinea* (146)	*Jacaranda mimosifolia* (46)	*Catalpa bignonioides* (13)	*Acacia dealbata* (5)
				Platanus hispanica (136)	*Magnolia grandiflora* (40)	*Phoenix Dactylifera* (12)	*Washingtonia filifera* (4)
				Melia azedarach (105)	*Cupressus sempervirens* (30)	*Citrus aurantium* (11)	*Schinus molle* (4)
				Cedrus deodara (90)	*Koelreuteria paniculata* (28)	*Cupressus lusitánica* (10)	*Euonymus alatus* (3)
				Ulmus pumila (87)	*Ailanthus altissima* (25)	*Phytolacca dioica* (10)	*Syringa Vulgaris* (3)

Table 2 (*continued*)

Name	Allergenic species (%)	Density (Trees/ha)	Species richness	Species (N° individuals)			
				Ligustrum sp. (86)	*Acer negundo* (24)	*Casuarina equisetifolia* (9)	*Yucca sp.* (2)
				Pinus halepensis (86)	*Thuja plicata* (23)	*Celtis australis* (9)	*Araucaria sp.* (1)
				Vitex agnus-castus (79)	*Robinia pseudoacacia* (22)	*Abies sp.* (8)	*Sophora japónica* (1)
				Punica granatum (48)	*Phoenix Canariensis* (19)	*Parkinsonia aculeate* (6)	*Prunus salicina* (1)
				Callistemon citrinus (47)	*Morus alba* (18)	*Feijoa sellowiana* (6)	
				Pittosporum tobira (47)	*Brachychiton populneus* (14)		
Paseo de la Victoria	28.13	110	32	*Citrus aurantium* (235)	*Cupressus sempervirens* (8)	*Ginkgo biloba* (3)	*Olea europea* (1)
				Celtis australis (80)	*Brachychiton populneus* (8)	*Quercus ilex* (3)	*Aesculus hippocastanum* (1)
				Phoenix canariensis (45)	*Yucca sp.* (6)	*Magnolia grandiflora* (3)	*Ligustrum lucidum* (1)
				Platanus hispanica (44)	*Populus nigra* (5)	*Robinia pseudoacacia* (3)	*Cedrus deodara* (1)
				Phoenix dactylifera (40)	*Chamaerops humilis* (4)	*Araucaria excelsa* (2)	*Laurus nobilis* (1)
				Washingtonia filifera (25)	*Cedrus atlántica* (4)	*Pinus pinea* (2)	*Ceratonia siliqua* (1)
				Casuarina equisetifolia (18)	*Pittosporum tobira* (4)	*Sophora japónica* (2)	*Arbutus unedo* (1)
				Cercis siliquastrum (18)	*Jacaranda mimosifolia* (4)	*Punica granatum* (2)	*Prunus cerasífera* (1)