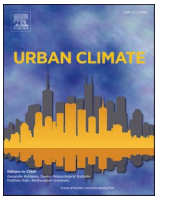
Urban Climate 54 (2024) 101866

Contents lists available at ScienceDirect

Urban Climate

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



The allergenic potential of green urban areas in the Macaronesian islands: The case of Funchal City (Madeira)

Irene Camacho [a,*], Álvaro Macías-de-la-Rosa [b], Roberto Camacho [c], Agnieszka Grinn-Gofroń [d], Paloma Cariñanos [e,f]

[a] Madeira University, Faculdade de Ciências da Vida, Campus Universitário da Penteada, Funchal 9020-105, Portugal
[b] Institute of Parasitology and Biomedicine López-Neyra (IPBLN), Spanish National Research Council, Ave. del Conocimiento 17, Armilla 18016, Granada, Spain
[c] Madeira University, Escola Superior de Tecnologias e Gestão, Campus Universitário da Penteada, Funchal 9020-105, Portugal
[d] Institute of Biology, University of Szczecin, Wąska 13 Street, Szczecin 71-415, Poland
[e] Department of Botany, University of Granada, Granada 18071, Spain
[f] Andalusian Institute for Earth System Research (IISTA-CEAMA), University of Granada, Granada 18071, Spain

ARTICLE INFO

Keywords:
Allergenic plants
Urban green spaces
Allergenic index
IUGZA
Funchal city

ABSTRACT

Public gardens are elements that constitute the urban green infrastructure. Such units provide ecosystem services that are becoming a key concern in urban planning strategies.

In this survey the allergenic potential of two public gardens in Funchal, a city exhibiting subtropical and Mediterranean climatic features, was assessed. Different allergenic risk scenarios were considered, and the Allergenicity Indexes recalculated. Results show that the Municipal Garden exhibits an I_{UGZA} (Index of Urban Green Zone Allergenicity) of 0,39 and Santa Catarina Park an I_{UGZA} of 0,16, which are considered spaces of moderate and low allergenicity level, respectively. Among the tested scenarios that could aggravate the I_{UGZA} values, the worst would be an extension of the pollen season for all species. This might represent an issue considering the overall trend towards an earlier start and later end of the pollen season from important allergenic plants in Europe. The assessment of the I_{UGZA} should include all plant biotypes of an urban green area in subtropical regions as they allow us to infer more precisely on the real risk population is exposed to. It seems that increasing species diversity can improve the allergenic indexes, but novel invasive species should be studied to assess their allergenicity level.

1. Introduction

Currently more than half of the world's population lives in cities and a considerable proportion is exposed to several allergenic pollen types. The plant cover composing the urban ecosystems may comprise allergenic plants because of unsuitable green space planning (Calaza et al., 2018).

Owing to the close relationship between allergenic plants and pollinosis, research about allergenic potential of urban areas has received more attention by the local and scientific communities. Accordingly, most of the surveys have estimated the allergenic

* Corresponding author.
E-mail addresses: ireneg@staff.uma.pt (I. Camacho), alvaro.macias@ipb.csic.es (Á. Macías-de-la-Rosa), roberto.camacho@staff.uma.pt (R. Camacho), agnieszka.grinn-gofron@usz.edu.pl (A. Grinn-Gofroń), palomacg@ugr.es (P. Cariñanos).

https://doi.org/10.1016/j.uclim.2024.101866
Received 20 July 2023; Received in revised form 5 February 2024; Accepted 9 March 2024
Available online 16 March 2024

potential of urban green spaces (Cariñanos et al., 2014; Cariñanos et al., 2016; Kasprzyk et al., 2019; Aerts et al., 2021) and some have provided guidelines to plan hypoallergenic spaces (Cariñanos and Casares-Porcel, 2011; Calaza et al., 2018).

Past and recent urban green designs relied mostly on aesthetic and management criteria. As such, abundance and space distribution of plant species in green spaces have been based on their tolerance to urban environmental stresses and adaptation to the local climate. Also, considerations such as easy maintenance, preference for male specimens and plant originality have been deemed preferable (Cariñanos et al., 2014). Consequently, there has been a massive use of some plant species to the detriment of others, giving rise to an overrepresentation of some pollen types in the atmosphere of several cities and regions. Therefore, such design options led to the introduction of species with allergenic potential and subsequent rise of sensitization rates in the exposed population (Cariñanos and Casares-Porcel, 2011). In addition, the presence of specific plant species with allergenic potential, along with chemical and particulate pollutants, has rapidly increased the number of patients with pollinosis in urban areas (Oh, 2022).

Despite the overall beneficial effect of urban green spaces on public health, there is a growing body of research on composition, distribution pattern and phenological characteristics of allergenic pollen plants in the urban ecosystems in order to avoid exposure of urban residents and visitors to pollen allergens (Calaza et al., 2018; Kasprzyk et al., 2019). Most studies regarding urban green designs, allergenic risk and ecological services or disservices have been performed in countries with Temperate and Mediterranean climates, whereas they have been scarce in tropical and sub-tropical regions.

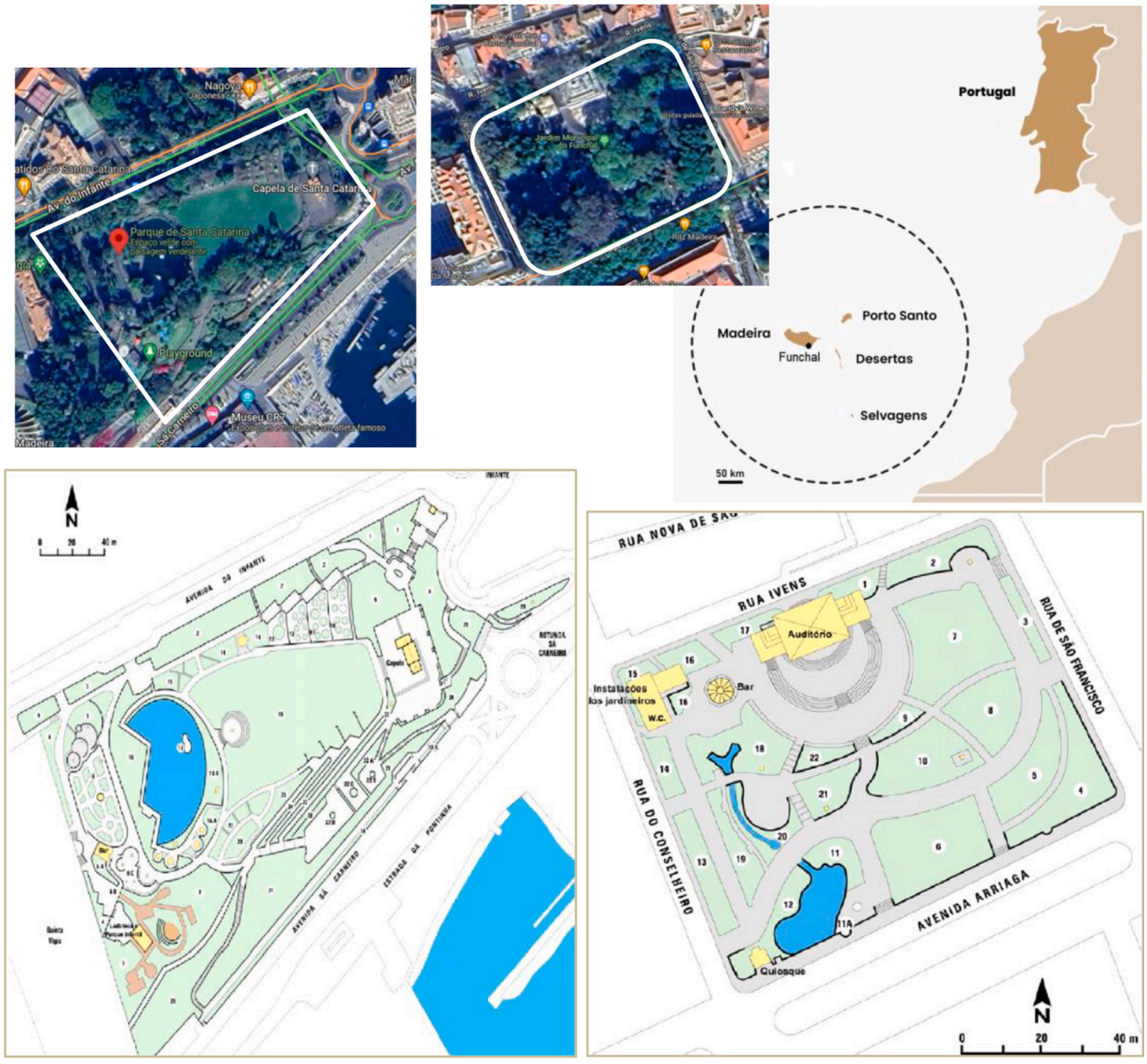


Fig. 1. – Map location of Funchal, Portugal (top right) and satellite views of Santa Catarina Park (top left) and Municipal Garden (top centre) (Google maps). Schematics of both gardens, with plant beds coloured in green, for Santa Catarina Park (bottom left) and Municipal Garden (bottom right) Source: Quintal, 2007. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The present study took place in Madeira, an island influenced by the Temperate and Mediterranean macro-bio-climates (Rivas-Martínez, 2001). Due to its geographic position, orography and edaphic conditions, Madeira is considered a subtropical region, showing a great variety of microclimates that allowed the introduction of a wide array of plant species from all over the world (Borges et al., 2008). Many of the introduced plants were brought in for their economic importance or as ornamentals for gardens. The island offers many public access gardens of historical and botanical richness and the many gardens and parks of Funchal, the capital city, are no exception. Exotic species such as *Acacia* spp., *Eucalyptus globulus*, *Pinus pinaster* and *Pinus radiata* can be found surrounding the city nowadays, whereas centuries ago we had a laurel forest. Such changes in the original natural environment may have implications for asthmatic and allergic sufferers (Hanski et al., 2012). In fact, new species introduced into an area are likely to be non-native, and thus, their impacts on allergic and respiratory health in the sensitised population are unknown and can become an important issue (Kasprzyk et al., 2019).

Madeira also belongs to Macaronesia, corresponding to one of the most biodiverse regions in Europe (Quintal, 2007). Tropical and subtropical regions typically exhibit specific climate features, high plant productivity and biodiversity levels, but information regarding the allergenic impact of tropical urban forests is still limited, as is their subsequent impact on human well-being (Escobedo et al., 2023).

The aim of the present work is to determine the overall allergenic potential of two highly visited public gardens in Funchal, a city with sub-tropical climatic features. In addition, several potential allergenic risk scenarios were considered, and the respective I_{UGZA} calculated. The study shall bring new insights about the allergenic potential of two important green spaces of the region, infer the public health risk to both locals and visitors and, if necessary, propose mitigation strategies regarding urban vegetation management.

2. Material and methods

2.1. Selection of sites and plant species inventory

The study took place in Funchal city (N 32° 39.037′, W 16° 54.494′), the capital of Madeira. Madeira is the largest island of Madeira Archipelago (Fig. 1), located in the Northeast Atlantic Ocean, 850 km Southwest of Portugal and 750 km West of the Northwestern African coast. The island has a total area of 737 km^2, with a maximum length of 57 km, in an East-West direction, and a maximum width of 23 Km, North-South. The resident population in Funchal is of around 120.000 people, corresponding to the most populous insular city in the country (Direção Regional de Estatística da Madeira, 2021; Pordata, 2023).

The climate of the Archipelago is largely influenced by the Eastern branch of the Azores anticyclone, especially from Spring to Fall. The mean annual air temperature is 18.7 °C, the temperature range is only 6.4 °C and August is the hottest month (22.3 °C) whereas February is the coolest (15.9 °C). The average annual air temperature in the archipelago of Madeira depends markedly on the altitude, decreasing when the altitude increases.

On the lowlands of Madeira, below 200 m (North) – 300 m (South) of altitude, the climate is characterized by a long dry season during the summer months and the vegetation is dominated by xerophytic plants. Above those altitudes, the climate is temperate, with both direct and indirect precipitation all year round (as consequence of persistent clouds of orographic origin), thus there is permanent availability of water in the soil for plant development (Quintal, 2007).

The landscape morphology where Funchal urban area is located is an amphitheatre of large dimensions, which abruptly rises from sea level to a mountain range that culminates beyond the 1800 m of altitude, creating favourable conditions for a great phytoclimatic diversity (Santos et al., 2004; Quintal, 2007). Funchal boasts 33 public green spaces that present a balance between arboreal taxa (30.7%), shrubby taxa (33.9%) and herbaceous taxa (35.5%) (Quintal, 2007). According to this author, the most frequent families found in all green spaces are: Bignoniaceae, Asteraceae, Poaceae, Lamiaceae, Lauraceae and Fabaceae. Some species belonging to Asteraceae and Poaceae families also occur on the studied gardens and can contribute to the annual pollen integral (APIn) of Funchal (Camacho et al., 2020). On this basis, the regular monitoring of airborne pollen started in Madeira in 2002, by means of a Hirst-type volumetric spore trap located at Madeira University, following well established guidelines. The yearly average APIn in Funchal, defined as the annual sum of daily pollen concentrations, was 2524 during the period 2002–2017 (Camacho et al., 2020). The airborne pollen spectrum is dominated by some important allergenic taxa/pollen types like Urticaceae, Poaceae, Myrtaceae, Cupressaceae, Pinaceae, *Plantago*, *Platanus*, Amaranthaceae and *Rumex* (Camacho et al., 2016). The local population reveal high sensibilization rates to those pollen taxa, namely: Grasses (17.2%), Pellitory/*Parietaria* (7.5%), Plane/*Platanus* (5.2%), Pine/*Pinus* (2.6%), Timothy grass/*Phleum* (1.7%) and Goosefoot/*Chenopodium* (1.7%) (Camacho, 2017).

Two of the most visited gardens of Funchal city centre were chosen for this study (Fig. 1):

Municipal Garden (N 32° 38.843′, W 16° 54.677′) was built in 1880 and lies between 18 and 20 m above sea level, it has a total area of 8.300 m^2, with a built-up area – auditorium, bar, gardeners' facilities, and toilets – of 880 m^2, while 2.720 m^2 correspond to sidewalks and the garden area occupies 4.700 m^2 (Quintal, 2007). It is an almost flat garden, sheltered by the surrounding buildings. With an almost quadrangular shape, it has more than two dozen beds, with no defined geometric patterns, separated by wide sidewalks with a floor of small pebbles. In the west, there is a pond with fountains and a stream.

Santa Catarina Park (N 32° 38.766′, W 16° 54.865′) was opened to the public after 1966, being the biggest green space of the city centre, with a total area of 35.200 m^2. The built-up space includes a chapel, a playground, a bar, and sanitary facilities, totalling 530 m^2, while 7.720 m^2 correspond to sidewalks. The landscaped area occupies 26.950 m^2 (Quintal, 2007). The altitude ranges from 30 to 10 m and the dominant exposures are to the Southeast and South. The lagoon is one of the structural elements of the park, it has fountains and there is a small island for nesting and resting for swans and ducks in the middle.

The parks under study were visited between March and August of 2021 and the data on the number of plants, covered area and

taxonomic identification in each park was recorded in a field registration form. A plant list from a previous study by Quintal (2007) was used to check and update during the field trips. The studied plants were only angiosperms and gymnosperms, being included trees, shrubs, climbing and herbaceous species. Taxa identification was performed according with the botanical nomenclature of Griffits (1994), Carapeto et al. (2021) and Digital Flora of Portugal (https://jb.utad.pt/flora). The native flora of Madeira was identified based on Press and Short (1994) and Quercetea. (2004). Each record included the scientific and family names, the number of specimens (only for trees), the occupied surface area (m^2), plant height and geographic origin. In the case of trees, the maximum height was inferred from literature data.

2.2. Species diversity

As biodiversity is linked to the resilience of ecosystems, the application of "Santamour rule" was assessed, where no >10% of any species, no >20% of any one genus and no >30% of one family of trees should be planted in urban green areas. A lack of species diversity renders the urban forest more vulnerable to pest outbreaks, diseases, and stress due to climate change (NCC National Capital Commission, 2021). Quantitative data analysis was used to obtain the diversity index and the evenness index (Baliton et al., 2020) for trees and shrubs. The diversity index (H′) (Shannon-Wiener) formula is described in Eq. 1:

$$H' = \Sigma \left\{ \left(\frac{ni}{n}\right) \times ln\left(\frac{ni}{n}\right) \right\} \quad (1)$$

where: ni = Number of individuals of the i-th species; n = Number of individuals of all species. The evenness index (E) was calculated using the following formula:

$$E = \frac{H'}{Hmax} \quad (2)$$

where: H′ = Diversity Index; H max = ln S; S = Species richness. The description of each category of both indexes is shown in Table 1.

To assess the correlation between the I_{UGZA} and the diversity and evenness indexes, a Pearson correlation test was performed using the Excel® Microsoft® 365.

2.3. Determination of the Allergenicity index

To estimate the potential allergenicity of both urban parks, detailed field surveys were conducted, and an inventory of all flower-producing individuals was performed. A quantitative index, which estimate the allergenicity of urban green spaces in general (I_{UGZA}, Index of Urban Green Zone Allergenicity) developed by Cariñanos et al. (2014) was calculated. The I_{UGZA} considers two types of parameters: the biological ones, assigned to each species, while the biometric parameters estimate their behaviour as a source of allergen emissions, based on crown diameter and height (Table 2). The height of shrubs and herbaceous plants were measured using a metal measuring tape. A list of biological parameters for the most common tree species in Mediterranean cities was consulted (Cariñanos and Marinangeli, 2021). The combination of above-mentioned parameters yields the following formula (Eq. 3):

$$IUGZA = \frac{1}{PAV\ x\ ST\ x} \sum_{i=1}^{k} PAV \times Si\ x\ Hi \quad (3)$$

Where PAV = Potential Allergenicity Value for each species, S_T = Total surface area of the park in m^2, k = number of species, S_i = Surface area covered by the *i*-species in m^2, H_i = maximum height reachable by the *i*-species in meters. PAV is yielded by three variables in the Mediterranean area (Eq. 4, Table 2):

$$PAV = ap_i \times sp_i \times dpp_i \quad (4)$$

being (ap_i) allergenic potential of the *i*-th species (0, 1, 2, 3 or exceptionally 4 for main local allergens) (sp_i), strategy of pollination of the *i*-th species (0,1,2,3), (dppi) duration of the principal pollination period of the *i*-th species in weeks (1–3) (Cariñanos et al., 2014; Cariñanos et al., 2017; Cariñanos et al., 2019; Cariñanos and Marinangeli, 2021).

The combination of these parameters gives a potential allergenicity value for each species in a green space, ranging from 0 (for species scoring 0 for each parameter) to a maximum of 27, or even 36, if the species is considered a major local allergen. PAVs assigned to each plant species and their allergenicity is categorized as nil (0), low (1–6), moderate (8–12), high (16–24) or very high (27–36) (Cariñanos et al., 2014; Cariñanos et al., 2016; Carinanos et al., 2016).

Table 1
Classification of Diversity Index (H′) and (E) values.

H′	Description	E	Description
<1	Low diversity, low stability of community	(E) value close to 1	The species are evenly distributed
1–3	Moderate diversity, moderate spread number of individual of each species, moderate stability of community		
>3	High diversity, high spread number of individual of each species, high stability of community	(E) value is close to 0	The species are uneven

Table 2
- Scale of values for the parameters used for PAV and biometric parameters (Cariñanos et al., 2014).

	Parameter		Additional sources of information
PAV	Allergenic potential (ap)	0 = non-allergenic 1 = low allergenicity 2 = moderate allergenicity 3 = high allergenicity 4 = main local allergens	(Camacho et al., 2016; Camacho et al., 2020)
	Pollination strategy (sp)	0 = only female-sex individuals 1 = entomophilous 2 = ampiphilous 3 = anemophilous	Published literature on individual species (Cariñanos et al., 2016; Cariñanos and Marinangeli, 2021)
	Duration of the pollination period (dpp)	1 = 1–3 weeks 2 = 4–6 weeks 3 ≥ 6 weeks	Camacho et al., 2016; Camacho et al., 2020)
Biometric parameters	Horizontal crown projection (trees/shrubs)	Small-diameter: <4 m Medium-diameter: 4–6 m Large-diameter: >6 m	
	Herbs (meadows, rose beds, lawn coverage,…)	m^2 of covered surface	
	Height (trees/shrubs)	Mean height attained at reproductive maturity depending on local bio climate zone. Simplified scale: 2, 6, 10, 14 m exceptionally 18 m	
	Herbs (turf, grass, lawn,…)	H = 0.25 m^2 (minimum height when these species are adequately maintained)	

The I_{UGZA} is expressed as a ratio which allows comparing an urban green space with a hypothetical area with similar features and maximum allergenicity. Application of the index yields a value between 0 or null allergenicity and 1 or maximum allergenicity, for spaces registering maximum scores in all factors and measured parameters.

I_{UGZA} values >0.3 may be considered indicative of high allergenicity (Cariñanos et al., 2014) and the allergy symptom's triggering threshold in the local population was set to 0.30 (Cariñanos et al., 2017). Accordingly, urban green parks can be classified as parks with low (<0.2), moderate (0.2–0.3) or high allergenicity (>0.3) (Cariñanos et al., 2019).

2.4. Allergenic potential scenarios

As the I_{UGZA} represents the year-round allergy risk for a particular site, the index was further calculated considering potential allergic risk scenarios and the prevailing airborne pollen spectrum of Funchal city. In sequence, 10 potential allergy risk scenarios were considered, as shown in Table 3.

The main scenarios considered were OT (Only trees), where flowering predominates in winter and spring, as in the case of Cupressaceae, Fabaceae, Pinaceae and Platanaceae; WH (Without Herbaceous plants) includes the genera of weeds of allergenic importance such as *Parietaria*, *Urtica*, *Plantago, Rumex* and also grasses that normally bloom in Funchal city during spring to autumn; and W2 (Without the 2 most prevalent airborne pollen allergens, Urticaceae and Poaceae). PAV 9–36 hypothesises the removal of plants with PAV values equal or higher than 9; Long PS (Long pollen seasons for all species) and Short PS (Short pollen seasons for all species) infers the allergenic risk under oscillating climatic scenarios, that is, in Long PS, the possibility of the rising temperatures inducing a higher pollen production rates, or in the Short PS, corresponds to water stress conditions which induce less pollen production.

The Kruskal-Wallis tests, used to determine whether there were significant differences in the obtained I_{UGZA} values and the re-calculated index considering the abovementioned scenarios, was performed using Statistica TIBCO Software Inc., (2020), Data Science Workbench, version 14, http://tibco.com.

3. Results

3.1. Floristic characterization of the green spaces

In the present survey, the overall allergenic potential of two public gardens in Funchal city was assessed. A total of 173 plant species belonging to 63 different families were recorded in the Municipal Garden, whereas in Santa Catarina Park 210 species were inventoried, corresponding to 68 plant families. Half of the total area of the Municipal Garden corresponds to green area (50,94%), whilst in the other site the green area represents 36,45%.

The families with the highest species richness in Municipal Garden were Araceae (14 species), Arecaceae (10) and Fabaceae (10). In turn, the genera with most species were: *Dracaena* (5 species), *Philodendron* (5) *Crinum* (4) and *Callistemon* with 3 species.

In regard to species abundance in Municipal Garden, the tree species with highest number of individuals were *Howea forsteriana* (12), *Cordia myxa* (11), *Plumeria rubra* (9), *Nolina recurvata* (9) *Chorisia speciosa* (7), *Phoenix roebelinii* (7), *Agathis robusta* (7), *Cycas revoluta* (6), *Tipuana tipu* (4), *Syagrus romanzoffiana* (4), *Livistona chinensis* (4), *Encephalartos transvenosus* (4) and with 3 specimens each *Jacaranda mimosifolia*, *Gingko biloba*, *Kigelia africana*, *Schefflera actinophylla*, and *Dracaena erecta*. The shrub species with the highest number of individuals were *Dracaena deremensis* (19), *Cordyline fruticosa* (16), *Agave attenuate* and *Cordyline terminalis* (11) and *Brugmansia versicolor* (9).

The families that presented the highest species richness in the second site, Santa Catarina Park, were Arecaceae (13 species), Fabaceae (11) and Asparagaceae (10). The genera with most species in this park were: *Euphorbia* (5 species), *Ficus* (5), *Erythrina, Phoenix,* and *Dracaena* with 4 species each, and *Araucaria* with 3 species.

In this second site, the tree species with highest number of individuals were *Tipuana tipu* and *Archontophoenix cunninghamiana* with 16 individuals, 14 of *Jacaranda mimosifolia* and *Encephalartos transvenosus,* 13 of *Agathis robusta*, 12 of *Cinnamomum camphora* and *Spathodea campanulata* and 10 of *Howea forsteriana*. Regarding shrubs, *Brugmansia versicolor* (10), *Yucca gloriosa* (9), *Phormium tenax* (8), *Cycas revoluta* and *Eugenia uniflora* with 7 specimens were the most abundant.

Table 3
– Description of the hypothetical scenarios used to calculate the I_{UGZA}.

Hypothetic Scenario	Description
OT	Only trees
WH	Without Herbaceous plants
W2	Without the 2 most prevalent airborne pollen allergens (Urticaceae and Poaceae)
PAV 9	Without species with PAVs ≥9
PAV 12	Without species with PAVs ≥12
PAV 18	Without species with PAVs ≥18
PAV 27	Without species with PAVs ≥27
PAV 36	Without species with PAVs = 36
Long PS	Long pollen seasons for all species
Short PS	Short pollen seasons for all species

In Municipal Garden, *Chlorophytum comosum* (Liliaceae) was the species that revealed the highest surface area covered (9.64%), followed by *Stenotaphrum secundatum* (Poaceae) or lawn (8.89%), *Clivia nobilis* (Amaryllidaceae) (7,38%), *Clerodendrum splendens* (Verbenaceae) (3,46%) and *Wedelia trilobata* (Asteraceae) (2,91%). In turn, *Stenotaphrum secundatum* (Poaceae), accounted to almost 12.6% of the surface in Santa Catarina Park, followed by *Hemerocallis fulva* (Hemerocallidaceae) (8,06%), *Agave attenuata* (Agavaceae) (5,43%), *Acalypha wilkesiana* (Euphorbiaceae) (4,16%) and *Asparagus setaceus* (Liliaceae) (4,03%).

The representativeness of plant's biotype was similar on both gardens (Fig. 2), except for climbing plants, which had up to a total of 0.5% in Santa Catarina Park. Plants that occurred as a "Group" totalled 96 species (55,17%) in the Municipal Garden, whereas in Santa Catarina Park there were 113 species (53,80%). For the remaining species on both sites, the total number of individuals ranged between 12 to a single specimen.

Almost 38% of the green surface of Municipal Garden is occupied by plant species derived from Africa/South Africa, followed by plants of Asian (18,34%) and South America origin (9,71%) (Fig. 3). In the second site, 94,77% of the green surface is occupied by plant species derived from the African continent, while a remaining fraction (5,23%) is occupied by species from diverse regions and continents.

3.2. Species diversity

On both sites, the Santamour rule was observed (Supplementary Table 1), either both for tree species, genera, and families. The number of tree species and genera didn't surpass 8,5% of the total in either garden, whereas the number of trees belonging to the same family barely reached 23%. According to the H′ and E values (Table 4) for the Municipal Garden, there is a moderate diversity of tree species, being unevenly distributed in that site, whereas in Santa Catarina Park there is a high diversity of tree and shrub species, being both evenly distributed.

3.3. Allergenic potential assessment

The calculation of the I_{UGZA} index revealed a value of 0,39 for the Municipal Garden and 0,16 for Santa Catarina Park, which, in practical terms, corresponds to urban green spaces of moderate and low allergenicity levels respectively.

The dependency between the I_{UGZA} values and H′ and E indexes were further examined using a Pearson's correlation test, which showed that allergenicity indexes were negatively correlated with the Shannon-Weaver biodiversity score for the Municipal Garden (H';-0.719, $p = 0.018$) and for Santa Catarina Park (H';- $= -0.510$; $p = 0.042$) (Table 5). A non-significant positive correlation between I_{UGZA} scores and the Evenness Index was found.

The relative proportion of plant species assigned to each biometric parameters on both gardens are shown in Table 6. About 93% and 86% of the species from Municipal Garden and Santa Catarina Park, respectively, presented null or low allergenic potential. Between 80% to 82,18% of all species were entomophilous and 84%, on average, showed long pollination periods. Anemophilous plants account 6 to 8% on both sites.

The families that contributed most to the I_{UGZA} in Municipal Garden were Gingkoaceae (33,72%), Lauraceae (23%), and Ulmaceae (8,17%) and in Santa Catarina Park were Lauraceae (11,12%), Araucariaceae (7,16%) and Oleaceae (3,84%) (Table 7). In turn, the species that attained the highest PAV values in Municipal Garden were *Araucaria columnaris* (PAV = 18), *Gingko biloba* (PAV = 18), *Celtis australis* (PAV = 12) and *Phoenix roebelinii* (PAV = 12) (Fig. 4). In Santa Catarina Park, the highest PAV values belonged to spontaneous *Parietaria judaica* (PAV = 36), *Fraxinus americana* (PAV = 27), followed by *Cortaderia selloana* (PAV = 18), *Araucaria* spp. (PAV = 18), *Cedrus deodara* (PAV = 18), and *Platanus* sp. (PAV = 18). *Phoenix roebelinii*, *Phoenix* sp. and *Quercus ilex* all attained a PAV of 12.

In Municipal Garden, most species with moderate to high PAV occupied surface areas below 25 m^2, whereas those with moderate

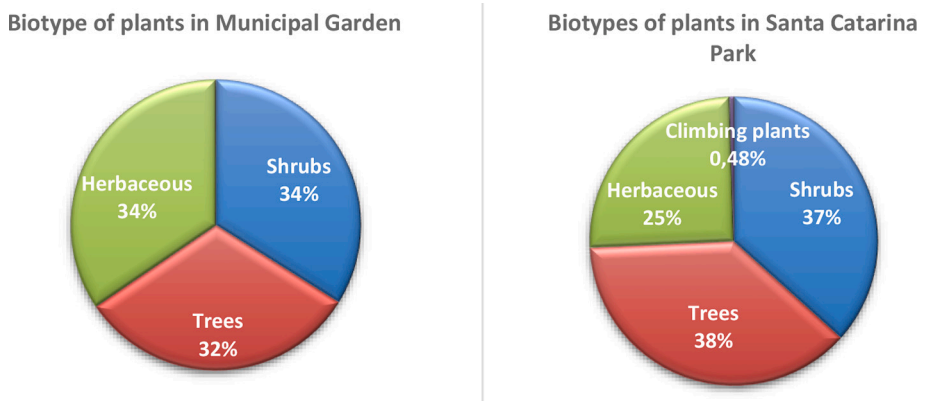
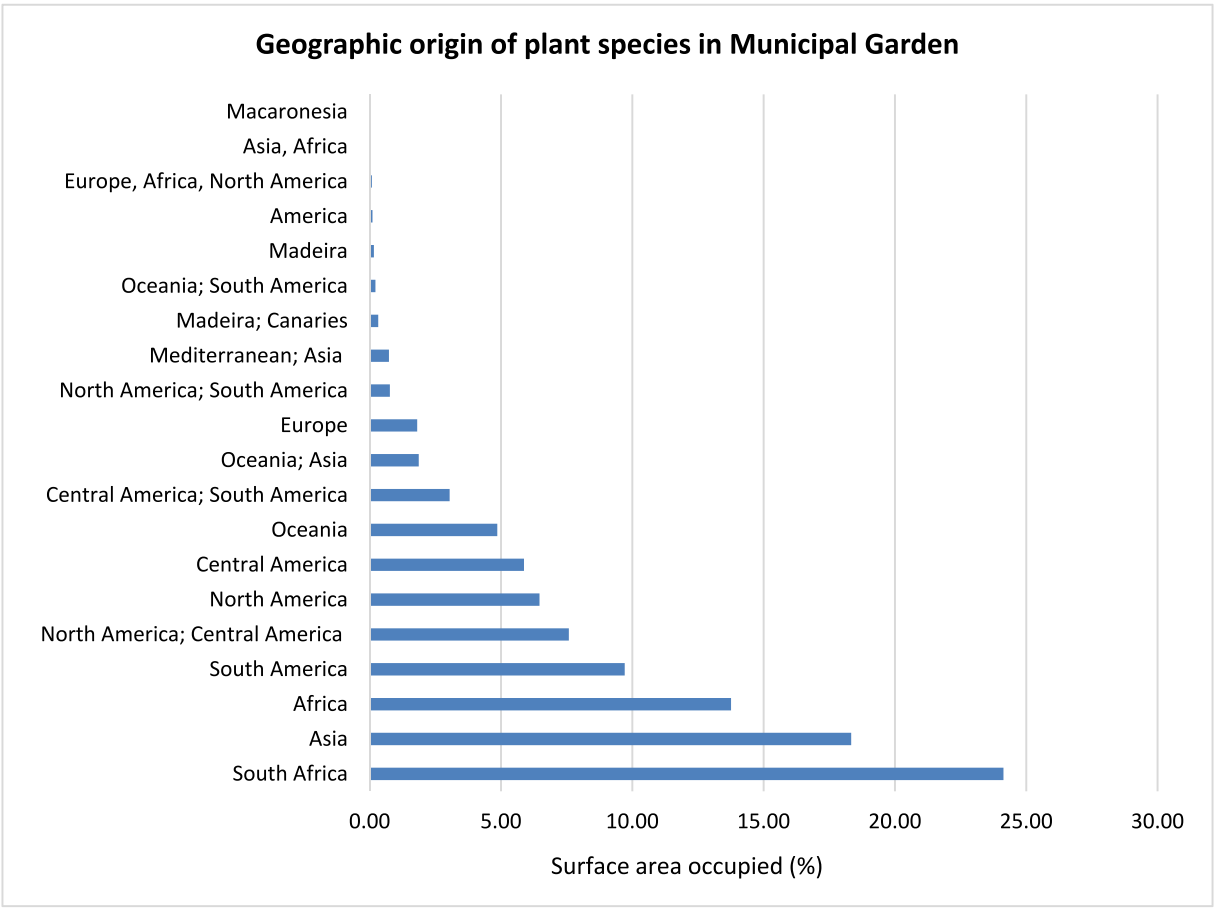
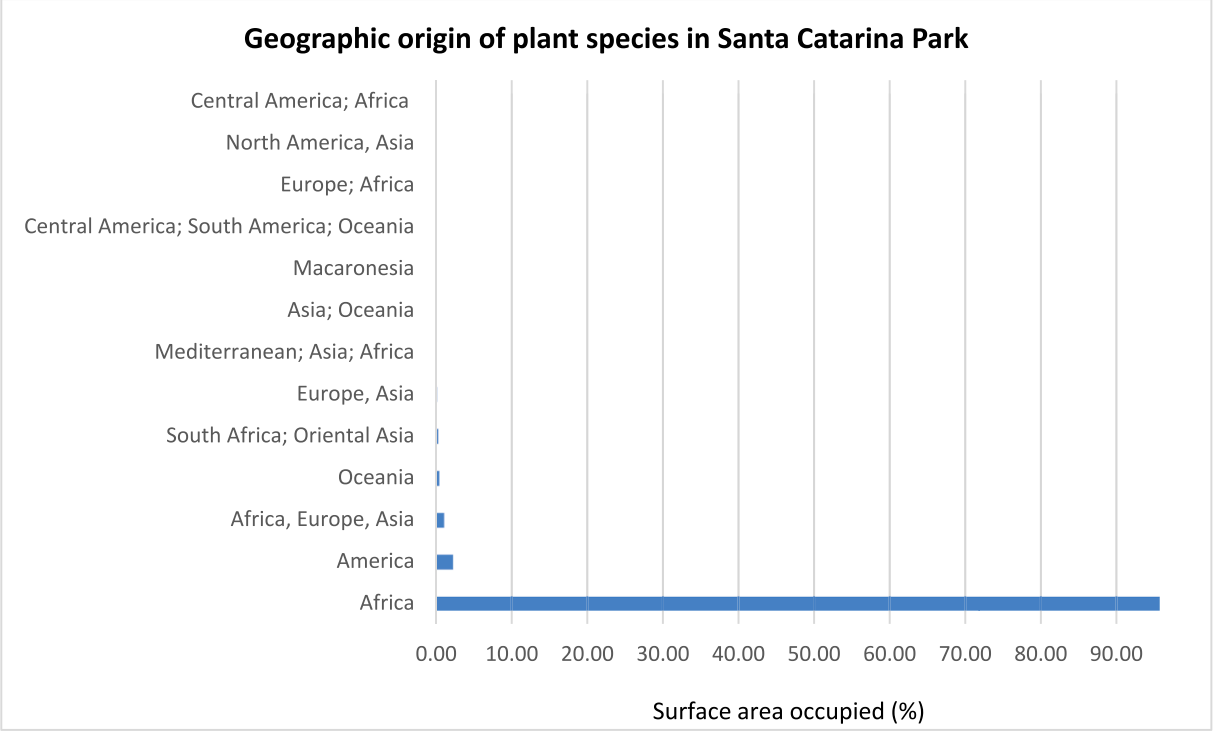


Fig. 2. - Proportion of plant biotypes on both green areas under study. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)





(caption on next page)

Fig. 3. – Percentage of surface area occupied by plant species on each garden according to their geographic origin.

Table 4
- Diversity index (H′) and Evenness Index (E) obtained to both green sites.

		Diversity index (H′)	Classification	Evenness Index (E)	Classification
Municipal Garden	Tree	1,56	Moderate diversity	0,39	The species are unevenly distributed
	Shrubs	3,25		0,84	The species are evenly distributed
Santa Catarina Park	Tree	4,01	High diversity	0,93	
	Shrubs	3,42		0,84	

Table 5
Pearson's correlation coefficients between the I_{UGZA} and the assessed H′ and E indexes.

Index	I_{UGZA} (Municipal Garden)	*p* values	I_{UGZA} (Santa Catarina Park)	*p* values
Diversity (H′)	-0.719*	0.018	−0.510*	0.042
Evenness (E)	0.640	0.721	0.340	0.296

* Statistical significance at $p \leq 0.05$.

Table 6
– Relative proportion of plant species assigned to each biometric parameters on both gardens.

PAV parameter	Municipal Garden		Santa Catarina Park	
	Number of species	%	Number of species	%
Allergenic potential				
0	126	72,41	135	64,29
1	36	20,69	46	21,90
2	11	6,32	20	9,52
3	1	0,57	8	3,81
4	0	0,00	1	0,48
	174	100	210	100
Pollination strategy				
0	1	0,57	1	0,48
1	143	82,18	168	80,00
2	19	10,92	23	10,95
3	11	6,32	18	8,57
	174	100	210	100
PPPi				
1	6	3,45	10	4,76
2	19	10,92	27	12,86
3	149	85,63	173	82,38
	174	100	*210*	100

PAV, such as *Rumex* sp. and *Alternanthera ficoidea,* attained highest areas (Fig. 5).

On regards to Santa Catarina Park, it is possible to verify that, in general, plant species with the highest PAV occupied reduced areas compared to those with lowest PAV values. For example, *Araucaria columnaris* (PAV = 18) occupied a total area of 5 m^2 and *Parietaria judaica* (PAV = 36) of 6 m^2, whilst *Alternanthera ficoidea* with lower PAV (9) revealed the highest surface area.

3.4. Allergenic potential scenarios

The scenario that would aggravate the I_{UGZA} value corresponds to an extended pollen season for all species present in both sites (Long PS) (Fig. 6). The absence of plants belonging to Urticaceae and Poaceae (W2), wouldn't affect the current index in Municipal Garden, nor those plants with PAVs equal to 36 (*Parietaria judaica*) in Santa Catarina Park. More, in the latter, the absence of herbaceous plants or even solely the presence of trees, would result in a slight positive effect on the allergenic index. In addition, the scenarios without plants that exhibit PAV values equal or higher than 9 (PAV 9, 12, 18 and 27), would lower the overall indexes. Lastly, the hypothetical scenario of reduction of the pollen season in all species (short PS) in both sites, would result in the highest reduction of the current I_{UGZA} values.

The observed differences between the current I_{UGZA} values and each scenario presented are, nevertheless, not statistically significative (Kruskal-Wallis applied to Municipal Garden: $p = 1{,}000$ and to Santa Catarina Park: $p = 0{,}4335$) ($p > 0{,}05$).

Table 7
– Families and species that contributed most to the I_{UGZA}.

Family/Species - Municipal Garden	Contribution to the Index
Gingkoaceae	**33,72%**
Gingko biloba	33,72%
Lauraceae	**22,99%**
Cinnamomum camphora	22,99%
Ulmaceae	**8,17%**
Celtis australis	8,17%
Araucariaceae	**7,66%**
Araucaria columnaris	7,66%
Arecaceae	**5,33%**
Syagrus romanzoffiana	2,76%
Livistona chinensis	1,23%
Phoenix roebelinii	0,74%
Archontophoenix cunninghamiana	0,61%
Fabaceae	**5,30%**
Albizia saman	4,29%
Other families	**<0,50%**

Family/Plant species - Santa Catarina Park	Contribution to the Index
Lauraceae	**11,12%**
Cinnamomum camphora	11,12%
Araucariaceae	**7,16%**
Araucaria araucana	3,56%
Araucaria columnaris	1,48%
Araucaria heterophylla	2,12%
Oleaceae	**3,84%**
Fraxinus americana	3,74%
Jasminum sp.	0,02%
Ligustrum lucidum	0,03%
Ligustrum vulgare	0,06%
Areceae	**0,89%**
Archontophoenix cunninghamiana	0,30%
Livistona chinensis	0,08%
Phoenix canariensis	0,03%
Phoenix reclinata	0,21%
Phoenix roebelinii	0,07%
Phoenix sp.	0,01%
Syagrus romanzoffiana	0,13%
Washingtonia filifera	0,02%
Pinaceae	**0,73%**
Cedrus deodara	0,73%
Fagaceae	**0,59%**
Quercus ilex	0,59%
Platanaceae	**0,59%**
Platanus sp.	0,59%
Myrtaceae	**0,58%**

(*continued on next page*)

Table 7 (*continued*)

Family/Plant species - Santa Catarina Park	Contribution to the Index
Callistemon rigidus	0,08%
Callistemon viminalis	0,03%
Eucalyptus citriodora	0,40%
Eucalyptus sideroxylon	0,08%
Anacardiaceae	**0,54%**
Schinus molle	0,32%
Other families	**<0,50%**

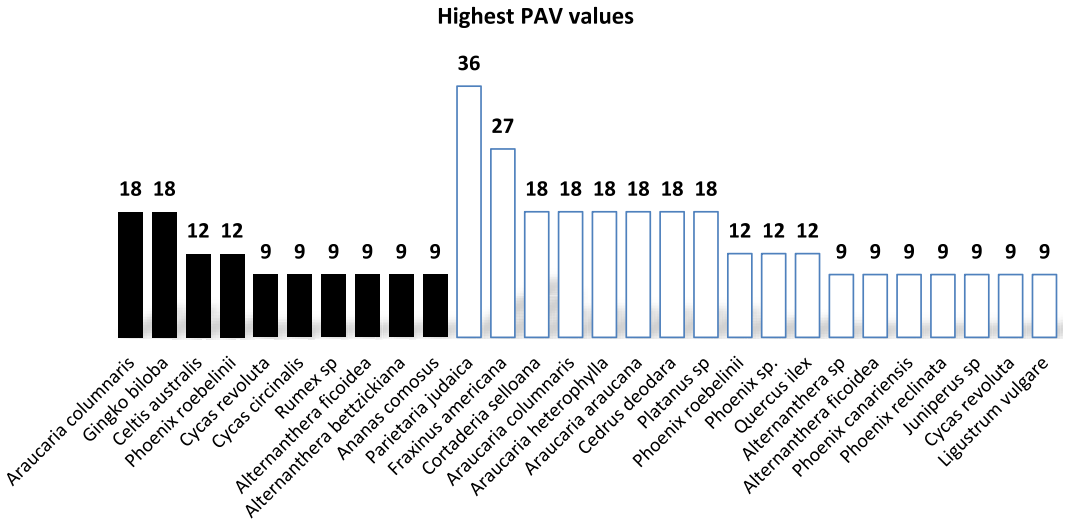


Fig. 4. – Plant species that exhibit the highest PAV values (black columns – Municipal Garden; white columns – Santa Catarina Park).

4. Discussion

The in-situ inventories performed in 2 public green gardens of Funchal allowed to infer the potential allergic risk of these spaces. To the best of our knowledge, this is the first survey performed in a Macaronesian island. From a bioclimatic perspective, Madeira Island shows both Temperate and Mediterranean climatic features (Rivas-Martínez, 2001), but due its geomorphological conditions, is also considered a subtropical region. Given these peculiarities, the assessment of the Urban Green Zone Allergenicity Index (I_{UGZA}), which has been preferably applied in Mediterranean regions (Velasco-Jiméneza et al., 2020; Sabariego et al., 2021), in Temperate (Kasprzyk et al., 2019; Kara and Aşık, 2022) and Tropical sites (Escobedo et al., 2023) was also applied here.

Both studied gardens reveal a considerable number of plant species and families (Municipal Garden - 173 species, 63 families; Santa Catarina Park - 210 species, 68 families). The above mentioned geoclimatic conditions have promoted a natural adaptation of different plant species (Borges et al., 2008), which is a fact that explains the observed biodiversity and the multiple geographic proveniences of the species. As >50% of species on both sites occurred in groups and are herbaceous plants, the H′ and E indexes were applied to trees and shrubs, revealing high diversity of shrubs species in both sites, but moderate diversity for trees in Municipal Garden, and high diversity in the other studied area.

Most works devoted to allergenicity index characterization have focused mainly on trees (Cariñanos et al., 2019; Jochner-Oette et al., 2018; Cariñanos et al., 2019; Velasco-Jiméneza et al., 2020) and few have included herbaceous plants (Kasprzyk et al., 2019). In our survey all plant biotypes were considered, including shrubs, herbs and climbing plants, that are submitted to regular gardening maintenance on both studied sites in Funchal and normally reveal less longevity compared to tree specimens. As a result, the floristic inventory performed by our group differs from those obtained by Quintal in 2007, thus, it will be necessary to reassess the vegetation cover in the coming years to infer the allergenic risk at that time.

Quintal in 2007 observed a predominance of Asteraceae species in both sites under study, in addition to those belonging to Fabaceae and Agavaceae families. Currently, we found a prevalence of Araceae, Arecaeceae, Asparagaceae taxa, among other angiosperms, that is a fact that has changed the reported geographic origins. The most important airborne pollen allergens described for Europe derived from plant species of Mediterranean origin. Except for the anemophilous species *Celtis australis,* found in the Municipal Garden, which is a moderate allergen of Mediterranean and Asian origin, most inventoried plant species came from various regions and continents. Also, the single specimen of *Quercus ilex* found in Santa Catarina Park is considered an important allergen native from the Mediterranean area, but its weak representativeness and low occupied surface didn't contribute much to the allergenic risk of this

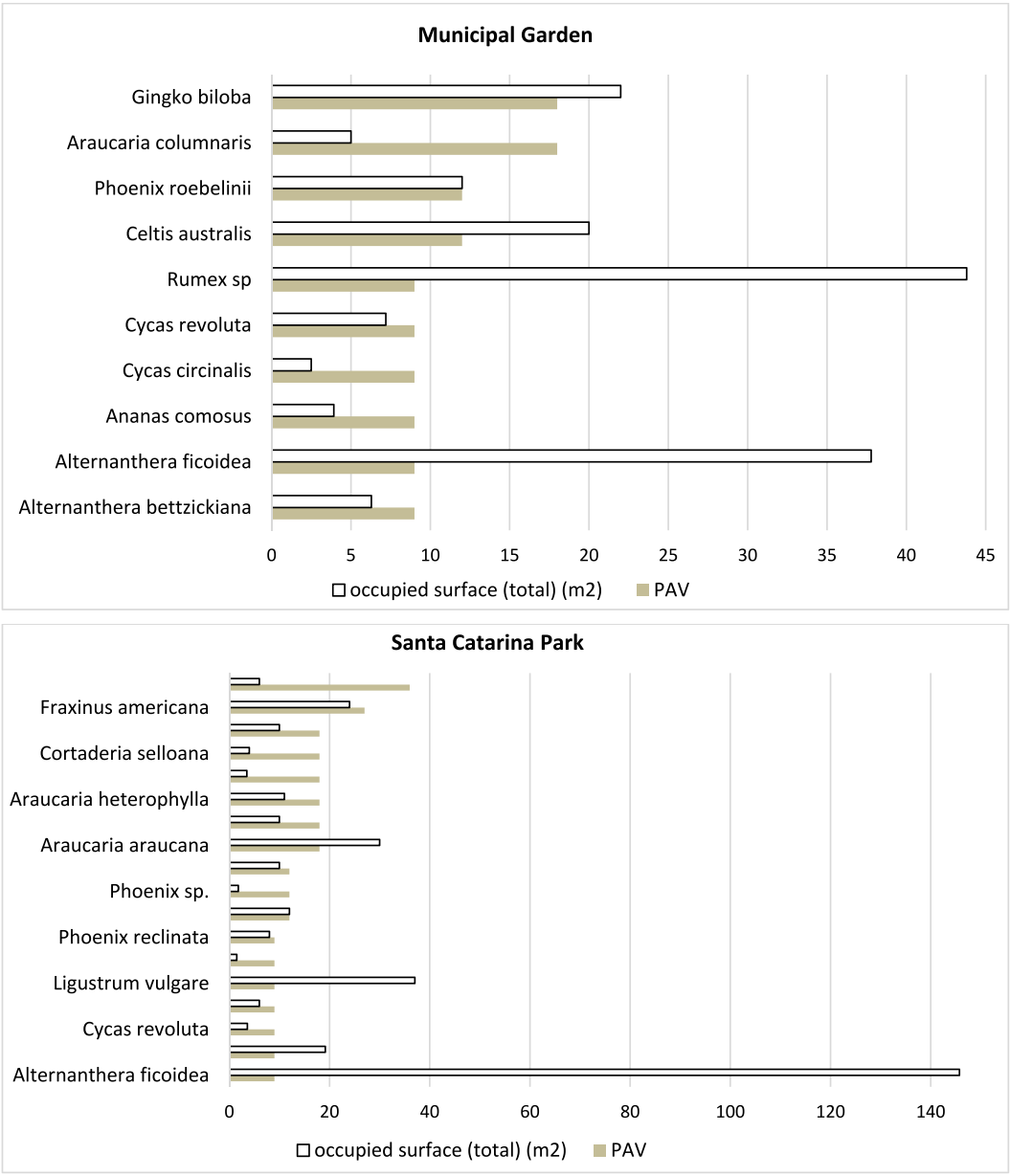


Fig. 5. – Surface area occupied by plant species with the highest PAV values on both sites.

place.

The ratio of tree species diversity, assessed by the Santamour rule for each green site, certifies that both ecosystems are resilient, being less vulnerable to pests and diseases, with less risk for widespread and rapid tree mortality (NCC National Capital Commission, 2021). Ultimately, the biodiversity level attested by the rule suggests that both sites are more prepared to respond to stress due to climate change, in comparison to urban green forests that rely solely on a few individual species and cultivars (NCC National Capital Commission, 2021).

The allergenicity index obtained by Municipal Garden was 0,39, which according to Cariñanos et al. (2014), means this park poses a moderate risk for pollen allergy sufferers. Despite the long pollination periods for most species, about 93% of them presented null allergenic potential. In addition, it was found that 80% of all species use entomophilia as the main pollination strategy. Kasprzyk et al. (2019) also obtained I_{UGZA} values around the allergenic threshold, for two parks in Rzeszów (Poland), mainly due to the occurrence of specimens of *B. pendula*, *C. avellana*, *F. excelsior*, *C. betulus*, *Quercus* sp. and *Acer* sp. These allergenic species prevail in temperate regions of Europe but barely occur in our studied sites.

Municipal Garden has a green area surface of 4228,2 m^2 (50,94% of the total park area), hosting a great diversity of plants, but several species that exhibit moderate allergenic potential (*Celtis australis* (PAV = 12; area = 20 m^2) and *Phoenix roebelinii* (PAV = 12;

Fig. 6. – Scatterplot showing the variation of I_{UGZA} under 10 hypothetical scenarios. The horizontal dashed line corresponds to the I_{UGZA} base values in each site.

area = 12 m^2)), and some of high allergenic potential (*Araucaria columnaris* (PAV = 18; area = 5 m^2) and *Gingko biloba* (PAV = 18; area = 22 m^2)) influenced heavily the value of the I_{UGZA}. Despite the reduced surface area occupied by such few species in a small green urban site, it has negatively affected the baseline allergenic index. In addition, Municipal Garden exhibits a lower diversity index than Santa Catarina Park, revealing higher tree crown volume and less turf or paved areas than Santa Catarina Park, which might aggravate the overall allergenic index.

On the other hand, the I_{UGZA} obtained for Santa Catarina Park was 0,16, which in practical terms corresponds to a green space of low allergenicity level. As in Municipal Garden, most of the species present in this park have null or low allergenic potential to visitors (86%) and 82,18% are entomophilous. Despite that, several species show PAVs considered high to very high, as was the case of the main local allergen *Parietaria judaica* (PAV = 36) (occupied area = 6 m^2), *Fraxinus americana* (PAV = 27) (occupied area = 14 m^2), *Cortaderia selloana* (occupied area = 4 m^2), *Araucaria* spp. (occupied area = 51 m^2), *Cedrus deodara* (occupied area = 3,5 m^2), and *Platanus* sp. (occupied area = 10 m^2), (all obtained a PAV = 18). Albeit their high PAV values, their contribution to the I_{UGZA}, is low due to its low representativeness and occupied surface, meaning they didn't intensify much the allergenic risk of this place.

The results also show an inverse correlation between allergenicity and the Diversity index (H'), a fact also observed in similar surveys (Cariñanos et al., 2016; Cariñanos et al., 2017). This suggests that the greater the species' diversity, the less likely occurrence of allergic symptoms. According to Hanski et al. (2012), environmental biodiversity is negatively correlated with atopy among urban populations. As expected, a scenario that would aggravate the I_{UGZA} values would be an extended pollen season of all species presented on both sites (Long PS), whilst an opposite scenario, of diminishing pollen seasons in all species (short PS) in both sites, would result in

a reduction of the current I_{UGZA} values. It has been observed that the main pollen seasons from important allergenic plants in Central Europe have been lasting longer and the days with allergenic potential have been rising in line with the local temperature rising trend (Makra et al., 2011), especially in the Mediterranean region (Bonofiglio et al., 2012; Gehrig and Clot, 2021). As the overall pollen seasons have been tending to elongate over time, it poses a higher risk to allergic people that visit urban green infrastructures. The other hypothetical scenario of Only trees (OT) would result in a slight, although not significant, reduction of the allergenic indexes. In fact, the tree pollen allergens that dominate in the airborne pollen spectrum of Funchal are composed by Cupressaceae, Pinaceae and *Platanus* taxa, which flowering predominates in winter and spring (Camacho et al., 2016), but their representation in the studied areas is frankly low.

Regarding the other considered scenarios, Without Herbaceous plants (WH), and Without plants that exhibit PAV values higher that 9 (PAV 9, 12, 18, 27 and 36), they would result in a slight, although no significant improvement of the allergenic indexes, which partly corroborates the correlation coefficient result obtained between the I_{UGZA} and the Shannon-Weaver biodiversity index.

As mentioned before, most of the species showing high PAVs values, (capable of increasing the I_{UGZA} significantly) had low representativeness in both green sites. Lastly, a scenario Without the 2 most prevalent airborne pollen allergens (Urticaceae and Poaceae) (W2), wouldn't affect the current index value in Municipal Garden but could lower the I_{UGZA} in Santa Catarina Park due to the spontaneous occurrence of *Parietaria judaica*. Regarding other allergenic weeds such as *Urtica* and *Plantago* that appear in the pollen spectrum of Funchal, we assume that is because the lawns are mowed often, their representativeness is very low.

4.1. Recommendations towards a low respiratory allergic risk

The studied spaces are sites that present a wealth of native and non-native species of inestimable value for the city and for those who visit them. The desirable balance between the services that these ecosystems provide to the city and the potential risk of causing respiratory allergy in the population sensitised to certain allergenic taxa is difficult to maintain. Based on this study, it is possible to point out some practical recommendations that should help to keep respiratory allergic risk levels low, in the case of Parque de Santa Catarina, and to reduce this risk threshold index, in the case of Municipal Garden.

The following considerations about the plants that attained PAV values considered high and very high are related to the herbaceous species *Cortaderia selloana* and *Parietaria judaica*. *Cortaderia selloana* is on the National List of Invasive Species (Decree-Law n. ° 92/2019, July 10, 2019) and in the last few decades, this Poaceae originated from South American, commonly known by Pampas grass, has expanded worldwide in several countries, including those in Western Europe (Rodríguez et al., 2021). According to these authors, *C. selleona* might cause respiratory allergies to a similar extent to local grasses and it pollinates later than the local grasses, which would extend the period of grass allergies in the region for about three months every year. Taking this evidence into account, the planting of this plant as an ornamental is not recommended and its removal from urban green spaces is strongly advised.

In turn, *Parietaria* belongs to the Urticaceae family and is considered the most important cause of pollen allergies in the Mediterranean (D'Amato et al., 2007). It was found growing spontaneously on walls of Santa Catarina Park, the reason why it wasn't removed during the regular garden maintenance. Although there are many Urticaceae species, *Parietaria judaica* and *P. officinalis* are the most relevant because they're involved in the allergy pathogenesis. *Parietaria* which is well widespread in regions with Mediterranean climate, shows long pollen seasons and apparently increases pollen loads over time, features capable of causing long-lasting allergy symptoms (Ciprandi et al., 2018).

In the case of trees showing high PAV values, to which attention is required, the planting of female trees of *Ginkgo biloba* is recommended whenever it's time to replace the existing ones. This species has gained popularity in many cities around the world due to its aesthetic value and good adaptation to urban conditions (Roloff et al., 2018), however there is evidence that it has high potential of allergenicity (Cariñanos and Marinangeli, 2021).

Caution must also be taken with *Araucaria* species, particularly in Santa Catarina Park, in which 8 specimens occur. According to Cariñanos and Marinangeli (2021), the PAV value assigned to *Araucaria* species is classified as high and there is evidence that they may produce pollinosis in highly atopic individuals (Taketomi et al., 2006). *Araucaria* species correspond to the tallest trees in Funchal's gardens, surpassing 40 m high (Quintal, 2007) and use anemophily as a pollination strategy (Latorre et al., 2020). In addition, its pollen season lasts 2 to 3 months, occurring in February–March, from April–May, or from May to July (Quintal, 2007), that is a fact that patients sensitised to this pollen type and allergists should be aware of. Notwithstanding, the araucarias have been used as ornamental trees for centuries worldwide, both for their pine cones and for their beauty, size and longevity, which in some cases gives them the status of "monumental trees" or "trees of public interest", including in Portugal (*Araucarias in Portugal: Ornamental and Monumental. Florestas. Pt*, 2023).

A final note on Arecaceae, one of the families that presented the highest species richness in both studied sites. These plants, especially palm trees, are mostly distributed in tropical and subtropical regions where rainfall is not abundant, often considered ecologically and aesthetically important where they occur (Huertas et al., 2011). Allergic sensitisation to pollen of different species of Arecaceae family has been documented worldwide, especially on the Mediterranean Coast and in the Arabian Peninsula where the presence of Date-palm (*Phoenix dactylifera* L.) is abundant (Räsänen, 2000; Almogren, 2009). According to Fernández and López (2000), the clinical relevance of palm pollen will probably grow due to its ornamental planting throughout the Mediterranean coastline, where extensive palm plantations for economical purposes can be found. Palm species have hermaphroditic or unisexual flowers, generally very small, almost seated, sometimes in groups of 3 (two male and one female) (Simpson, 2010), presenting a clearly wind-pollination strategy. Another important biological parameter assigned to these species is that male date palms commonly produce inflorescences over a long period, a condition that can be further extended by more than a month depending on climatic conditions (Karim et al., 2022). This fact represents an additional concern to allergic sufferers during the pollen season that normally

occurs between January and July (Quintal, 2007).

From the inventory carried in the 2 green areas, it was possible to identified 6 additional species that belong to the National List of Invasive Species: 2 herbaceous – *Phytolacca americana* (Phytolaccaceae), *Zantedeschia aethiopica* (Araceae); 3 shrubs – *Agave americana* (Agavaceae), *Crassula ovata* (Crassulaceae), *Lantana camara* (Verbenaceae), and 1 tree – *Pittosporum undulatum* (Pittosporaceae). Despite their PAV values between 0 and 3, categorized as low allergenic risk, urban green designers, and entities responsible for the maintenance of local green spaces should avoid the planting of species signalled as invaders, though used as ornamental and for commercial purposes. Many invasive species have unknown allergenicity, but most of them are being classified as allergenic (Cariñanos and Casares-Porcel, 2011), which means that their rapid spread and overrepresentation on local plants communities corresponds to an additional source of sensitization for the local and foreign population.

In conclusion, it is recommended the inclusion of plants belonging to shrub and herbaceous biotypes in research dedicated to the assessment of allergenic risk in urban green areas, as they allow a more accurate inference of the real risk to which the population is exposed. This assessment is particularly important in tropical and subtropical regions that exhibit a considerable diversity of native and non-native taxa of bushes and herbaceous plants.

Although herbs and shrubs constitute plant communities subject to frequent maintenance and show less longevity compared to trees, species diversity seems to be a protective measure against atopy. Furthermore, some species can contribute negatively to I_{UGZA} and represent major local allergens.

One of the limitations of this study refers to the non-seasonal nature of the I_{UGZA} as pollination occurs at a certain time of the year for each species, meaning the risk is variable throughout the year. The I_{UGZA} considers solely the maximum height of the trees, though some might never reach their maximum height in result of diseases, natural disasters, or maintenance of the spaces.

Given the specificity of I_{UGZA} for each garden as a managing tool for pollen allergen emissions in urban green spaces, it would be appropriate to extend this survey to other urban parks and gardens in the region, allowing a better inference of the exposure risk of the population. Furthermore, it would be interesting to analyse the role of meteorological parameters (such as temperature, precipitation, etc.) in future studies given their influence on biological parameters that define the I_{UGZA} value.

Author statement

I state that data related to the original article entitle: "The allergenic potential of green urban areas in the Macaronesian islands: the case of Funchal City (Madeira)" will be totally available for query during the review process, and upon request after publication.

The corresponding author.

(Irene Camacho)

This original article entitle: "*The allergenic potential of green urban areas in the Macaronesian islands: the case of Funchal City (Madeira)*" focused in 2 public gardens, which are common elements that constitute the urban green infrastructure of any city. Such green units provide ecosystem services that are becoming a key concern in urban planning strategies and policies. As so, the present work should provide useful tools on respect to:

- Biodiversity resources
- Invasive plants impact and ecosystem disservices
- Land Management and Planning
- Nature protection policies
- Outdoor air quality and public health
- Pollen allergy avoidance
- Sustainable Development
- Urban green spaces

Institutional review board statement

Not applicable.

CRediT authorship contribution statement

Irene Camacho: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Álvaro Macías-de-la-Rosa:** Methodology. **Roberto Camacho:** Writing – review & editing, Methodology. **Agnieszka Grinn-Gofroń:** Writing – review & editing, Methodology. **Paloma Cariñanos:** Writing – review & editing, Visualization.

Declaration of competing interest

The authors declare no conflicts of interest.

Data availability

Data will be made available on request.

Acknowledgments

The authors are grateful to Professor Raimundo Quintal for providing the flora databases of each study site, and to Professor Agnieszka Strzelczak for the help with the statistical analysis.

Funding

Paloma Cariñanos thanks to the University of Granada-Plan Propio for financial support through Pre-Competitive Research Projects Pre-Greenmitigation3 (PP2022.PP34).

Appendix A. Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.uclim.2024.101866.

References

Aerts, R., Bruffaerts, N., Somers, B., Demoury, C., Plusquin, M., Nawrot, T.S., Hendrick, M., 2021. Tree pollen allergy risks and changes across scenarios in urban green spaces in Brussels, Belgium. Landsc. Urban Plan. 207 https://doi.org/10.1016/j.landurbplan.2020.104001. Article 104001.

Almogren, A., 2009. Airway allergy and skin reactivity to aeroallergens in Riyadh. Saudi Med. J. 30 (3), 392–396.

Araucarias in Portugal: Ornamental and Monumental. Florestas. Pt. Retrieved from: https://florestas.pt/descobrir/araucaria-bidwillii-a-arvore-das-pinhas-gigantes/. Accessed June 23, 2023.

Baliton, R.S., Landicho, L.D., Cabahug, R.E.D., Paelmo, R.F., Laruana, K.A., Rodriguez, R.S., Visco, R.G., Castilho, A.K.A., 2020. Ecological services of agroforestry systems in selected upland farming communities in the Philippines. Biodiversitas 21, 707–717. https://doi.org/10.13057/biodiv/d210237.

Bonofiglio, T., Orlandi, F., Ruga, L., Romano, B., Fornaciari, M., 2012. Climate Change Impact on the Olive Pollen Season in Mediterranean Areas of Italy: Air Quality in Late Spring From An Allergenic Point of View. Environmental Monitoring Assessment. https://doi.org/10.1007/s10661-012-2598-9.

Borges, P.A.V., Abreu, C., Aguiar, A.M.F., Carvalho, P., Jardim, R., Melo, I., Oliveira, P., Sérgio, C., Serrano, A.R.M., Vieira, P., 2008. A List of the Terrestrial fungi, Flora and Fauna of Madeira and Selvagens Archipelagos. Direcção Regional do Ambiente da Madeira and Universidade dos Açores, Funchal and Angra do Heroísmo.

Calaza, P., Cariñanos, P., Escobedo, F.J., Schwab, J., Tovar, G., 2018. Building green infrastructure and urban landscapes. Unasylva-An International Journal of Forestry and Forest Industries 69, 11–21.

Camacho, I., 2017. Inhalant allergens in Portugal. Int. Arch. Allergy Immunol. 172, 67–88.

Camacho, I., Caeiro, E., Ferro, R., Camacho, R., Câmara, R., Grinn-Gofroń, A., Smith, M., Nunes, C., Morais-Almeida, M., 2016. Spatial and temporal variations in the annual pollen index recorded by sites belonging to the Portuguese aerobiology network. Aerobiologia 33, 265–279. https://doi.org/10.1159/000458150.

Camacho, I., Caeiro, E., Nunes, C., Morais-Almeida, M., 2020. Airborne pollen calendar of Portugal: a 15-year survey (2002-2017). Allergol. Immunopathol. 48, 94–201. https://doi.org/10.1016/j.aller.2019.06.012.

Carapeto, A., Pereira, P., Porto, M., 2021. Guia da flora de Portugal Continental, 1st ed. Edições Lisboa Capital Verde Europeia, Lisboa.

Cariñanos, P., Casares-Porcel, M., 2011. Urban green zones and related pollen allergy: a review. Some guidelines for designing spaces with low allergy impact. Landsc. Urban Plan. 101, 205–214. https://doi.org/10.1016/j.landurbplan.2011.03.006.

Cariñanos, P., Marinangeli, F., 2021. An updated proposal of the potential Allergenicity of 150 ornamental trees and shrubs in Mediterranean cities. Urban For. Urban Green. 63 (2021), 127218 https://doi.org/10.1016/j.ufug.2021.127218.

Cariñanos, P., Casares-Porcel, M., Quesada-Rubio, J.-M., 2014. Estimating the allergenic potential of urban green spaces: A case-study in Granada, Spain. Landsc. Urban Plan. 123, 134–144. https://doi.org/10.1016/j.landurbplan.2013.12.009.

Cariñanos, P., Adinolfi, C., De la Guardia, C.D., De Linares, C., Casares-Porcel, M., 2016. Characterization of allergen emission sources in urban areas. J. Environ. Qual. 45, 244–252. https://doi.org/10.2134/jeq2015.02.0075.

Carinanos, P., Casares-Porcel, M., De La Guardia, A.V.D., La Cruz-Marquez, R.D., De La Guardia, C.D., 2016. Charting trends in the evolution of the La Alhambra forest (Granada, Spain) through analysis of pollen-emission dynamics over time. Clim. Chang. 135, 453–466. https://doi.org/10.1007/s10584-015-1589-6.

Cariñanos, P., Casares-Porcel, M., de la Guardia, C.D., Aira, M.J., Belmonte, J., Boi, M., Elvira-Rendueles, B., De Linares, C., Fernández-Rodriguez, S., Maya-Manzano, J.M., Rosa Pérez-Badía, R., Rodriguez-de la Cruz, D., Rodríguez-Rajo, F.J., Rojo-Úbeda, J., Romero-Zarco, C., Sánchez-Reyes, E., Sánchez-Sánchez, J., Tormo-Molina, R., Maray, A.M.V., 2017. Assessing allergenicity in urban parks: A nature-based solution to reduce the impact on public health. Environ. Res. 155, 219–227. https://doi.org/10.1016/j.envres.2017.02.015.

Cariñanos, P., Grilo, F., Pinho, P., Casares-Porcel, M., Branquinho, C., Acil, N., Andreucci, M.B., Anjos, A., Bianco, P.M., Brini, S., Calaza-Martínez, P., Calvo, E., Carrari, E., Castro, J., Chiesura, A., Correia, O., Gonçalves, A., Gonçalves, P., Mexia, T., Mirabile, M., Paoletti, E., Santos-Reis, M., Semenzato, P., Vilhar, U., 2019. Estimation of the allergenic potential of urban trees and urban parks: towards the healthy Design of Urban Green Spaces of the future. Int. J. Environ. Res. Public Health 16. https://doi.org/10.3390/ijerph16081357 article 1357.

Ciprandi, G., Puccinelli, P., Incorvaia, C., Masieri, S., 2018. Parietaria allergy: an intriguing challenge for the allergist. Medicina 54, 106. https://doi.org/10.3390/medicina54060106.

D'Amato, G., Cecchi, L., Bonini, S., Nunes, C., Annesi-Maesano, I., Behrendt, H., Liccardi, G., Popov, T., Van Cauwenberge, P., 2007. Allergenic pollen and pollen allergy in Europe. Allergy 62, 976–990. https://doi.org/10.1111/j.1398-9995.2007.01393.x.

Decree, 2019. Decree-Law n. ° 92/2019, July 10, 2019. Retrieved from: https://faolex.fao.org/docs/pdf/por187765.pdf. Accessed June 12, 2023.

Direção Regional de Estatística da Madeira, 2021. Estatísticas Demográficas da Região Autónoma da Madeira. Funchal.

Escobedo, F.J., Dobbs, C., Cariñanos, P., 2023. Neotropical urban forest allergenicity and ecosystem disservices can affect vulnerable neighbourhoods in Bogota, Colombia. Sustain. Cities Soc. 89. Article 104343.

Fernández, J., López, G., 2000. Palmae. Descriptión y distribuición en España. En Atlas de Aerobiología y Polinosis, SEAIC y Forum Siglo XXI (Schering-Plough).

Flora Digital of Portugal, 2024. Flora Digital of Portugal. Retrieved from: https://jb.utad.pt/flora. Accessed June 19, 2023.

Gehrig, R., Clot, B., 2021. 50 years of pollen monitoring in Basel (Switzerland) demonstrate the influence of climate change on airborne pollen. Front. Allergy 2, 677159. https://doi.org/10.3389/falgy.2021.677159.

Griffits, M., 1994. Index of Garden Plants. The New Royal Horticultural Society Dictionary. The Macmillan Press Ltd, London and Basingstoke.

Hanski, I., von Hertzen, L., Fyhrquist, N., Koskinen, K., Torppa, K., Laatikainen, T., Karisola, P., Auvinen, P., Paulin, L., Mäkelä, M., Vartiainen, E., Kosunen, T.U., Alenius, H., Haahtela, T., 2012. Environmental biodiversity, human microbiota, and allergy are interrelated. Proc. Natl. Acad. Sci. USA 109, 8334–8339. https://doi.org/10.1073/pnas.1205624109.

Huertas, A.J., López-Sáez, M.P., Carnés, J., 2011. Clinical profile of a Mediterranean population sensitised to date palm pollen (Phoenix dactylifera). A retrospective study. Allergol Immunopathol (Madr) 39, 145–149. https://doi.org/10.1016/j.aller.2010.06.007.

Jochner-Oette, S., Stitz, T., Jetschni, J., Cariñanos, P., 2018. The influence of individual-specific plant parameters and species composition on the allergenic potential of urban green spaces. Forests 9, 284. https://doi.org/10.3390/f9060284.

Kara, B., Aşık, Y., 2022. Assessing allergenicity of urban parks: a case study from Aydin, Turkey. Aerobiologia 38, 247–262. https://doi.org/10.1007/s10453-022-09745-8.

Karim, K., Awad, M.A., Manar, A., Monia, J., Karim, A., Mohammed, E., 2022. Effect of flowering stage and storage conditions on pollen quality of six male date palm genotypes. Saudi J. Biological Sci. 29, 2564–2572.

Kasprzyk, I., Wójcik, T., Cariñanos, P., Borycka, K., Ćwik, A., 2019. Evaluation of the allergenicity of various types of urban parks in a warm temperate climate zone. Aerobiologia 35, 57–71. https://doi.org/10.1007/s10453-018-9537-3.

Latorre, F., Rotundo, C., Sierra, M.L.A., Fassola, H., 2020. Daily, seasonal, and interannual variability of airborne pollen of Araucaria angustifolia growing in the subtropical area of Argentina. Aerobiologia 36, 277–290. https://doi.org/10.1007/s10453-020-09626-y(0123456789.

Makra, L., Matyasovszky, I., Deák, A.J., 2011. Trends in the characteristics of allergenic pollen circulation in Central Europe based on the example of Szeged, Hungary. Atmos. Environ. 45, 6010–6018. https://doi.org/10.1016/j.atmosenv.2011.07.051.

NCC National Capital Commission, 2021. NCC Forest Strategy, 2021-2026, Canada, 26. Retrieved from: https://ncc-website-2.s3.amazonaws.com/documents/2021_Forest-Strategy-Final.pdf. (Accessed 19 June 2023).

Oh, J.-W., 2022. Pollen allergy in a changing planetary environment. Allergy, Asthma Immunol. Res. 14, 168–181. https://doi.org/10.4168/aair.2022.14.2.168.

Pordata. Estatísticas sobre Portugal e a Europa. Fundação Francisco Manuel dos Santos. Retrieved from: https://www.pordata.pt/sobre+a+pordata. Accessed December 10, 2022.

Press, J.R., Short, M., 1994. Flora of Madeira. HMSO, London.

Quercetea., 2004. Revista da Associação Lusitana de Fitossociologia. Lisboa.

Quintal, R., 2007. Quintas, Parques e Jardins do Funchal - Estudo fitogeográfico. In: PhD Dissertation Presented to the School of Arts and Humanities. University of Lisbon.

Räsänen, L., 2000. Inhalant allergy in the United Arab Emirates. Allergy 55, 5–96.

Rivas-Martínez, S., 2001. Bioclimatic Map of Europe – Thermotypes. Cartographic Service, University of Léon, Léon.

Rodríguez, F., Lombardero-Vega, M., San Juan, L., de Las Vecillas, L., Alonso, S., Morchón, E., Liendo, D., Uranga, M., Gandarillas, A., 2021. Allergenicity to worldwide invasive grass Cortaderia selloana as environmental risk to public health. Sci. Rep. 11, 24426. https://doi.org/10.1038/s41598-021-03581-5.

Roloff, A., Gillner, S., Kniesel, R., Zhang, D., 2018. Interesting and new street tree species for European cities. J. For. Res. 1, 1–7.

Sabariego, S., García-Ventura, C., Cariñanos, P., 2021. Estimating the allergenic potential of urban green areas in the city of Madrid (Spain). Aerobiologia 37, 561–573. https://doi.org/10.1007/s10453-021-09705-8(0123456789.

Santos, F.D., Valente, M.A., Miranda, P.M.A., Aguiar, A., Azevedo, E.B., Tomé, A.R., Coelho, F., 2004. Climate change scenarios in the Azores and Madeira islands. World Resource Rev. 16, 473–491.

Simpson, M.G., 2010. Arecales. Diversity and Classification of Flowering plants in Plant Systematics, 2nd ed. https://doi.org/10.1016/B978-0-12-374380-0.50008-7. eBook ISBN: 9780080922089.

Taketomi, E.A., Sopelete, M.C., Moreira, P.F.S., Vieira, F.A.M., 2006. Pollen allergic disease: pollens and its major allergens. Revista Brasileira de Otorrionolaringologia 72, 562–567.

Velasco-Jiménez, M.J., Alcázar, P., Cariñanos, C., Galán, C., 2020. Allergenicity of the urban green areas in the city of Córdoba (Spain). Urban For. Urban Green. 49, 126600 https://doi.org/10.1016/j.ufug.2020.126600.