Urban Forestry & Urban Greening 63 (2021) 127218

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

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

An updated proposal of the Potential Allergenicity of 150 ornamental Trees and shrubs in Mediterranean Cities

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ARTICLE INFO

Handling Editor: Francesco Ferrini

Keywords:
Allergen emission
Allergenic urban trees
Class of allergenicity
Ecosystem disservices
Value of Potential Allergenicity (VPA)

ABSTRACT

The allergenic potency of the pollen emitted by urban vegetation is one of the effects that need the most attention in the near future due to its high impact on the quality of air and the health of citizens. Many of the problems derived from the allergenic behavior of urban flora have their origin in the lack of knowledge about the intrinsic allergenic capacity to the most common species of urban forests, as well as the lack of consensus among the few existing lists. This work aims to check and update the value of potential allergenic (VPA) of 150 frequent trees and shrubs in Mediterranean cities.

Two of the most complete current lists and with the most realistic allergenicity assignments have been used to build up the list. For each of the taxa included, a detailed evaluation of the attributes that participate in the allergenic potential of the species has been carried out, and according to them, each species has been assigned an allergenicity class. In the event of discord in the information from different sources, the most conservative criterion has been applied. For the taxa in which the current class is significantly higher than the previously assigned: Ailanthus altissima, Celtis australis, Eucalyptus camaldulensis, Fraxinus excelsior, Gingo biloba, Juglans regia or Liquidambar styraciflua among them, a more detailed specific section has been included. This update of the VPA of 150 Mediterranean urban forests species become a useful tool for management and planning of green areas, and also a risk mitigation measure for people affected by pollen allergen.

1. Introduction

Pollen grains emitted by terrestrial vegetation are one of the main components of atmospheric bioaerosol, both because of how it contributes to atmospheric Particulate Matter (PM) (Després et al., 2012; Fröhlich-Nowoisky et al., 2016), and because of its direct involvement in respiratory diseases and other chronic illnesses (Brunekreef et al., 2000). With an approximately 30 % of the world population affected, respiratory diseases related to atmospheric pollen currently constitute a global public health concern (Linneberg et al., 2016). According to the European Academy of Allergy and Clinical Immunology, it is estimated that 100 millions of European suffer from allergic rhinitis in the coming years as a result of the impacts of climate change (D'Amato et al., 2014). The Mediterranean region has been identified as one of the most vulnerable areas to climatic change worldwide due to its particular environmental, climatic, urban, and social characteristics (Cramer et al., 2018). In turn, the region also stands out for the expectations in the growth of pollen-related allergies, as a result of the impact that environmental alterations can have on the geographical distribution range of plant species and modifications on allergen emission patterns (De Sario et al., 2013). In urban environments, this situation will be further exacerbated by episodes of heat islands and worsening air quality, which will have a greater impact on the reproductive phenology of the species that make up the urban green infrastructure (Zipper et al., 2016). Given the evidence that prevalence rates are increasing worldwide (Pawankar, 2014), the implementation of environmental control measures to reduce triggers and risk factors have been identified by the World Allergy Organization (WAO) as the most effective way of minimizing the impact on health and associated socio-economic costs (Pawankar et al., 2013). Along these lines, the World Health Organization has recommended the urgent need to intervene to improve air quality and to reduce pollution levels in the cities. The VII European Environment Action Program includes among its priorities the safeguarding of its citizens from environment-related pressures which would lead to risks to human

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https://doi.org/10.1016/j.ufug.2021.127218
Received 25 September 2020; Received in revised form 6 May 2021; Accepted 9 June 2021
Available online 12 June 2021

health and well-being, with a special emphasis on continuing to improve outdoor air quality and to enhance the sustainability of the Union's cities (UE Decision N°. 1386/2013).

In order to meet these goals, many cities are implementing strategies aimed at strengthening their resilience to the effects of climate change and mitigating its side effects on air quality. In this line, the reinforcement and implementation of green infrastructure elements in urban environments is indicated as one of the most effective measures to improve air quality (Hewitt et al., 2019). Notable are the campaigns carried out by cities such as New York, Milan, or London to plant several million more trees in their streets as a measure to reduce the presence of gaseous pollutants (Million Tree New York: https://www.milliontreesnyc.org/; Milan Strategy for Smart City: http://www.ponmetro.it/wp-content/uploads/2019/12/MI_Siragusa.pdf; Reforest London: https://www.reforestlondon.ca/); or the rankings to establish the urban tree species most suitable for controlling PM pollution (Yang et al., 2015; Letter and Jäger, 2020). But in the race against time in which many cities are immersed in their quest to be "the greenest city in the world", the impact that emissions of substances intrinsic to plant species themselves (such as allergens or Biogenic Volatile Organic Compounds, BVOCs) can have on the Urban air quality is a factor that is barely considered today (Grote et al., 2017). Some recent work has highlighted that the general ignorance of the potential allergenicity of many of the species frequently used in urban forests has been one of the main causes of the growing allergenicity that affects the urban population (Cariñanos and Casares-Porcel, 2011; Cariñanos et al., 2016a; Cariñanos et al., 2019a; Velasco-Jiménez et al., 2020). It has also been highlighted that pollen emissions from some of the urban tree species have the greatest impact on biological air quality and public health (Manninen et al., 2014; Cariñanos et al., 2016a). Despite its significant impact, it is paradoxical that only a few regulations have been passed to "reduce the impact of allergenic flora" in the planning of green zones (Marinangeli and Plutino, 2018). In this sense, the case of Italy is noteworthy since in the National Strategy on Urban Greening of 2018 (MATTM, 2018), has incorporated for the first time measures to reduce the impact of the allergenic flora planted in the green zones, as well as the implementation of Nature based solution to re-greening of "grey areas".

Studies on urban vegetation as a source of allergen emission have a long history. Many countries and cities around the world have had an aerobiological station for several decades, from which results on the content of allergens in the atmosphere are obtained (Buters et al., 2018). These results have allowed patients to have useful and detailed information to avoid exposure to specific allergens and to improve their quality of life (Marinangeli and Fares, 2020). The right to be informed about the biological content of the air has even been recognized in the "Letters of Rights" of different associations of patients with respiratory diseases (Dottorini, 2016; Marinangeli and Dottorini, 2017). However, the absence of policies recommending the avoidance of allergen-emitting plants in urban areas has only aggravated the health impact of allergen emissions. It has not been until recently that allergenic flora has been approached with a more holistic treatment, with the participation of a wide range of stakeholders and scientific disciplines. One of the first outstanding initiatives on allergenicity of garden plant species are those of Ogren (2000, 2002), which established the Ogren Plant Allergy Scale (OPALs), a system to measure the potential of a plant to cause allergic reactions in humans. Another of the works highlighted is that of Hruska (2003) which, considering several biological and phenological characteristics of the plants present in several urban ecosystems of Italy, established a phytoallergenic potential for the different species. More recent are the proposals of Cariñanos et al. (2014, 2016a) and Ortolani et al. (2015), which have developed lists with the characteristics and attributes of allergenicity of the 100 most utilized species in the urban green, with the aim of making known the species that cause the most allergenicity problems in the population. However, despite these advances, the disagreements and even errors existing between the different lists and methods to characterize the allergenicity of the species are still frequent. Then, we are still far from having consensual and standardized allergenicity criteria such as those existing for other tree traits, which can be incorporated when making decisions about the selection of species in urban environments, or to plan mitigation measures on the allergenic risk already existing.

In an attempt to cover the knowledge gap in this area, this work intends to check, update andverify the allergenic capacity of some of the most common urban trees in Mediterranean urban forests, in order to offer an understandable, practical and easy-to-apply tool available to any stakeholder. The generation of a unique allergenicity list will allow to establish the basis for building a database of allergenicity parameters of urban trees for universal use, but also to reinforce the consideration of the allergenic value criterion when designing and planning sustainable and low-impact allergenic green areas. Only then, actions such as carrying out a preliminary screeining of the allergenic risk of green areas, improving the quality of life of people affected by allergies, designing a specific tree management to reduce the emission of allergens, will also be possible.

2. Material and methods

The first step to create the unique list of urban flora was to merge two of the most complete and with the most realistic allergenicity assignment current lists of urban trees, such as the proposals of Cariñanos et al. (2014, 2016a) and Ortolani et al. (2015). In the works of Cariñanos et al. (2014, 2016a), with the creation of the Urban Green Zone Allergenicity Index (I_{UGZA}), the specific allergenicity of 150 urban trees was assessed according to a series of biological attributes: pollination strategy (ps), duration of the main pollination period (dpp), and intrinsic allergenic potency of pollen grains (pa) due to the presence of allergenic molecules. The product of these three parameters generates a specific Value of Potential Allergenic (VPA) of each species, which ranges between 0 and 36, defining five allergenicity classes: nil, low, moderate, high, or very high. The values to be assigned to each parameter are presented in Table 1.

Ortolani (in Ortolani et al., 2015) conducted a systematic review on the allergenicity of 100 tree and shrub species destined for urban green infrastructure. The consideration of a species as allergenic is based on the existence of scientific evidence that pollen exposure causes hay-fever symptoms and that pollen grains can cause allergic sensitization. This evidence was later evaluated by a committee of experts who used a GRADE approach (Grading Reccomendations Assessment Development and Evaluation) to clarify the allergenicity of the species as High, Moderate, or Low. The risk associated with this allergenicity was also classified as evident, probable, possible, or not evident according to the quality of the evidence and/or the opinion of the experts.

Once the list was generated, a detailed taxon-to-taxon evaluation was then carried out to detect possible disagreements in the attributes that had been applied when assigning an allergenicity class to the species. The criteria to be applied were also established in cases where large

Table 1
Value of biological parameters to establish the Value of Potential Allergenicity (VPA) of each specie (adapted from Cariñanos et al., 2014, 2016b).

Parameter	Values
Pollen emissions (pe)	1= Entomophilous 2= Anphiphilic 3= Anemophilous
Principal Pollination Period (ppp)	1 = 1−3 weeks 2 = 4−6 weeks 3= > 6 weeks
Allergenic potential (ap)	0= no allergenic 1= low allergenicity 2= moderate allergenicity 3= high allergenicity 4= very high allergenicity

disparities were detected between both authors. Among these criteria, the search and comparison of the information was verified only in reference sources of proven scientific quality. For example, Flora d'Italia (Pignatti, 1982, 2019), Flora Ibérica (Castroviejo et al., 1986-2012), and Flora Europaea (Tutin et al., 1964) were consulted to determine pollination strategies, flowering periods, and other biological characteristics of interest. In the case of the pollination strategy (ps), special emphasis has been placed on species that have the possibility of being pollinated by both wind and insects, a strategy that is known as amphiphilia or mixed-pollination, and which may have relevance both for the emission of pollen and for the attraction of pollinators. When assigning the value of the parameter duration of the pollination period (dpp), the possible effects that climate change may have (or is already having) on the reproductive phenology of plant species in urban environments have been taken into account. So, for the species whose information is already available, the value for this parameter has been adjusted, taking into account its possible temporal increase in relation to the current one.

For the assignment of the intrinsic allergenicity parameter of the species, priority has been given to the species having a record in the Allergen Nomenclature Database, approved by the World Health Organization and the International Union of Immunological Societies (WHO/IUIS) (http://www.allergen.org), or have a referenced record of allergens in the Allergome Database, which contains information on the existence of allergenic molecules in different organisms and structures, from bibliographic reviews made since the early sixties (Mari et al., 2009). In the event that there were no records in the previous databases, scientific references have been searched in specialized databases (PubMed, Scopus, Web of Science) on the existence of allergens in a particular specie's pollen grains and/or the Ig-mediated response in the sensitized population.

Once the allergenicity of each species was verified, and in the case in which a different value from those already assigned by the previous authors was obtained, then it was agreed to apply the "the most conservative criterion" – that is, to maintain the value that was most supported by scientific evidence. For these taxa, in addition to including a detailed upgrading table on the changes made and the agreed allergenicity class, a specific section has been included in the discussion chapter.

Finally, once the attribute values of each species was reviewed and adjusted (if necessary), the definitive Value of Potential Allergenic (VPA) was assessed for each taxon, according to the Allergenicity Classes presented in Table 2.

3. Results

The agreed list on potential allergenicity of 150 of the main trees and shrubs frequent in Mediterranean urban forests are presented in Table 3. From them, 141 (94 %) come from the lists established by Cariñanos in different works (Cariñanos et al., 2014, 2016a, 2017) and 88 (58,7 %) come from the list established by Ortolani (Ortolani et al., 2015). 75 taxa are common to both lists and thus are those whose allergenicity have been evaluated in more detail.

In relation to the allergenicity of the species, 88 taxa (58.7 %) have nill or low allergenicity, while 62 taxa (41.3 %) have moderate to very high allergenicity. The taxa with the highest VPA are those included in the *Betulaceae, Oleaceae, Cupressaceae, Moraceae,* and *Salicaceae* families, which include some of the best represented genera in urban forests of the Mediterranean region, such as: *Cupressus, Morus, Olea, Juniperus, Fraxinus, Populus* or *Salix*.

In 40 of the 75 common taxa in both lists there were significant disagreements in the allergenicity value assigned by the different authors. The value assigned by Cariñanos was often higher than that of Ortolani. Thus, in the 7 taxa of value Nil in Ortolani's list *(Koelreuteria paniculata, Lagerstroemia indica, Liriodendron tulipifera, Magnolia* spp., *Malus* spp., *Pyrus* spp., *Sophora japonica*), the final agreed value was Low; 20 of the taxa that Ortolani had categorized as low allergenic were increased in their categorization – some to moderate (*Acer negundo, Ailanthus altissima, Castanea sativa, Cedrus deodara, Celtis australis, Phoenix* spp., *Pinus* spp., *Pterocarya fraxinifolia, Liquidambar styraciflua, Tamarix* spp. *, Quercus ilex* and *Trachycarpus fortunei, Tilia* spp.), some to high (*Juglans* spp., *Populus nigra* "Italica", *Populus alba* "pyramidalis", *Salix alba, Salix purpurea*), and even to very high (*Broussonetia papyrifera, Carpinus betulus, Taxus baccata*). All of them have undergone an exhaustive revision of their flowering and allergenic attributes.

Table 4 shows the updated potential allergenicity of the 14 taxa to which, after an exhaustive revision, the most conservative criterion has been applied due to the significant disagreements. The revised allergenicity of each one of them reveals that the attribute of potential allergenicity (PA) is the one with the greatest discrepancy between the two lists. In some cases such as *Eucalypthus*, *Fraxinus, Ginkgo biloba, Tamarix* and *Tilia*, the adjusted attribute has been the duration of the flowering period (DPP), which used to be longer in the case of the Ortholani listing when considering full months instead of weeks, as in Cariñanos' proposal (Supplementary Material Tables 1–13). The type of pollination (TP) has been reviewed and agreed upon for *Ailanthus altissima, Eucalypthus camaldulensis, Liquidambar styraciflua, Tamarix* spp., *Tilia* spp. and *Trachycarpus fortunei*, all of them with ambiguity when it comes to being considered strictly anemophilic or entomophilous (Supplementary Material Tables 1–13).

4. Discussion

The massive use of allergenic species in urban green infrastructure is one of the main reasons why the percentage of the urban population affected by allergen emissions from urban trees has increased significantly in recent decades (Lovasi et al., 2013; D`Amato et al., 2014). Among the causes of this increase, some authors point out the interactions between atmospheric pollutants and allergens (Schiovani et al., 2017), or the effect that urban climate conditions can have on the species themselves, altering their flowering period and pollen production and emission (Neil et al., 2014). But the origin of this problem continues to be the massive use of allergenic species in urban green infrastructure. The better adaptability of some species to urban environmental conditions, their greater tolerance to pruning, and their ecological plasticity have caused *Platanus, Acer, Fraxinus, Betula, Carpinus, Celtis, Cupressus, Morus,* and *Tilia* genus to be over-represented on the streets of numerous cities with different bioclimatic characteristics (Pauleit et al., 2002; Sjöman et al., 2017). The prevalence of the species selected without a phytosociological approach has determinated a lower level of biological diversity and resilience of the urban ecosystem (Capotorti et al., 2020), and that the pollen emissions of some of these species are involved in the development of respiratory problems in the population (Singh and Marthus, 2012; Schmidt, 2016). Given this problematic situation, the establishment of a Value of Potential Allergenic (VPA) to 150 of the main tree species in Mediterranean urban forests conducted in this research represents significant progress in implementing measures to control and mitigate this impact. Firstly, the assignment of a specific allergenicity value to each taxon allows immediate characterization for this trait, so that this attribute can be included among the criteria considered for enhancing ecosystem

Table 2
Classes of Allergenicity according to the Value of Potential Allergenicity (VPA) of the species (adapted from Cariñanos et al., 2014).

VPA	Class of Allergenicity
0	Nil
1–6	Low
8–12	Moderate
16–24	High
27–36	Very High

Table 3
Value of Potential Allergenicity (VPA) of 150 ornamental urban trees and shrubs in the Mediterranean cities. The + and— signs indicate the variation in the allergenicity class higher or lower than that established by the authors in previous works.

SPECIES	CARIÑANOS' PROPOSAL	ORTOLANI'S PROPOSAL	AGREED ALLERGENICITY (QUALITATIVE)	VPA QUANTITATIVE	VARIATION
Abies spp.	Low	———	Low	1	
Acacia spp.	Low	Moderate	Low	1	—
Acer spp (excl. *A. negundo*)	Moderate	——	Moderate	2	
Acer negundo	High	Low	Moderate	2	—
Aesculus hippocastanum	Moderate	Low	Low	1	—
Ailanthus altissima	High	Low	High	3	
Albizia julibrissin	Low	——	Low	1	
Alnus glutinosa	High	High	High	3	
Alnus incana	High	High	High	3	
Amelanchier canadensis	——	Low	Nil	0	—
Araucaria spp.	High	——	High	3	
Arbutus unedo	Low	Low	Low	1	
Bahuinia spp.	Low	——	Low	1	
Berberis julianae	——	Low	Nil	0	—
Betula spp.	Very High	High	Very High	4	
Brachychiton spp.	Low	——	Low	1	
Broussonetia papyrifera	Very High	Low	Very High	4	
Callistemum spp.	Moderate	——	Moderate	2	
Calocedrus decurrens	Moderate	——	Moderate	2	
Camelia japonica	Low	——	Low	1	
Campsis radicans	——	Low	Low	1	
Carpinus betulus	Very High	Low	Very High	4	+
Carya spp.	High	——	High	3	+
Castanea sativa	Moderate	Low	Moderate	2	
Casuarina equisetifolia	Very High	——	Very High	4	
Catalpa bignonioides	Low	Low	Low	1	
Cedrus atlantica	Low	Low	Low	1	
Cedrus deodara, C. libani	Moderate	Low	Moderate	2	+
Ceiba insignis	Low	——	Low	1	
Celtis australis	Moderate	Low	Moderate	2	+
Cephalotaxus drupaceae	Moderate	——	Moderate	2	
Ceratonia siliqua	Low	Low	Low	1	
Cercidiphyllum japonicum	Moderate	——	Moderate	2	
Cercis siliquastrum	Low	Low	Low	1	
Chamaerops humilis	High	——	High	3	
Chamaecyparis lawsoniana	Very High	——	Very High	4	
Chimonanthus praecox	——	Low	Low	1	
Citrus spp.	Low	Low	Low	1	
Cornus sanguinea	——	Low	Low	1	
Corylus avellana	Very High	Very High	Very High	4	
Cotoneaster spp.	Low	Low	Low	1	
Crataegus spp.	Low	Low	Low	1	
Cryptomeria japonica	Very High	High	Very High	4	
Cupressocyparis leylandii	Very High	——	Very high	4	
Cupressus spp.	Very High	High	Very High	4	+
Cydonia oblonga	Low	——	Low	1	
Diospyros kaki	Low	Low	Low	1	
Dombeya wallichi	Low	——	Low	1	
Dracaena drago	Low	——	Low	1	
Eleagnus angustifolia	Low	——	Low	1	
Eryobotria japónica	Low	Low	Low	1	
Erythrina spp.	Low	——	Low	1	
Eucalyptus chamaldulensis	Moderate	Low	Moderate	2	
Eucommia ulmoides	Moderate	——	Moderate	2	
Euonymus japonicus	Low	——	Low	1	
Fagus sylvatica	Moderate	Moderate	Moderate	2	
Feijoa sellowiana	Low	——	Low	1	
Ficus spp.	Low	Low	Low	1	
Ficus carica	Low	Low	Low	1	
Firmiana simplex	Low	——	Low	1	
Forsythia viridissima	Low	Low	Low	1	
Fraxinus angustifolia	Moderate	——	Moderate	2	
Fraxinus excelsior	High	High	Very High	4	+
Fraxinus ornus	High	Moderate	High	3	+
Ginkgo biloba	Moderate	Moderate	High	3	+
Gleditsia triacanthos	Low	Low	Low	1	
Grevillea robusta	Low	——	Low	1	
Gymnocladus dioicus	Low	——	Low	1	
Hesperocyparis macrocarpa	Very High	——	Very High	4	
Hibiscus syriacus	Low	Low	Low	1	
Hovenia dulcis	Low	——	Low	1	
Ilex aquifolium	Low	——	Low	1	
Jacaranda mimosifolia	Low	——	Low	1	

(continued on next page)

Table 3 (*continued*)

SPECIES	CARIÑANOS' PROPOSAL	ORTOLANI'S PROPOSAL	AGREED ALLERGENICITY (QUALITATIVE)	VPA QUANTITATIVE	VARIATION
Juglans nigra	High	Low	High	3	
Juniperus spp.	Very High	High	Very High	4	+
Koelreuteria paniculata	Low	Nil	Low	1	+
Laburnum anagyroides	Low	——	Low	1	
Lagerstroemia indica	Low	Nil	Low	1	
Lagunaria pattersonii	Low	——	Low	1	
Larix decidua	Moderate	——	Moderate	2	
Laurus nobilis	Low	Low	Low	1	
Lavandula angustifolia	——	Nil	Nil	0	
Ligustrum spp.	Moderate	Moderate	Moderate	2	
Liquidambar styraciflua	High	Low	Moderate	2	+
Liriodendron tulipifera	Low	Nil	Low	1	+
Maclura pomífera	——	Nil	Nil	0	
Magnolia spp.	Low	Nil	Low	1	+
Mahonia aquifolium	——	Nil	Nil	0	
Malus spp.	Low	Nil	Low	1	+
Melia azederach	Low	——	Low	1	
Mespilus germánica	Low	Low	Low	1	
Metasequoia glyptostroboides	Very High	——	Very High	4	
Metrosideros excelsa	Low	——	Low	1	
Morus alba "pendula"	High	Moderate	High	3	+
Morus nigra	Very High	Moderate	Very High	4	+
Musa spp.	Low	Low	Low	1	
Myrtus communis	Low	——	Low	1	
Nerium oleander	Low	——	Low	1	
Olea europaea	High	Very High	Very High	4	+
Ostrya carpinifolia	High	High	High	3	
Parkinsonia aculñeata	Low	——	Low	1	
Pawlonia tomentosa	Low	Low	Low	1	
Persea gratissima	Low	——	Low	1	
Phoenix spp.	Moderate	Low	Moderate	2	+
Photinia serrulata	Low	——	Low	1	
Phyllirea angustifolia	Low	Low	Low	1	
Phytolacca dioica	Low	——	Low	1	
Picea spp.	Low	——	Low	1	
Pinus spp.	Moderate	Low	Moderate	2	+
Pistacia atlántica	Moderate	——	Moderate	2	
Pittosporum tobira	Low	——	Low	1	
Platanus x acerifolia	High	Moderate	High	3	+
Platycladus orientalis	Very High	——	Very High	4	
Podocarpus neriifolius	Very High	——	Very High	4	
Populus alba "pyramidalis"	High	Low	High	3	+
Populus x canadensis	Low	Low	Low	1	
Populus nigra "Italica"	High	Low	High	3	+
Populus spp.	——	Low	Low	1	
Prunus spp.	Low	Low	Low	1	
Pseudotsyga menziesii	Low	Low	Low	1	
Pterocarya fraxinifolia	High	Low	Moderate	2	—
Punica granatum	Low	Low	Low	1	
Pyrus spp.	Low	Nil	Low	1	
Quercus ilex	High	Low	Moderate	2	—
Quercus robur	Very High	Moderate	Moderate	2	—
Rhus typhina	High	——	Low	1	
Robinia pseudoacacia	Low	Low	Low	1	
Rosa spp.	Low	——	Low	1	
Rosmarinus officinalis	——	Low	Low	1	
Salix alba	High	Low	High	3	+
Salix purpurea	High	Low	High	3	+
Sambucus nigra	Low	Low	Low	1	
Schinus spp.	Low	——	Low	1	
Sophora japónica	Low	Nil	Low	1	+
Sorbus spp.	Low	Low	Low	1	
Spiraea x vanhouttei	——	Low	Low	1	
Tamarix spp	Moderate	Low	Moderate	2	+
Taxodium distichum	Very High	——	Very High	4	
Taxus baccata	Very High	Low	Very High	4	+
Tetraclinis articulata	Very High	——	Very High	4	
Thuja plicata	Very High	——	Very High	4	
Tilia spp.	Low	Low	Moderate	2	
Tipuana tipu	Low	——	Low	1	
Trachycarpus fortunei	Moderate	Low	Moderate	2	+
Ulmus spp.	High	Moderate	High	3	+
Viburnum tinus	Low	Low	Low	1	
Washingtonia spp.	Low	——	Low	1	
Wisteria sinensis	Low	——	Low	1	
Yucca spp.	Low	——	Low	1	
Zelcova serrata	Moderate	——	Moderate	2	

Table 4
Upgrating box - The most discordant species or genus (in alphabetical order) and the new calculated values of VPA.

Taxum (agreed values)	EP	DPP	PA	VPA index n.	Allergenic Class
Ailanthus altissima	2	3	3	18	high (3)
Celtis australis	3	2	2	12	Moderate (2)
Eucalyptus camaldulensis	2	3	2	12	Moderate (2)
Fraxinus excelsior	3	3	3	27	Very High (4)
Ginkgo biloba	3	3	2	18	High (3)
Juglans nigra	3	3	2	18	High (3)
Liquidambar styraciflua	2	2	3	12	Moderate (2)
Morus alba	3	2	3	18	High (3)
Morus nigra	3	3	3	27	Very High (4)
Olea europea	3	3	4	36	Very High (4)
Tamarix spp	2	2	3	12	Moderate (2)
Tilia spp, *Tilia platyphillos*	2	2	2	8	Moderate (2)
Trachycarpus fortunei	2	2	3	12	Moderate (2)
Ulmus spp	3	2	3	18	High (3)

services in urban environments (Samson et al., 2017). It could also be used as a proposal to standardize the allergenic scales available in tools such as Specifind (http://www.greeninurbs.com/p_specifind/) or i-Tree Eco (https://www.itreetools.org/tools/i-tree-eco), in which the high number of values to be assigned, from 1 to 10, or the consideration of other possible non-pollen allergens in plants (Ogren, 2002), make it difficult to interpret the result. But it can also have a practical application as a tool for the design of new elements of urban green infrastructure, in which the combination of species with different allergenicity values results in a green space with low allergenic impact. Specific management actions in already existing green spaces, such asprogressive substitution of male individuals, diversification of monospecific populations, or targeted pruning, (Cariñanos et al., 2014, 2017; 2019a, b) may be also planned. The qualitative value of the VPA allows, at the same time, its direct use in models or indexes of evaluation and quantification of the costs or disservices of urban trees. Along these lines, proposals such as the Index of Urban Green Zone Allergenicity (I_{UGZA}), which allows asses the allergenicity of a given green space according to the species of trees that grow in it, (Cariñanos et al., 2014, 2017,2019a) ; or the recent Norma Granada ©, tool for the economic valuation of trees, palms and ornamental shrubs developed by the Spanish Association of Public Parks and Gardens (AEPJP) (https://www.aepjp.es/norma-granada/), already use the potential allergenicity value as an intrinsic factor of an existing, substituted or newly introduced specimen (Calaza-Martínez et al., 2020). The revision and update of the allergenicity list carried out in this work represents an advance over the previous proposals on which it has been based, as it reviews and unifies the criteria for assigning values to allergenicity parameters. In relation to the list established by Ortolani et al. (2015), the new listing corrects some attributes which were not correctly assigned. With respect to the list of Cariñanos et al. (2014, 2016a, 2017), the reviews on flowering strategy, flowering period, and allergenic capacity are currently more accurate. Overall, the most remarkable progress is that in this proposal qualitative and quantitative ranges have been unified so that the result is a practical proposal, modulable to allergenicity situations in different areas and easy to use by different stakeholders.

It should be noted that although this list may currently be considered as "*consensus,*" it should be reviewed periodically as new pollen allergens are detected and as new species are incorporated into the species catalog for urban trees (Roloff et al., 2018). The important climatic changes expected in the Mediterranean region in the coming decades will also have a great impact on the vegetation causing many species to adapt their reproductive phenology to the new temperature and precipitation conditions (Gordo and Sanz, 2010). In the urban environment, the impact will be even greater due to the intensification of processes such as "urban heat islands" (Shashua-Bar et al., 2010). For the plant species that make up urban forests, this may have an impact on the duration and intensity of flowering periods which may become longer. These longer flowering periods would result in an increase in the currently assigned allergenic value (D'Amato and Liccardi, 2002; Nicolaou et al., 2005). Another attribute that can be affected is the pollination strategy of the species. In fact, one of the most important drivers in the current pollinator crisis is the increase in temperatures which modifies the reproductive cycles of pollinating insects (Hegland et al., 2009) and generates an asynchrony between the pollinators and the pollination period. A shift is also being detected in amphiphilic species towards wind-pollinated behavior which alleviates the desynchronization or shortage of their specific pollinators (Hesse et al., 2000). As for other species that could be part of the list, one could foresee intensification more intensive introduction of taxa currently present in the most arid areas of the Mediterranean macroclimate, such as *Acacia, Casuarina, Eucalyptus, Juniperus,* or *Tamarix* (FAO, 1989).

Fourteen of the taxa that have had the greatest change in their VPA in relation to the original lists are discussed in detail below.

4.1. Ailanthus altissima (Mill) Swingle.

Ailanthus altissima was officially introduced in Europe in the 18th century to produce shantung silk (Pignatti, 2019). However, there are some artistic references before this date, such as the image that appears in the Tables of "San Bernardino Bottega" by the painter Perugino, of the National Gallery of Umbria, dated in 1473 (Fig. 1). As an urban tree, it has been used because it is resistant to air pollution. Despite this, the EU has advised against planting this tree in green zones due to its highly invasive character, especially for its ability to reproduce by vegetative branches. These branches contain allelopathic substances that inhibit the growth of the seeds of other species. Regarding its allergenicity, the discrepancies between the Ortolani and Cariñanos listings is due to the pollination strategy, amphiphilic in the first and anemophilic in the second, and the allergenic potency of the pollen. The existence of proven scientific references for this attribute (Ballero et al., 2003; Mousavi

Fig. 1. *Ailanthus altissima* painted in 1473, "Tavolette di S. Bernardino", by Pinturicchio, National Gallery of Umbria, Perugia, Italy (Photo credit: Francesca Marinangeli).

et al., 2016), has resulted in a final allergenicity as High (3) (Table 1 Suppl. Mat).

4.2. Celtis australis L.

Celtis is an andromonoic species, with hermaphrodite and male flowers on the same specimen, and its apetal flowers present a clear wind-pollinated strategy (More and White, 2003). Despite this attribute, pollen emissions are usually not very high, with aerobiological records being presented in low-moderate amounts (Green and Dettman, 2004). As an urban tree, it is suitable because of its pollution tolerance, with a great capacity to capture carbon in its foliage, and the beauty of its domed crown, with long arching branches. On the contrary, its extensor radical system, advantageous in the fixation of unstable lands, can damage infrastructure. As for its allergenicity, the current consensus value has taken into account the existence of references that indicate the presence of allergens both in the pollen of this species and in similar species (Alvarez et al., 2000; Baroni et al., 2008) (Table 2 Suppl. Mat).

4.3. Eucalyptus camaldulensis Dehnh.

This typical Australian species was introduced into Europe as a windbreak tree in coastal areas due to its high resistence to salinity. But the main reason for its expansion, especially througout the Iberian Peninsula, is due to the industrial interest in its wood pulp for the manufacture of paper pulp (Silva-Pando and Pino-Pérez, 2016). Its pollination strategy is not very clear, since its floral attributes are compatible with both anemophilia (absence of floral parts, numerous stamens), as well as for pollination by insects, and even birds and small mammals (CAB International, 2000). These characteristics have caused discrepancies in the different listings – Ortolani et al. (2015) assigned a ps value of 1 while Cariñanos et al. (2016a) assigned a value of 3 (Table 3 Suppl. Mat). The Moderate potential allergenicity value has been agreed upon taking into account existing references from their area of origin (Gibbs, 2015). In urban environments, its introduction should be valued for a number of reasons, especially due to its high capacity to form ozone – more than 10 g O_3/plant/day – from the emission of BVOCs (Peñuelas and Standt, 2010).

4.4. Fraxinus excelsior L.

This European-Caucasian tree is widely used in wild (hygrophitic) and urban forests. Its reproductive biology has some peculiarities, since according to some authors it can be amphiphilic (Albert et al., 2013), or anemophilic (Thomas, 2016). There may also be variations in the duration of its pollination period. Cariñanos stated that the pollination period is less than 6 weeks (Cariñanos et al., 2016a) while Ortolani stated longer pollination periods (Ortolani et al., 2015). Both authors do agree on their allergenic potential value (VPA = 18, high). However, this value was increased to very high (4) (Table 4 Suppl. Mat) due to the existence of numerous references as allergenic in the winter period (Vara et al., 2016; Gassner et al., 2019); but above all because of its relationship with the Oleaceae family, whose *Olea* pollen is a major allergen in the Mediterranean region (Torres et al., 2015).

4.5. Ginkgo biloba L.

Ginkgo biloba has become a common tree in many cities around the world. Its interest as a relict species, its good adaptation to urban conditions, and the beauty of its golden flamed leaves in autumn, have made it a kind of “fashion” in urban forestry (Roloff et al., 2018). Despite its popularity, there are some aspects of allergenic relevance that are not yet well known. One is the time of its flowering period. Although in its places of origin flowering usually takes place in June-July (Del Tredici, 2007), Ortolani states it to be April–June, while direct observations carried out in the populations of Granada has established the folowering period between April-May (Cariñanos et al., 2013). The duration of this period also ranges from just 3 weeks (Cariñanos et al., 2016a,b), to more than 3 months (Ortolani et al. (2015). The value of VPA for both, however, coincides: 12, Moderate (Table 5 Suppl. Mat). However, the increasingly clear verification of its importance as an allergen (Kimura et al., 2001; Yun et al., 2000; Mossabeb et al., 2001), and the increasingly frequent presence of its pollen in aerobiological counts, has led us to agree on its high potential of allergenicity. As an urban tree, it would be advisable to use it moderately, facilitating its presence as a unique and symbolic specimen in green infrastructure elements. The large size that it can reach and its great longevity can turn it into an authentic “monumental tree living”, like the almost 200-year-old specimen in the Botanical Garden of the University of Granada (Fig. 2).

4.6. Juglans nigra L.

This monoecious tree is the only species of Juglandaceae that grows spontaneously in Europe. It is cultivated for its edible fruits (nuts) and its precious wood. The pollination, anemophile type, can extend from spring in the warmer areas (Ricciardelli D'Albore and Intoppa, 2000), to summer. Pollen is a resource for bees and other pollinators such as *Osmia*. There are discrepencies in its allergenicity levels. In Ortolani, both *Juglans nigra* and *Juglans regia* are assigned null allergenicity, while Cariñanos assigned a VPA of 18 and a high class of allergenicity, as a result of a longer flowering period and a high allergenic capacity. Therefore, it has been agreed to assign a high definitive allergenicity value to *Juglans nigra* due to the contrast in different sources (Costa et al., 2014; Downs et al., 2014) (Table 6 Suppl. Mat). The presence of allergens in their seeds, which can establish cross-reactions pollen-food allergy syndrome in sensitive patients, should not be overlooked (Cariñanos et al., 2019b).

4.7. Liquidambar styraciflua L.

This deciduous tree native to the Eastern United States has been cultivated in temperate areas around the world. It was first brought to Europe in 1681 brought by John Banister to be planted in the gardens of Fulham Abbey. From there it spread to other areas as a prayer tree, mainly due to its colors, including green, orange, red, and bright purple, which its leaves acquire in autumn. Its presence in Europe is not very high due to its low adaptation to drought conditions (Baraldi et al., 2019) and to its tendency to expand rapidly and invade land (Adams et al., 2015). Its pollen has been reported as allergenic by numerous sources (Esch et al., 2001; Mahmoudi, 2016). It presents male inflorescences composed of numerous globular heads with abundant flowers without perianthium, which would support the strategy of wind-pollination (Ickert-Bond and Wan, 2013). However, and according to the conservative criterion, its level of allergenicity has been established as Moderate (Table 7 Suppl. Mat), since it is not among the main ornamental trees of European cities (Pauleit, 2003), and its use is very restricted by its slight invasive behavior and its participation in atmospheric ozone formation (Karlik and Pittenger, 2012).

4.8. Morus alba L., Morus nigra L.

The history of mulberry trees in European urban forests dates back to the 7th century, when the Arabs brought the art of working silk fiber to Muslim Spain. From there, it spread to the rest of Europe. In the 16th and 17th centuries there were 2 million mulberry trees in Spain, but in the mid-19th century the disease of the silkworm caused the abandonment and disappearance of many specimens (Sarto and Torra, 2018). Since then, its use has been restricted to an ornamental and shade tree in parks and road alignments, whose leaves continue to supply the small number of silkworm breeders so frequent during the school stage. The dioecious nature of these species has favored that female specimens be avoided due to the nuisances that their fruits cause when they fall to the ground,

Fig. 2. Ginkgo-tree in the Historical Botanical Garden, University of Granada, Spain. I is one of the oldest Ginkgos introduced into Europe in 1889. (Photo Credit: Manuel Casares-Porcel).

in a clear example of botanical sexism (Cariñanos and Casares-Porcel, 2011).

As for flowering, there are hardly any differences between the two species, although it seems that the flowering period is slightly more extensive in *Morus nigra*. In relation to the allergenic potential, Cariñanos assigned a VPA of 18 due to the existence of references that confirm its severity (Papia et al., 2020). The revised allergenicity is presented in Table 8 (Suppl. Mat).

4.9. *Olea europaea L.*

Although the olive tree has been the subject of much attention in the Mediterranean region due to its allergenic characteristics (Gaussorgues, 2009), we have found it convenient to dedicate a section in this work to discuss some of its aspects, since the olive tree is frequently used as an urban tree (Leva and Petruccelli, 2011). In addition, it is in the urban environment where it is most abundant to establish cross-reactions with the pollen of other species of the Oleaceae family: privet trees (*Ligustrum* spp.), ash (*Fraxinus* spp.) trees, *Syringa*, and *Jasminum*. When establishing its potential allergenicity value, several aspects have been taken into account. On the one hand, although the olive tree is considered an amphiphilic species (Giovanetti, 2018), the prevailing pollination strategy is anemophilia especially conditioned by a centuries-old domestication process (Cuevas and Polito, 2004). On the other hand, although the flowering of a single specimen lasts only 7 days, the number of existing specimens and varieties and the climatic diversity of the region make its flowering extend from April to mid and even late July. The combination of allergenicity attributes can therefore range between high or very high. It has been agreed to keep the value very high, since its value is reflected as the main allergen (Table 9 Suppl. Mat.). It should be recommended to limit its presence in urban areas, especially in areas with many sensitive people and near schools, busy areas, etc.

4.10. *Tamarix spp., Tamarix gallica L.*

The *Tamarix* genus has several species which are well adapted to coastal environmental conditions, arid and semi-arid climates, and salty soils, which gives it the ability to withstand some of the urban environment conditions (Guerrero-Maldonado et al., 2016).

Again, there are significant differences in the allergenic consideration of this plant by different authors. Depending on its pollination, it is considered strictly entomophilous or that the wind may participate in the dispersal of pollen (Brotherson and Field, 1987; De Loach et al., 2011). It is visited by bees to collect nectar and produce honey and honey-dew (Ricciardelli D'Albore and Intoppa, 2000). There are also disagreements over the duration of the flowering period, which is extensive for Ortolani. But the most significant disagreement is recorded for the allergenic potential: null for Ortolani et al., 2015 and Moderate (12) for Cariñanos et al., 2016a,b. After a comprobation of its allergenicity in the Allergome© database (Mari et al., 2009), the moderate class of allergenicity is confirmed in the Revised Value Tables (Table 10 Suppl. Mat). Given its good adaptability to urban conditions, ability to resist atmospheric pollutants such as SO_2 and fluorids, its moderate use, without forming large populations, is recommended.

4.11. *Tilia spp, Tilia platyphillos Scop*

The lime tree (*Tilia* spp) is one of the most common urban trees in Europe, due both to its resistance to biotic and abiotic stress, and to its privileged place in European Mythology: it is a sacred tree for Greek and German mythologies and a national symbol in Slovakia, Romania, Slovenia, and the Czech Republic (Tenche-Constantinescu et al., 2015). Lime trees are monoecious trees, live a very long time, and can live from sea level to 1200−1600 m altitude in the coldest areas. During the flowering period, which usually takes place between May-June, or until July in temperate zones, the fragrant flowers attract bees and other pollinators because of their abundant nectar that produce a single-flower honey and honey-dew (Ricciardelli D'Albore and Intoppa, 2000). The significant amounts of pollen they produce, about 43,000 per flower (Weyszko-Chmielewska and Sadowka, 2010), in a flowering period that barely lasts 40 days, make moderate concentrations can be detected in the aerobiological samples (Kasprzyk, 2004). Its allergenicity has been referenced by several authors (Mur et al., 2002). The adjustments between both proposals have resulted in a moderate potential allergenicity value (2) (Table 11 Suppl. Mat.). This is not the only disservice it presents, since frequent visits by pollinators or the intense smell of its flowers, based on BVOCs, may be other allergy-causing agents in the sensitive population.

4.12. *Trachycarpus fortunei (Hook.) H. Wendl*

This species is native to China but has a high presence in Mediterranean countries. It is grown as an ornamental palm in parks and gardens around the world because it tolerates cool summers and cold winters. Sometimes it grows wild, becoming an invasive plant. The pollination of *Trachycarpus* has generated some doubts, since it is sometimes indicated as entomophilic, but on other occasions it is referred to as amphiphilic (Ricciardelli D'Albore and Intoppa, 2000; Pignatti, 2019). The pollen type that *Trachycarpus* presents is the common one for most of the Areacaceae, that is, it is is symmetric monosulcate, so it is indistinguishable from optical microscopy in aerobiological sampling when there are specimens of *Phoenix* or *Washingtonia* in the vicinity (Harley and Baker, 2010). It is visited by bees to collect pollen and nectar. In the allergenicity review, the values corresponding to the pollination strategy and allergen potency value have been adjusted, so the result is a moderate allergenicity level (Table 12 Suppl. Mat.).

4.13. *Ulmus spp., Ulmus minor Mill.*

There are three species of *Ulmus* present in Europe. These species have a wide range of distribution and are native to most countries: white elm (*Ulmus laevis*), wych elm (*Ulmus glabra*), and field elm (*Ulmus minor*), which have the southernmost and westernmost distribution. Elm trees are deciduous medium-sized trees, components of mixed broadleaved coll forests near rivers and flood plains. The introduction in Europe in the mid-twentieth century of the fungal pathogen *Ophiostoma*, which caused Dutch Elm Disease, devastated European populations in two destructive epidemics (Potter et al., 2011). As an example, more than 2000 individual trees had to be replaced in the forests surrounding the Monument of La Alhambra in Granada (Spain), a World Heritage Site and UNESCO Site, which it has seen its landscape modified due to the effects caused (Cariñanos et al., 2016b). It is visited by bees to collect pollen (pink coloured) and to produce honey-dew by *Eriosoma ulmi* L. and *Cacopsylla ulmi* (Forster)

For this group, both Ortolani and Cariñanos have agreed that these species utilize anemophilous pollination and have non-extended flowering periods. However, while Ortolani assigns a moderate allergenicity value, Cariñanos assigned an allergenic value of 3, which has been consensual upon as a definitive allergenicity value for this group of trees, backed by the existence of references that indicate it is a powerful aeroallergen with participation in asthma processes (Oh, 2018) (Table 13 Suppl. Mat.).

5. Conclusion

The obligation on the part of administrations to strengthen the resilience of cities to the effects of climate change through Nature-Based Solutions makes it necessary to generate tools and instruments that highlight the aspects that need to be improved in urban green areas to turn them into healthier, sustainable, and inclusive spaces. Generating an universal list on the allergenicity associated with 150 species of prominent urban trees in Mediterranean cities fulfills this function, helping to minimize the impact on the health of people affected by pollen emissions from urban green spaces. The list agreed in this work aims to be a tool that facilitates the qualitative/quantitative allergenic characterization of the species, and that in this way management measures and action plans on the allergenic urban green infrastructure can be implemented. This list establishes the principles and criteria for the allergenicity to be considered as a species selection criterion, both the usual ones in the current planting panels and those that are incorporated as the effects of climate change oblige some to be replaced and introduce others better adapted to the new conditions.

The update of the VPA of 150 tree species often used in green infrastructure in Mediterranean cities becomes a useful instrument for managing and planning green areas, in which the agreed values are closer to the real situation, so that the risk for people affected by pollen allergies is also closer to reality. This list also establishes the bases for a consensus and universal database on the allergenic potential of urban trees, which can be expanded with more species from other biogeographic and bioclimatic zones. With this updated version, the allergenicity criterion can no longer be avoided when considering the selection criteria of the material to be incorporated in urban green areas.

CRediT authorship contribution statement

Paloma Cariñanos: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing - original draft, Writing - review & editing. **Francesca Marinangeli:** Conceptualization, Data curation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgements

The authors appreciate all the comments they have received from anonymous people through the Breathing in the Parks initiative.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ufug.2021.127218.

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