Biol Invasions
https://doi.org/10.1007/s10530-024-03303-8

ORIGINAL PAPER

Different phenological behaviour of native and exotic grasses extends the period of pollen exposure with clinical implications in the Madrid Region, Spain

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Received: 4 January 2024 / Accepted: 22 March 2024

Abstract Exotic allergenic species constitute an important element of global change and are an emergent health issue in Europe due to their potential allergenicity. The grass pollen season is of great importance from the allergic point of view because it includes pollen from ubiquitous species which are responsible for high sensitization rates. In this study, we used flowering phenology data for dominant grass species in the city of Madrid (Spain) and airborne pollen data to explore differences between native and exotic species and their potential contribution to the observed peaks of pollen exposure. We found that exotic grasses flowered later than Mediterranean native grasses, and that ornamental grass species (such as *Cortaderia selloana* and *Pennisetum villosum*) cause an unusual second pollen season in autumn with implications for public health. These results support the need to coordinate the efforts of plant ecologists and aerobiologists to protect the population by identifying sources of allergenic pollen and sustain the appropriate urban plans.

Keywords Exotic species · Grasses · Pollen exposure · Environmental health · Mediterranean region

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Introduction

The grass pollen season is of great importance from the public health point of view because it includes different groups of major and minor allergens which are responsible for the sensitization rates of an average of 15–20% of the population worldwide (Andersson and Lidholm 2003; García-Mozo 2017; Grewling et al. 2023). Grass pollen is produced by many ubiquitous species, resulting in longer pollen seasons than other plant taxa which cause pollinosis (Dirr et al. 2023).

Published online: 12 April 2024

Plant phenology is affected by various elements of global change, from the advance of spring phenophases over recent decades as a result of increasing temperatures (Piao et al. 2023) to longer flowering periods and growing seasons in metropolitan areas in response to the urban heat island (Wohlfahrt et al. 2019; Galán Díaz et al. 2023a). This produces changes in the spatiotemporal patterns of airborne pollen exposure (Rojo et al. 2021). Air pollution in urban areas also seems to produce a synergic increase in the incidence of allergic respiratory diseases (D'Amato et al. 2010; Reinmuth-Selzle et al. 2017; Verscheure et al. 2023).

Invasive exotic species represent another important element of global change (Vilà et al. 2011; Galán Díaz et al. 2023b). Exotic species are those that after being transported by humans outside their native range are able to sustain self-perpetuating populations; whereas invasive refers to exotic species that reproduce in large numbers and quickly spread over new areas, even replacing native species and altering ecosystem function (Richardson et al. 2000). In Mediterranean areas, *Poaceae* and *Asteraceae* are the two plant families with the highest number of exotic species in countries from Mediterranean Europe (Arianoutsou et al. 2010). It has been observed that the flowering period of exotic plant species and their response to abiotic factors differs from that of natives (Wolkovich et al. 2013; Wilsey et al. 2018). In Spain, the flowering period of exotic species often peaks later than native species, which might explain the great competitive potential of these species (Godoy et al. 2009). Ragweed (species of *Ambrosia* genus—*Asteraceae*, mainly *Ambrosia artemisiifolia* L.) is a clear example of an invasive species that has become an emergent health issue in Europe due to its potential allergenicity (Hamaoui-Laguel et al. 2015; Lake et al. 2017). In the case of other allergenic species such as grasses, different flowering patterns can extend the period of pollen exposure in highly invaded communities such as urban environments (Bernard-Verdier et al. 2022), which poses an increasing risk for public health. We therefore need to monitor and quantify the contribution of exotic grasses to pollen exposure and coordinate the efforts of both plant ecologists and aerobiologists to fully address this issue, e.g., protect the population by identifying sources of allergenic pollen and support appropriate urban plans.

The Madrid Region Palynological Network (PALINOCAM Network) is an air quality monitoring programme established in central Spain in 1994 and integrated in the Madrid Autonomous Region's Regional Asthma Prevention and Control Programme (Cervigón Morales 2005). The PALINOCAM Network has continuously monitored airborne grass pollen levels in Madrid over the last 30 years, as well as other allergenic taxa. In late 2014, the sampling station in the city of Collado Villalba was installed on the rooftop of the Hospital Universitario General de Villalba (latitude 40.65, longitude − 4.00). Since then, the Collado Villalba station has consistently reported a clear bimodal distribution of grass pollen concentration each year, with two marked peaks: (i) the first peak in May–June corresponding to native grasses growing in natural and seminatural grasslands (ruderal vegetation in periurban and urban environments) as supported by previous studies in Mediterranean areas (León-Ruiz et al. 2011; Ghitarrini et al. 2017; Romero-Morte et al. 2018); and (ii) the second peak occurring in September–October presumably belonging to exotic grasses widely planted in the Hospital gardens for ornamental purposes, which is the hypothesis to be tested in this work. These grasses belong to the genera *Cortaderia*, *Pennisetum*, *Panicum* and *Miscanthus*. *Cortaderia selloana* (Schult. & Schult.f.) Asch. & Graebn. and *Pennisetum villosum* R.Br. ex Fresen are invasive species regulated by the Spanish Catalogue of Invasive Alien Species (BOE 2013) which are nevertheless extensively used in horticulture (Bayón and Vilà 2019). Moreover, *Cortaderia selloana* can cause respiratory allergies to a similar extent as native grasses (Rodríguez et al. 2021).

In this study, (i) we compared the flowering phenology of common native and exotic grass species using in situ observations and bibliographical resources in order to explore the contribution of these species to each main airborne pollen peak; and (ii) we measured in situ pollen concentrations near the exotic sources and in adjacent natural grasslands using portable traps to empirically demonstrate that the second airborne pollen peak observed in the pollen trap of Collado Villalba is due to the presence of exotic ornamental grass species. We further discuss the implications in the context of biological invasions and public health.

Materials and Methods

Study case: Collado Villalba station

Collado Villalba is a municipality located in the northwest of the Autonomous Region of Madrid, and has a population of 65,657 inhabitants. It is a tourist area because of its position near the southern slopes of the Sierra de Guadarrama National Park and; and it is located 30 km from the Madrid metropolitan area which made it a good location to install a pollen trap (Martín Madrigal et al. 2002). Collado Villalba is located in the mesomediterranean termotipe (Rivas-Martínez et al. 2002). The mean annual temperature is 12.34 °C (minimum and maximum of 0.2 °C and 29 °C respectively) and annual rainfall is 420 mm (average climate data for 1970–2000 extracted from WorldClim version 2.1, Fick and Hijmans 2017).

The Hospital Universitario General de Villalba opened in October 2014 (Fig. 1). Shortly after, a pollen trap was installed which monitors pollen concentrations following the standardized aerobiological protocol using a Hirst-type trap method (Galán et al. 2014; UNE-EN 16868 2020). The natural vegetation around the building complex is mainly open

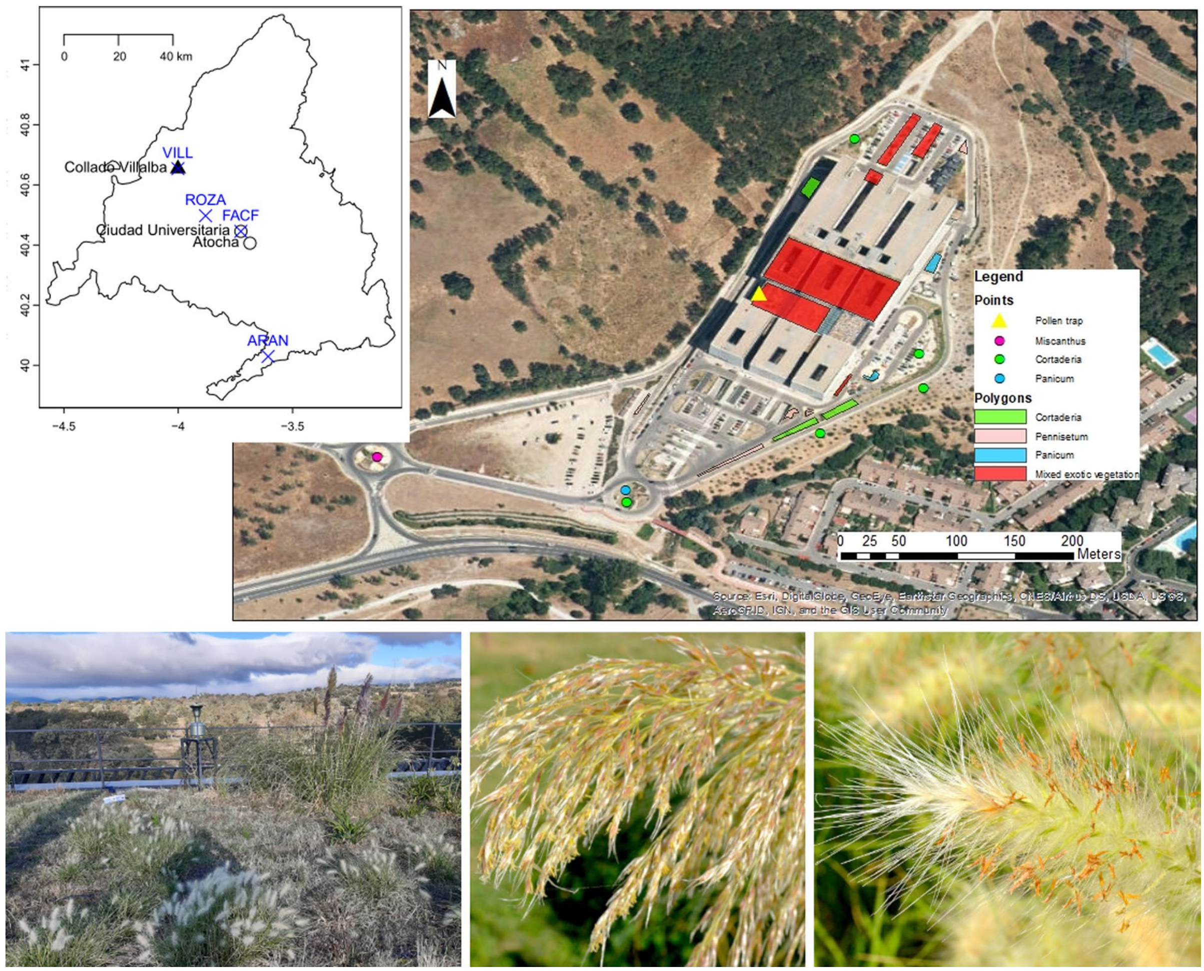

Fig. 1 Study area and pictures of the two most common exotic grass species found near the Hospital. Top left: Madrid Region, Hospital de Collado Villalba (black triangle), stations from the PALINOCAM Network (in blue) and sites where flowering phenology was monitored (circles). Top right: distribution of exotic plant species around Collado Villalba Hospital. Bottom, from left to right: the PALINOCAM Network pollen trap (6/10/2020) and the inflorescences of *Cortaderia selloana* and *Pennisetum villosum* (5/10/2023)

grasslands for farming and cleared oak (*Quercus rotundifolia* Lam.) and ash (*Fraxinus angustifolia* Vahl) woodlands, as well as other riparian vegetation (Martín Madrigal et al. 2002). The Hospital includes green areas on several of its rooftop terraces and around the main building, where many native and ornamental species have been planted. Species native to the Iberian Peninsula include *Betula* sp., *Tilia* sp., *Retama sphaerocarpa* (L.) Boiss., *Cistus ladanifer* L., *Teucrium fruticans* L. and *Lavandula* sp. Among the invasive species most extensively planted around the Hospital are *Cortaderia selloana* and *Pennisetum villosum* (Fig. 1). *Cortaderia* and *Pennisetum* are highly competitive grasses that displace native species and have the potential to transform the ecosystems they invade, causing important ecological and economic impacts (BOE 2013). *Panicum virgatum* L., *Lonicera japonica* Thunb., and *Miscanthus sinensis* Andersson are, to a lesser extent, other exotic species with great invasive potential planted in the green areas around the Hospital which are frequently used in Spain for ornamental purposes (Capdevila-Argüelles et al. 2011; Bayón and Vilà 2019).

Data gathering

In this study, we combined four data sources.

i. We used background airborne pollen concentration data from four stations in the PALINOCAM Network for the period 2015–2023 to compare the pattern observed in Collado Villalba (VILL) with other stations (ARAN: Aranjuez; FACF: Faculty of Pharmacy at the Complutense University; ROZA: Las Rozas) (Fig. 1). We chose these stations because they are representative of the entire airborne pollen spectrum of the city of Madrid (Rojo et al. 2024). FACF includes the most urbanised zones and it is characterised by high pollen exposure from allergenic ornamental plants such as species of the *Cupressaceae* family and *Platanus* genus. ARAN represents agricultural lands from the south and southeast where *Olea* pollen exposure is high as well as pollen from herbaceous species. ROZA covers transitional areas between the most urbanised and natural areas where pollen from the taxa *Poaceae*, *Plantago*, *Quercus* and *Fraxinus* dominate. VILL covers natural zones in the Guadarrama mountain range and it is characterised by high pollen exposure of the taxa *Quercus*, *Fraxinus*, *Cupressaceae* and *Pinaceae*. Estimates of pollen concentration are measured daily and represent the average number of grass pollen grains per cubic metre of air. Estimates were obtained following the standardized aerobiological protocol (Galán et al. 2014; UNE-EN 16868 2020). Pollen data are openly available from https://datos.comunidad.madrid/.
ii. In situ observations were done on the flowering phenology of populations of grass species that dominate Madrid urban and periurban areas to explore differences between native and exotic species. Phenological monitoring was carried out weekly from March to July in 2022 and 2023 at two sampling points in the city of Madrid: Atocha (latitude 40.40, longitude -3.68) and Ciudad Universitaria (40.44, -3.72). Data was collected for all grass species present in both sites that had at least a density of 25 individuals/m^2 for annuals and 25 individuals/10 m^2 for perennials (Romero-Morte et al. 2018). The phenological phases of the reproductive cycle of the plant species were monitored following the international BBCH system, with specific adaptations for grasses: the flowering period starts when the first anthers are visible on the plant (BBCH code 60) and ends when all anthers are dehydrated and all pollen has been released (BBCH code 69) (Meier 2003). The unit of measure for phenological phases is given in day of the year. We also mapped the location of all individuals of *Cortaderia*, *Pennisetum* and *Panicum* species in a 200 m radius around the Hospital and included direct observations at the species level from Villalba obtained from visits by the staff involved in the PALINOCAM Network since 2017. We did not find any naturalised individual of *Cortaderia*, *Pennisetum* and *Panicum* during the surveys, all of them were planted.
iii. Start and end dates of the flowering phenology period of native and exotic grass species in the Iberian Peninsula gathered from the literature. We complemented in situ observations with literature data because literature data comes from herbarium material and, therefore, they are

more representative of the Iberian Peninsula and less constrained by site-specific factors. We used three sources: Flora Ibérica (Devesa et al. 2020), Atlas of invasive alien plants in Spain (Sanz Elorza et al. 2004) and the Spanish Catalogue of Invasive Alien Species (BOE 2013).

iv. Airborne pollen concentration data obtained the 5th and 10th of October 2023 using two volumetric air samplers (Burkard Manufacturing Co Ltd) placed in the gardens near the Hospital (next to *Cortaderia* and *Pennisetum* plants –*d0*–) and adjacent areas (at least 30 m from *Cortaderia* and *Pennisetum* individuals –*control*–): (i) a personal volumetric air sampler located 70 cm above ground level, (ii) and a 7-day recording volumetric spore trap located 48 cm above ground level. We tested two sampling times (9 and 30 min) and report the results in grains/m^3. The aim was to empirically demonstrate that the second airborne pollen peak observed in the pollen trap of Collado Villalba is mostly due to the presence of *Cortaderia*. Air sampling in adjacent natural areas served as a control to ensure that the observed grass pollen does not originate from native grasses in natural and seminatural areas.

Data analysis

We first compared the seasonality of the pollen concentration in the four stations in the PALINOCAM Network for the period 2015–2023 and defined the start and end dates of the grass pollen season using a specific clinical approach for grasses (Pfaar et al. 2017). The clinical definition of the grass pollen season considers the risk for symptom development and refers to the minimal airborne pollen exposure necessary to trigger a nasal or conjunctival allergic reaction based on expert consensus. The start of the grass pollen season is defined as the first day of five (out of seven consecutive days) where daily pollen concentration is greater than 3 grains/m^3 which summation is above 30 grains/m^3. The end of the grass pollen season is defined as the last day of five (out of seven consecutive days) where daily pollen concentration is less than 3 grains/m^3 which summation is less than 30 grains/m^3. This method is implemented in the function ’*calculate_ps*’ from the AeRobiology R package (Rojo et al. 2019).

Second, we compared the flowering phenology of common native and exotic grasses (considering both in *situ* observation and the literature review). The phenological variable used for the analysis was the percentage of flowering individuals at each moment of the period studied. The flowering start date was defined as the day on which the number of flowering individuals exceeded 25% and the end date was the day when the number of flowering individuals no longer exceeded 25%.

Third, we compared the pollen concentration of portable pollen traps located in gardens near the Hospital and adjacent natural areas by applying a t-test on the log-transformed pollen data.

All analyses were performed in R (version 4.3.0). The data and codes used in this study are available at GitHub (https://github.com/galanzse/cortaderia).

Results

We detected many planted individuals of *Cortaderia selloana*, *Pennisetum villosum* and *Panicum virgatum* flowering in managed green areas of the Hospital. Individuals of *Miscanthus sinensis* were also located around the Hospital. Figure 1 includes a map of the location of the exotic grass species in the gardens and green areas of the Hospital. At the time we measured the pollen concentration (between 5 and 10th October 2023), the flowers of individuals of *Cortaderia selloana* were fully developed and releasing pollen, whereas the flowers from individuals of *Pennisetum villosum* and *Panicum virgatum* were entering senescence (Fig. 1).

The average background pollen concentration between April and July for the period 2015–2023 was 35 ± 38 grains/m^3 (mean ± sd) in FACF, ARAN and ROZA, and 28 ± 25 grains/m^3 in VILL (Fig. 2A). The average pollen concentration between September and October for the period 2015–2023 was 1 ± 1 grains/m^3 (mean ± sd) in FACF, ARAN and ROZA; and 21 ± 24 grains/m^3 in VILL (Fig. 2A). This resulted in a first clinical grass season common to all stations from March to August, and a second one unique to VILL from late summer to early autumn (Fig. 2B).

We sampled the phenology of 27 species across the two sites that were representative of urban and

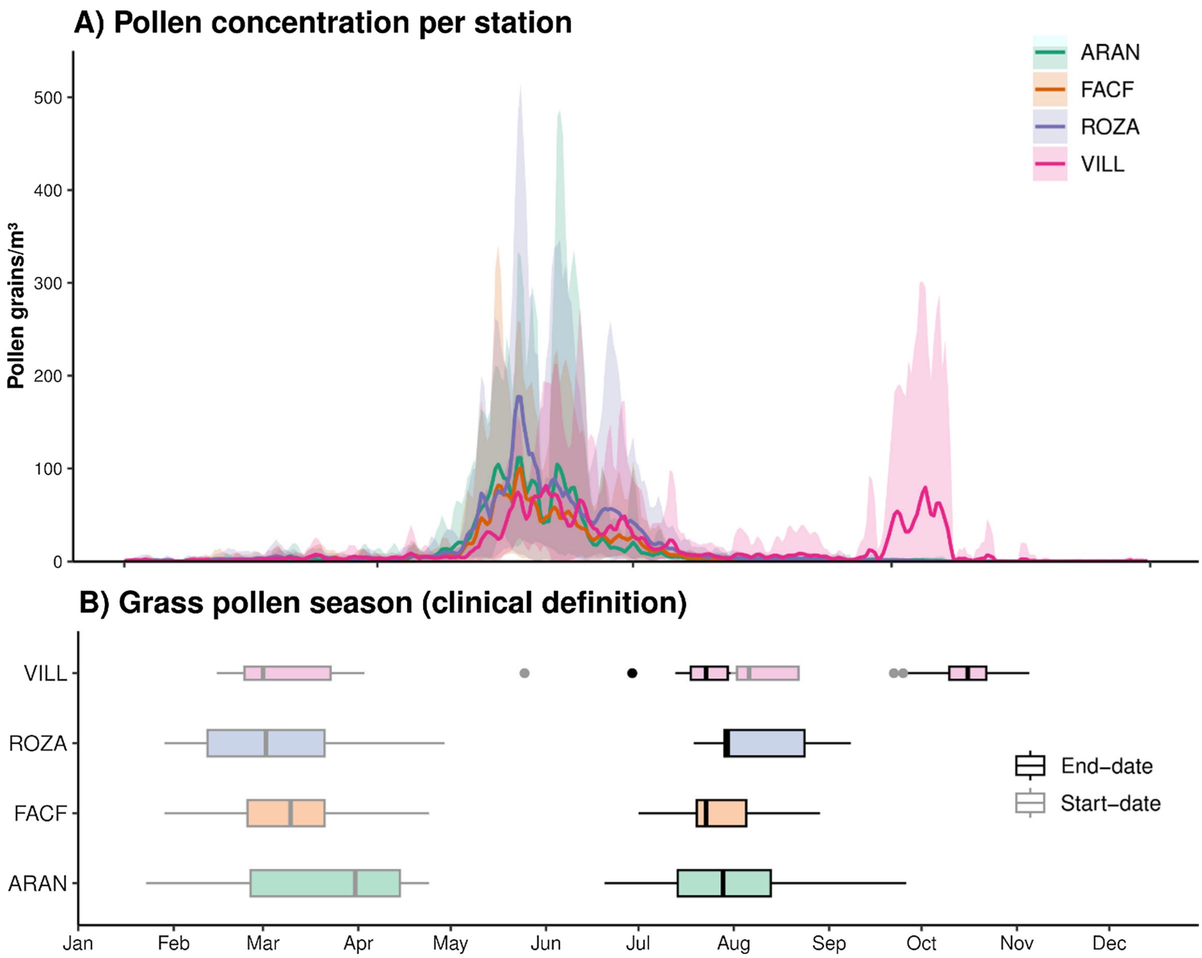

Fig. 2 **A** Pollen concentration per monitoring site for the period 2015–2023 (ARAN: Aranjuez, FACF: Faculty of Pharmacy, ROZA: Las Rozas, VILL: Villalba). **B** Clinical pollen season follows the criteria of the European Academy of Allergy and Clinical Immunology (Pfaar et al. 2017)

periurban areas in Madrid (Table 1). Three of these species were exotic: *Paspalum dilatatum*, *Setaria parviflora* and *Sporobolus indicus*. Populations of native grasses in the two sites flowered mainly from March to June, whereas populations of exotic species flowered from May to July (Fig. 3A). We did not find any native grasses flowering in fields adjacent to the Hospital in October 2023, but *Cortaderia* specimens were fully flowered (Fig. 3A). Thus, the general pattern was that native grasses flowered from February to July and exotic grasses from May to November (Fig. 3B). The literature review supported the general pattern which indicates that phenological differences between the species considered are expected to apply to the entire Iberian Peninsula (Fig. 3A).

The portable pollen traps detected 12 pollen types near the Hospital at the time the study was carried out, of which *Poaceae* was the most abundant (Table 2). The concentration of *Poaceae* pollen near the exotic sources (d0) was significantly higher than in adjacent grasslands (control) ($t(13.36) = 4.06$, $p < 0.001$; Fig. 4).

Discussion

In this study, we combined airborne pollen concentrations obtained from the Madrid Region Palynological

Table 1 Origin, taxonomy and photosynthetic pathway of common grasses found in the Madrid urban and periurban areas included in this study (Soreng et al. 2022). Acronyms are used in Fig. 3

Subfamily	Species	Acronym	Origin	Photosynthetic pathway
Chloridoideae	*Cynodon dactylon*	CyDa	Native	C4
	Sporobolus indicus	SpIn	Exotic	C4
Danthonioideae	*Cortaderia selloana*	CoSe	Exotic	C3
Panicoideae	*Panicum virgatum*	PaVi	Exotic	C4
	Paspalum dilatatum	PaDi	Exotic	C4
	Pennisetum villosum	PeVi	Exotic	C4
	Setaria parviflora	SePa	Exotic	C4
Pooideae	*Aegilops geniculata*	AeGe	Native	C3
	Aegilops triuncialis	AeTr	Native	C3
	Avena barbata	AvBa	Native	C3
	Avena sterilis	AvSt	Native	C3
	Bromus diandrus	BrDi	Native	C3
	Bromus hordeaceous	BrHo	Native	C3
	Bromus madritensis	BrMa	Native	C3
	Bromus rubens	BrRu	Native	C3
	Bromus tectorum	BrTe	Native	C3
	Catapodium rigidum	CaRi	Native	C3
	Dactylis glomerata	DaGl	Native	C3
	Elymus repens	ElRe	Native	C3
	Festuca arundinacea	FeAr	Native	C3
	Hordeum leporinum	HoLe	Native	C3
	Lamarckia aurea	LaAu	Native	C3
	Lolium rigidum	LoRi	Native	C3
	Piptatherum miliaceum	PiMi	Native	C3
	Poa annua	PoAn	Native	C3
	Poa bulbosa	PoBu	Native	C3
	Poa pratensis	PoPr	Native	C3
	Rostraria cristata	RoCr	Native	C3
	Trisetaria panicea	TrPa	Native	C3
	Vulpia ciliata	VuCi	Native	C3
	Vulpia myuros	VuMy	Native	C3

Network (PALINOCAM) and portable traps and flowering data for common native and exotic grasses from Madrid's urban and periurban areas to demonstrate the contrasting reproductive phenology of both groups of species and their contribution to airbone pollen. We found that allergenic invasive grasses extend the period of grass pollen exposure by flowering later than native species.

We found a first season of grass pollen between April and July from 2015 to 2023 in the four PALINOCAM stations considered, which corresponds to native grasses growing in Madrid's urban areas and parks. For most grass species, the flowering period observed in Madrid occurred earlier than the spring pollen peaks reported by the PALINOCAM stations. This well-known pattern in central Spain (Romero-Morte et al. 2020) occurs because the grass species that contribute most to the observed airborne pollen concentration mainly correspond to perennial grass species with high pollen production that flower from late April and May such as *Poa pratensis* and *Dactylis glomerata*, whereas earlier-flowering grass species (e.g., species belonging to the genera *Bromus* and *Hordeum*) release less pollen into the air (Andersson and Lidholm 2003; Matricardi et al. 2016; Romero-Morte et al. 2018).

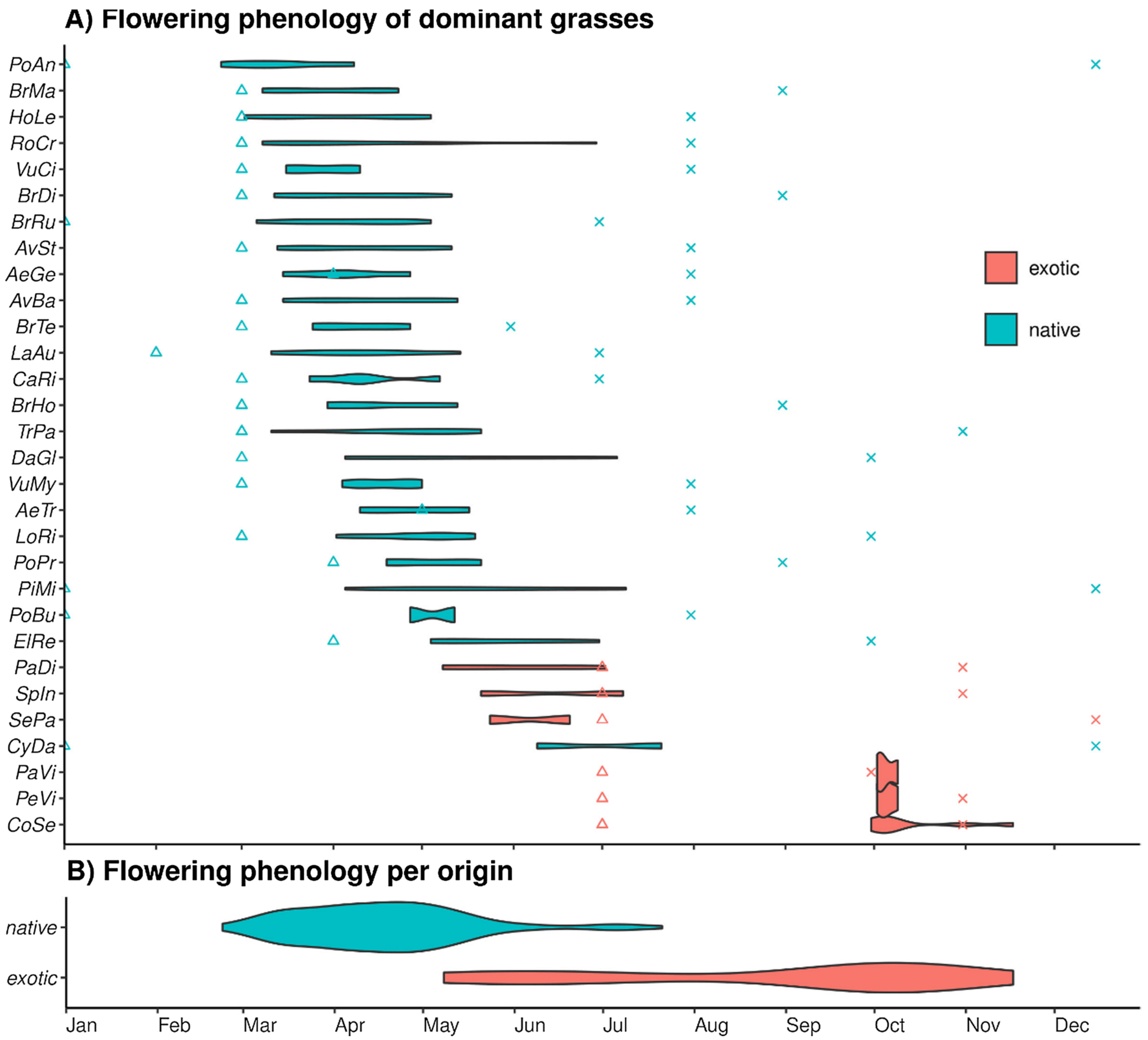

Fig. 3 Flowering phenology of native and exotic grass species in the Madrid Region. The phenological phases of the reproductive cycle of the plant species were monitored following the international BBCH system, with specific adaptations for grasses: the flowering period starts when the first anthers are visible on the plant (BBCH code 60) and ends when anthers are dehydrated and all pollen has been released (BBCH code 69). **A** Results at the species level. Triangles and crosses indicate the start and end of the flowering period based on bibliographical resources. Species acronyms can be consulted in Table 1. **B** Results grouped by origin (native/exotic)

The monitoring of populations indicated that the C4 exotic species of American origin *Paspalum dilatatum*, *Setaria parviflora* and *Sporobolus indicus* flowered significantly later in spring than any native species. The flowering phenology data obtained from the bibliographical resources (less constrained by site-specific factors) revealed that only the flowering phenology of four native species overlap with the abovementioned species: *Cynodon dactylon* (the only C4 native species), *Poa annua*, *Trisetaria panicea* and *Piptatherum miliaceum*. It has been reported that the start and end dates of the flowering period of exotic species after translocation match those in the native range (Godoy et al. 2009). Naturalized and ornamental warm-season grasses (C4) are able to flower during summer as they are well adapted to hot arid climates (Ehleringer and Monson 1993). The genus *Paspalum* includes three species considered

Table 2 Average concentration of pollen types found near the sources (d0) and in control plots, expressed in grains/m^3. Source (d0) refers to pollen traps located next to the exotic sources (i.e., *Cortaderia selloana* and *Pennisetum villosum*), and control includes measurements located in adjacent natural grasslands at least 30 m away from the exotic species

Pollen type	Control	Source (d0)
Asteraceae	1	0
Cupressaceae	4	5
Amaranthaceae	1	3
Pinaceae	3	5
Plantago	1	0
Platanus	0	1
Poaceae	6	93
Quercus	4	4
Urticaceae	2	3
Unidentified	3	3

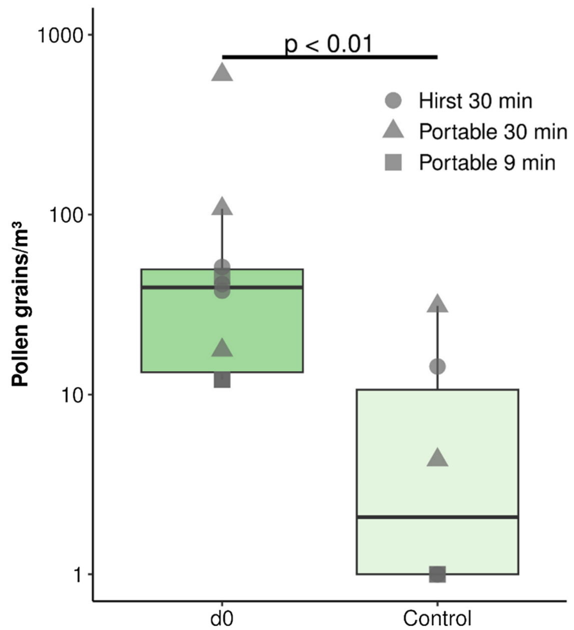

Fig. 4 Pollen concentrations obtained using portable traps located next to the exotic sources (d0) and in control plots situated at least 30 m away in adjacent areas dominated by native grasses. T-test: t(13.36) = 4.06, $p < 0.001$

invasive in Spain: P. *dilatatum, P. paspalodes* and *P. vaginatum* (Sanz Elorza et al. 2004). Species of *Paspalum* and *Cynodon dactylon* (subfamily *Chloridoideae*) cause pollinosis and show little cross-reactivity with species from the subfamily *Pooideae* and must be diagnosed using different tests (Matricardi et al. 2016).

The Collado Villalba pollen trap recorded a second pollen peak between September and October with a similar magnitude to the one observed in spring. Our results clearly show that *Cortaderia selloana* contributes substantially to the air pollen concentration observed in autumn, and that the *Poaceae* pollen concentration is 10–100 times greater near the sources compared to adjacent natural areas. Moreover, both the spring and autumn pollen seasons are considered to be of clinical interest following the European Academy of Allergy & Clinical Immunology criteria (Pfaar et al. 2017). The observed concentration of grass pollen therefore exceeded the clinical threshold and constitutes a risk for symptom development. *Cortaderia selloana* is a C3 species but also maintains the flowering pattern of its native range. As has been recently demonstrated by Rodríguez et al. (2021) in a study with 98 patients from northern Spain diagnosed with grass pollen sensitization, *C. selloana* pollen shares immunogenicity with native grasses, which has been related to the reactivation of allergic symptoms towards early autumn in certain regions. In addition, *C. selloana* is an invasive species included in the Spanish Catalogue of Invasive Alien Species because of its vigorous growth and capacity to alter and transform natural habitats (BOE 2013); its commercialization is prohibited in Spain. Although *C. selloana* is mostly associated with anthropogenic habitats (Domènech et al. 2005; Charpentier et al. 2020), the occurrence of these plant species near protected areas of great ecological value such as the Sierra de Guadarrama National Park is surprising (personal observation). This also applies to the presence of *Pennisetum villosum* (BOE 2013), another invasive species extensively planted in the Hospital Universitario General de Villalba, and *Panicum virgatum* and *Miscanthus sinensis*, two grasses with great invasive potential (Capdevila-Argüelles et al. 2011).

Biological invasions by plant species can increase the period of allergenic risk and the exposure to new aeroallergens. The best known example is ragweed, whose pollen represents an important public health issue in America where this plant is native (Katz et al. 2014; Katz and Carey 2014) and in central and eastern Europe where it is rapidly spreading as an exotic plant

(Hamaoui-Laguel et al. 2015; Skjøth et al. 2019). The changing patterns of pollen exposure produced by exotic grass species are less well known. As we have demonstrated in this study, exotic grass species show an intense autumnal grass pollen season where it would generally not otherwise occur. These results are of great concern for the sensitized population in the proximity of densely populated areas and sensitive building complexes such as hospitals, and support the need for the choice of ornamental species in urban planning and landscape design to comply with ecological and clinical criteria (Cariñanos et al. 2017; Sousa-Silva et al. 2021).

Conclusions

The interaction between different elements of global change is altering the known phenological patterns of plant species. The introduction of exotic plant species is occurring at unprecedented rates (Seebens et al. 2017) and has multiple consequences for urban and natural ecosystems: from declines in local and regional biodiversity and changes in ecosystem functioning (Richardson et al. 2000) to changes in the timing and quantity of pollen exposure (Ziska et al. 2011; Lake et al. 2017; Bernard-Verdier et al. 2022). The spread of invasive allergenic species may represent an important public health issue, beyond its negative ecological impacts. Our results support the need to coordinate efforts between regional and local authorities, researchers and companies involved in the commercialization of ornamental plant species, to share information and contribute towards a sensible use of ornamental plants and the eradication of invasive species.

Acknowledgements The Madrid Region Palynological Network (PALINOCAM Network) results from the cooperation of different public institutions: Madrid Regional Government, Complutense University of Madrid and several city councils in the Madrid Region. In this study, we particularly thank the city councils of Aranjuez and Las Rozas. We also thank all the technical staff at the pollen analysis laboratories for the generation of the pollen databases.

Author contributions JGD: Conceptualization, Methodology, Formal analysis, Data curation, Writing—original draft, Writing—review and editing. JRM: Investigation, Methodology, Writing—review and editing. AC: Investigation, Writing—review and editing. AMGB: Investigation, Resources, Writing—review and editing. PC: Investigation, Resources, Writing—review and editing. JR: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Supervision, Writing—review and editing.

Funding Funding for open access publishing: Universidad de Sevilla/CBUA. This research was funded by the Directorate-General for Public Health of the Madrid Autonomous Region thanks to an agreement signed with the Aerobiology Research Group of the Faculty of Pharmacy of Complutense University of Madrid as responsible of the scientific and technical supervision of the PALINOCAM Network. JGD is supported by a Margarita Salas fellowship funded by the Spanish Ministry of Universities and the European Union-Next Generation Plan.

Data availability The data and codes used in this study are available at GitHub (https://github.com/galanzse/cortaderia).

Declarations

Conflict of interest The authors have declared that no competing interests exist.

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