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Prolonging the period of allergenic burden: late-flowering grasses and local peculiarities

Lukas Dirr · Katharina Bastl · Maximilian Bastl · Markus Berger · Uwe E. Berger

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Summary
Background The grass pollen season is characterized by a particularly long duration, covering the months May to July in Europe but can vary depending on the altitude and geographical location.
Methods Three grass species whose flowering period takes place late in the season are discussed in detail: *Phragmites australis* (common reed), *Miscanthus* spp. (silvergrass), and *Zea mays* (maize).
Results *Phragmites australis* flowers between August and September and provides significant pollen concentrations at sites with large reed populations. *Miscanthus* spp. flowers from August to October and is found as an ornamental plant in urban areas and as a crop plant in rural areas. *Zea mays* flowers from July to October and can cause discomfort especially in the vicinity of cornfields.
Discussion Phenological observations are an important part of aerobiological routine work to gain insights into regional peculiarities like late-flowering grasses, which play a role in prolonging the duration of the grass pollen season.

Keywords Pollen season · Aerobiology · *Phragmites australis* · *Miscanthus* spp. · *Zea mays*

Grass pollen season in Europe

With nearly 12,000 species, the sweet grasses (Poaceae) represent one of the most diverse plant families in the world [1]. Their range extends across all continents (excluding Greenland and Antarctica) and regions defined as grasslands, i.e., habitats dominated by grasses, account for about 40% of the world's vegetation [2]. Apart from natural habitats, which usually have very high species diversity, grasses are also important in agriculture and include three of the most widely cultivated crops, maize (*Zea mays*), rice (*Oryza sativa*), and wheat (*Triticum aestivum*) [3, 4].

Despite the species richness, members of the family Poaceae typically share the following morphological characteristics: (1) an axis called a culm, divided into (usually) hollow internodes and solid nodes; (2) distichous arranged leaves with leave sheaths that often possess delicate ligules; (3) an inflorescence composed of spikelets [5]. However, the expression of these characteristics show a high level of variability, thus, allowing macroscopic classification of the Poaceae into numerous genera and species.

Looking at the pollen of Poaceae, the aforementioned diversity is no longer evident, as pollen morphology is extremely similar throughout the family. In the light microscope, grass pollen appears spherical (spheroidal) with only a single circular aperture (ulcus), often surrounded by a ring-like thickening called annulus. The pollen wall appears smooth (psilate) or shows small sculptural elements whose shape cannot be discerned in the light microscope (scabrat) [6–10].

This pollen morphological similarity makes it difficult or impossible to classify grass pollen more precisely under the light microscope [11] and therefore, complicates the work of aerobiologists who use such analyses to inform allergy sufferers about the currently expected pollen concentrations in the ambient air. This is because, despite morphological similarities, pollen from different grass species sometimes has very different allergenicity [12]. To provide grass pollen allergy sufferers with the best possible information on

L. Dirr (✉) · K. Bastl · M. Bastl · U. E. Berger
Department of Oto-Rhino-Laryngology, Medical University of Vienna, Währinger Gürtel 18–20, 1090 Vienna, Austria
lukas.dirr@meduniwien.ac.at

M. Berger
Department of Oto-Rhino-Laryngology, Klinik Hietzing, Wiener Gesundheitsverbund, Vienna, Austria

which species are causing allergenic burden at a given time, phenological fieldwork is a promising approach. However, this method requires a significant amount time and a thorough understanding of regional flora [13, 14].

It is crucial to document and study the grass pollen season in detail due to its complexity since grass pollen is one of the most important aeroallergens, with a sensitization rate of up to 30% in Europe [15]. As both the intensity and the detailed course of the grass pollen season are subject to fluctuations in regional climatic conditions, it is difficult to make generally valid statements. Only parameters such as the start and end of the season and the peak pollination period show a consistent trend at the European level. In Northern, Eastern and Central Europe, the grass pollen season starts at the beginning of May and lasts until the end of July (Fig. 1b–d). There is a time shift, especially in Mediterranean regions, where the start and end of the season are one month earlier (Fig. 1a–c). The altitude has an influence on the vegetation period as well, causing grasses at higher altitudes to start flowering 2–3 weeks later than those in lowland areas (Fig. 1c–e). Peak grass pollen concentrations in Europe are usually expected in June, 1–2 months after the start of the season (Fig. 1c; [16]).

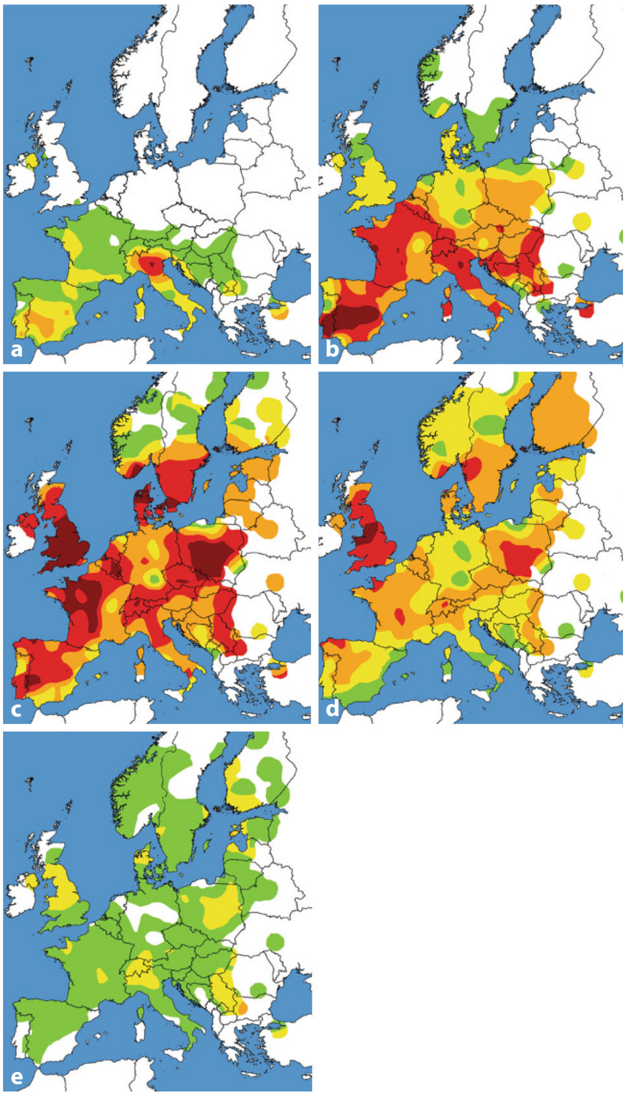

Fig. 1 Grass pollen season in Europe: **a** April, **b** May, **c** June and **d** July, **e** August. Allergenic burden: very low (*green*), low (*yellow*), moderate (*orange*), high (*light red*), and very high (*dark red*)

Few locally conducted studies, mainly in Italy [17] and Spain [18–20], show that different grass species are responsible for pollen concentrations during different phases of the season. However, experienced symptoms of affected allergy sufferers were disregarded in these publications and were first addressed in two Austrian studies [14, 21].

By including crowd-sourced symptom data [22] into the analysis these Austrian studies confirm that: (1) the grass pollen season can be divided into multiple phases, each characterized by different species that are inducing allergic symptoms [14], and (2) that the relevance of these species varies depending on geographic and climatic conditions [21].

The focus of these studies was primarily on the most widespread species in the respective regions, whereas various ornamental grasses or local peculiarities were often not investigated further. Although these local phenomena may cause an extension of the time of burden for grass pollen allergy sufferers due to deviating flowering times. In the further course of this work, three of these local characteristics and their effect on allergy sufferers will be discussed as examples.

Phragmites australis (common reed)

This grass species occurs worldwide, especially along the edges of water bodies and wetland habitats. It can be easily identified based on the habitat description, its height of up to 4 m, its ligule that is transformed to a hair-like structure and the spikelets whose spike axis are covered by long hairs (Fig. 2a; [5]). The plant has been used by humans as a building material for thousands of years, whether as thatch in the past [23] or as an insulating material of modern low-energy houses [24]. In addition, common reed is also used as roughage or in the production of "biofuels" and can be used to purify water or soil contaminated by heavy metals [25].

In addition to the above-mentioned morphological characteristics, common reed is also characterized by a late flowering period, which takes place only between August and September. A study conducted within one of the largest reed belt areas in Europe, around Lake Neusiedl in Austria, shows that this local feature has a significant effect on the time of burden for grass pollen allergy sufferers. During the flowering period of common reed, pollen concentrations of more than 20 pollen/m^3 air were recorded exclusively in the vicinity of Lake Neusiedl, and thus higher lev-

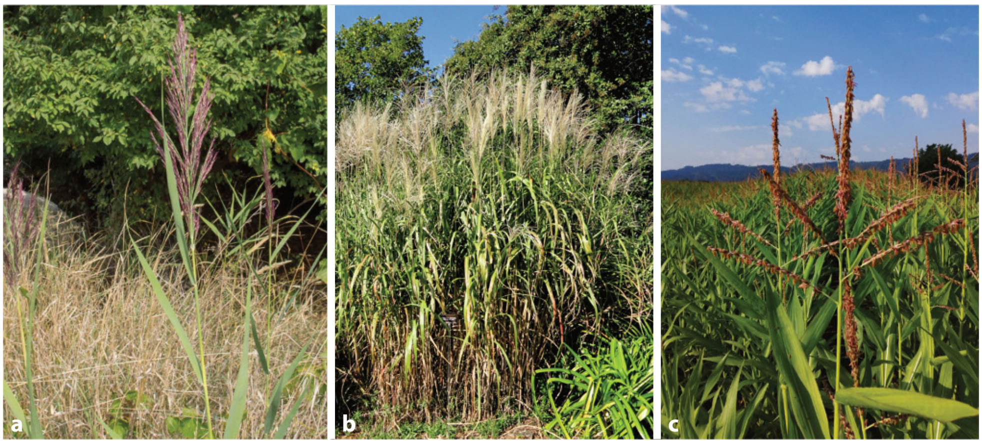

Fig. 2 Habitus of local peculiarities. **a** *Phragmites australis* (© Dr. Katharina Bastl), **b** *Miscanthus* sp., and **c** *Zea mays* (© Dr. Johannes M. Bouchal)

els than at all other measuring points in the country. The amount of pollen released by common reed significantly prolongs the clinically relevant time of burden. The effect of such a local peculiarity shows how important knowledge about local vegetation is when creating pollen forecasts and should be considered for other localities that are close to reed belt areas as well [26].

Miscanthus spp. (silvergrass)

This grass species is not native to Europe but has been regularly cultivated here since the 1980s. Unlike *Phragmites australis*, representatives of *Miscanthus* spp. are rarely found in wetland habitats but rather in locations with brown earth soils and high humus content. The perennial plants can grow flat or in dense tufts and reach a growth height of 1–3 m. Silvergrass is clearly distinguished from reed by the presence of a regular ligule and the dense, drooping inflorescences composed of spikelets (Fig. 2b; [5, 27, 28]).

In China and Japan, this plant has been used as animal feed for a long time and was first cultivated in Europe as an ornamental grass in urban areas. As renewable energy became more important, the cultivation of silvergrass also gained considerable momentum in Europe. However, in contrast to ornamental plant cultivation, which focuses on aesthetically pleasing varieties of the genus Miscanthus, the sterile hybrid *Miscanthus × giganteus*, known as giant miscanthus, is mainly used here. This 2–3 m tall plant is suitable for pellet production and energy generation, due to its low demands on fertilization and crop protection and its rapid growth. In addition, Miscanthus-based biomass finds applications in anaerobic digestion for biomethane production and enzymatic saccharification followed by fermentation for bioethanol production [5, 28–30].

The flowering period of this genus usually takes place from August to October [31] and thus much later than in many grass species growing in natural habitats [16]. In urban areas, where quite a few varieties of this genus are grown as ornamental plants, there may already be significant local exposure to grass pollen, thus, significantly prolonging the period of burden for grass pollen allergy sufferers. Due to the suitability of *Miscanthus × giganteus* as a biomass grass, an increase in pollen concentrations even in rural regions cannot be excluded and should be further monitored from an aerobiological point of view.

Zea mays (maize)

Maize or corn has its origin in America and was introduced to Europe after the continent was discovered by Christopher Columbus [5]. Since then, it has become one of the most important crops in Europe [3, 4]. The plant, which grows between 1–3 m high, appears very vigorous due to the 2–6 cm thick, pithy and unbranched axis. The up to 1 m long leaves and the characteristic flowers are other features that make identification of this plant very easy. The division into terminal male flowers and aggregate female flowers located in leaf axils, of which only the very long pistil protrudes from the cob in the juvenile state, is also a specific feature of *Zea mays* (Fig. 2c; [5]).

In addition to its use as food for humans, maize silage is also used as animal feed or to produce bioethanol [32]. Especially due to the blending of bioethanol with fossil fuel, maize may be increasingly cultivated in Europe in the future, not as a basis for food or livestock feed as before but as a raw material to produce bioethanol [33].

With a flowering period between July and October maize is also one of the late flowering grasses [5]. Combined with increasing cultivation rates, it may be expected that pollen from this plant would significantly prolong the grass pollen season but maize produces comparatively large and heavy pollen grains that show an increased sedimentation rate. Therefore, considerable pollen concentrations in the ambient air must usually only be expected in the vicinity of 20–40 m to the plant at average wind speeds.

Accordingly, it is unlikely that maize pollen will be transported over long distances and cause significant pollen exposure further away from crop fields. However, grass pollen allergy sufferers should anticipate allergenic burden after the main grass pollen season in close vicinity to large areas planted with maize [34, 35].

Outlook

Allergic diseases have shown a significant increase in both incidence and prevalence over the past decades. This can be attributed to changes in lifestyle, air pollution and increasing allergenicity of pollen, as well as a regionally increasing pollen concentrations [36]. These rising pollen concentrations in ambient air are not connected to increasing temperatures but to higher anthropogenic CO_2 emissions [37].

Particularly in cities, this may lead to significantly higher exposure during the grass pollen season in the future. Due to their late flowering compared to other grass species, the plants described here can significantly prolong the period of burden for allergy sufferers. For the benefit of those affected, the planting of late-flowering ornamental grasses such as silvergrass should therefore be avoided.

However, since grasses are not only used as ornamental plants, but also occur in natural habitats and play a very important role in the economy, complete allergen avoidance is not possible. Therefore, regular phenological observations are essential for aerobiologists to gain a better understanding of the vegetation and local peculiarities. This is the only way to provide allergy sufferers with the best possible information so that they can get through the pollen season with the least possible burden.

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Conflict of interest L. Dirr, K. Bastl, M. Bastl, M. Berger and U.E. Berger declare that they have no competing interests.

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