

Phenological Behaviour of Early Spring Flowering Trees

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Abstract

This chapter reports the phenological trends (reproductive and vegetative events) of some early spring and late winter flowering trees all around the world and especially Europe: *Corylus avellana* L. (hazel); *Quercus robur* L. (common oak); *Quercus ilex* subsp. *ballota*, (Desf.) Samp. (holm oak); *Betula* spp. (birch); *Salix alba* L. (willow); *Fraxinus angustifolia* Vahl. (ash); and *Morus alba* L. (white mulberry). They are deciduous and perennial trees growing in different climatic areas of Europe. They have anemophilous pollination liberating huge pollen concentrations to the atmosphere. Aerobiological surveys give us reproductive phenological information of these wind-pollinated species. The phenological response to climate during the last years was analysed, including budburst, leaf unfolding, flowering, fruit ripening, fruit harvesting, leaf colour change, and leaf fall. The response of each taxon to climate was different; most of the revised species and sites presented an advance of the early spring phenophases, especially budburst. On the contrary, some studies detected a delay in autumn vegetative phases, especially leaf fall events. The statistical analyses indicated that phenological advances are a consequence of the increasing temperature trend—minimum temperature being one of the most influential factors. The increase of temperature influenced that leaf unfolding and flowering dates showed a general advance expressed by negative correlations with temperature data, whereas the leaf colour change and leaf-fall presented positive correlations due to the delay of the colder temperatures. The phenological revised results can be considered as reliable and valuable bio-indicators of the impact of the recent climate change in the Northern Hemisphere, and especially Central and Southern Europe.

Keywords: phenology, anemophilous trees, climate change, *Corylus avellana* L. (hazel), *Quercus robur* L. (common oak), *Quercus ilex* subsp. *ballota*, (Desf.) Samp. (holm oak), *Betula* spp. (birch), *Salix alba* L. (willow), *Fraxinus angustifolia* Vahl. (ash), *Morus alba* L. (white mulberry)

1. Phenology

Phenology is derived from the Greek word *phaino*, meaning ‘to show’ or ‘to appear’. This science studies the recurring biological events as part of the animal and plant life cycles. These events are the phenological stages or phenological phases. Phenology not only studies the timing but also their relationships with weather and climate [1].

Sprouting and flowering of plants in spring and leaves’ colour change in the fall are examples of plant phenological events [2].

Phenology has been used as a proxy for climate and weather through all the human history, particularly in relation with agriculture, but only from the last century has emerged as a science in its own right [1]. In last years it is being recognized as an integrative measure of plant responses to the environment changes that can be scaled from a local to a global scale, including climate change. During the last 100 years, the Earth's climate has warmed by approximately 0.6°C. In this last century, two main periods of warming have been detected. The first one was between 1910 and 1945, and the second one from 1976 onward [3]. In this second period, the rate of warming is being doubled than in the first and greater than at any other time during the last 1000 years [3]. The response of the different ecosystems and species is not a global response to a global climate average [4]. To know the regional responses can be more relevant in the context of ecological response to climatic change. In this sense, phenological behaviour data are the more reliable actual bio-indicator of the climate change response. Moreover, sessile life-style characteristic of plants has led them to develop high plasticity phenotypes in order to reach better phenological adaptations to deal with environmental changes [5]. These changes include climate changes that are of critical ecological importance as they affect species competitive ability and net primary productivity. These changes can even prompt ecosystem structure transformations [6]. Therefore, the analysis of trends of spring phenological phases for the past decades could provide important information about changes in climate and the impact on sessile organisms' phenology such as plants and specially trees, with longer lifetimes and shorter capacity of area distribution change.

This study presents a review of recent studies on both vegetative and reproductive field phenological development of different tree species characterized by their foliation or flowering during early spring. The phenological response of different tree species in the North Hemisphere was reviewed: hazel (*Corylus avellana* L.), alder (*Alnus glutinosa* (L.) Gaertn), willow (*Salix alba* L.), birch (*Betula pendula* L.), holm oak (*Quercus ilex* subsp. *ballota*, (Desf.) Samp.) in South Europe and common oak (*Quercus robur* L.) in Central Europe, ash (*Fraxinus angustifolia* Vahl.), and white mulberry (*Morus alba* L.) [7]. All of them are anemophilous species producing high quantities of pollen grains spread to the atmosphere provoking allergy to the sensitized population [8]. Their huge quantities of pollen grains are also a phenological bio-indicator detected through aerobiological studies [9], also revised for the present review. Their phenological behaviour during last 40 years and the impact of the climate change on it were analysed. Particularly remarkable is the fact that the revised species are important for aerobiology and allergy studies, and therefore the changes experimented on their phenology have a special interest. This review offers valuable information due to the scarce number of researches studying field phenological data including those from the last quarter of the twentieth century.

2. Climate change

Climate change due to human activities has been witnessed for at least the last 100 years and is projected to continue for centuries to come. Climate change involves the whole climate system, including not only our atmosphere but also our hydrosphere, cryosphere, land surface, and biosphere [10].

Greenhouse gases and atmospheric concentrations have exponentially increased since the start of the Industrial Era (1750). Moreover, from this time the CO₂ concentrations have increased by 41% mostly due to the global use of oil fuel [3]. The latest measures of the year 2013 of the National Oceanic and Atmospheric Administration reveal that global annual mean atmospheric CO₂ concentration was 395.22 parts per million (ppm) [11], an increase of over 100 ppm from the

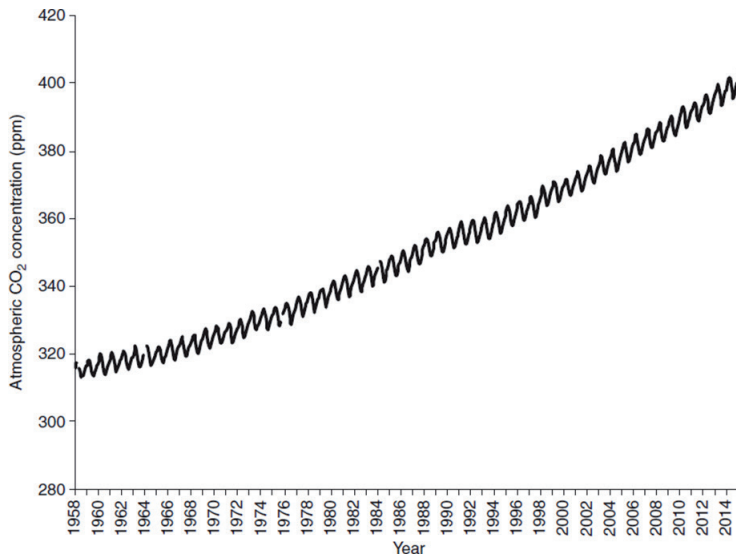


Figure 1.
 Monthly mean atmospheric carbon dioxide concentration from March 1958 to July 2015. Source: [11].

pre-Industrial Era. **Figure 1** shows that the increase in atmospheric CO₂ concentration since 1750 has not been linear, being higher in the last 60 years [11].

This increase in the atmospheric concentration of greenhouse gases such as CO₂ has led to warm the climate. Between 1880 and 2012, the Earth's average surface temperature warmed by 0.85°C [3]. Most of this warming occurred after 1951 [12]; the warming of the Earth's surface varies over space, the land surfaces tending to warm more than the oceans; and some parts of the Earth's surface temperatures have increased the double than other places. Changes in precipitation have also been observed. Since 1901, precipitation has increased over the mid-latitude land areas of the Northern Hemisphere, especially in intensity, with more frequent heavy rain episodes [12].

By the end of this century (2081–2100), global mean surface temperatures are projected to increase from 0.3°C to 4.8°C depending on the sites. The mean warming over land will be larger than over the ocean, and the Arctic region will warm more rapidly than the global mean [3]. With regard to precipitation, it is projected to increase by the end of this century [13]. However, there will be substantial spatial variation in precipitation changes, with some regions experiencing increases, some decreases, and some no change at all [13]. All these factors and the actual impact on phenology of early spring trees will be reviewed in the present chapter.

3. General phenological behaviour of all studied tree taxa

The revised species were selected because of their flowering time in early spring or late winter and because of their strong presence and distribution in Europe. They are anemophilous, deciduous, and perennial trees growing in different climatic areas of Europe: hazel (*Corylus avellana* L.) in Central and South Europe, oak (holm oak (*Quercus ilex* subsp. *ballota*, (Desf.) Samp.)) in Southern Europe, common oak (*Quercus robur* L.) in Central Europe, birch (*Betula* spp.) in Central and North Europe, willow (*Salix alba* L.) in Central and South Europe, ash (*Fraxinus angustifolia* Vahl.) in South Europe, and white mulberry (*Morus alba* L.) in South Europe [14]. All of them are endemic European species except for white mulberry [7].

Most of the revised species belong to the Fagales order, divided into the *Betulaceae*, *Salicaceae*, and *Fagaceae* families [14]. On the other hand, *Fraxinus* genus is in the *Oleaceae* family of the Lamiales order, and *Morus* in the *Moraceae* family of the Rosales order.

Fagales order comprises three families: *Betulaceae*, including the genera *Betula* (birch), *Alnus* (alder), and *Corylus* (hazel); *Fagaceae*, including the genera *Quercus* (oak) and *Fagus* (beech); and *Salicaceae* including the genus *Salix* (willow) [14]. These wind-pollinated trees have catkins, which dangle from the branch so that pollen is easily shaken loose in the wind. Interestingly, catkins in deciduous species emerge before the leaves, allowing the pollen to travel further away from the parent without the obstruction of foliage [15].

Birch is the major pollen allergen-producing tree in Northern Europe, although there are high levels of allergenic cross-reactivity between the representative plants of the genera of the order Fagales [16].

As it has been already mentioned, all the revised species are foliating or flowering in early spring in Europe and North America; nevertheless, there are some specific characteristics for each one.

Hazel and alder are the first (December–April) to blossom and to shed pollen in the outdoor air in Europe, followed by birch. This fact joint to an allergenic cross-reactivity between hazel and alder provokes that pollen from these species can act as a primer of allergic sensitization to *Betulaceae* pollen allergens. Consequently, clinical symptoms become more marked during the birch pollen season [17, 18]. In the central Alpine regions, the highest concentrations of *Alnus* pollen are found at the end of May and in early June [17].

In the case of *Betula*, the budburst occurs at March–April depending on the latitude and altitude. In South and Western Europe, the main flowering period usually starts at the end of March, whereas in Central and Eastern Europe, it occurs at early April. In northern areas the flowering season starts from late April to late May depending on the latitude [8]. Pollen values peak 1–3 weeks after the start of the season, so they are recorded in April in South Europe and in May in Northern Europe. Far shorter or longer periods, with yearly alternating low and high pollen production, have been observed in various European regions [17].

On the other hand, the onset of the oak season in spring, shortly before the beech pollen season, which is usually quite mild, can prolong the season in western, central, and eastern Europe [8]. One important characteristic of the oak pollen is the fact that it includes many species. In South Europe perennial species such as holm oak, kermes oak, and cork oak flower through all the spring from March to June [19]. In Central Europe, the pedunculate oak and the sessile oak usually flower in April–May [8].

Mulberry plants are normally dioecious, but they can also be monoecious on different branches of the same plant. The pendulous pistillate (female) and staminate (male) catkins are arranged on spikes and appear in April and May [20].

All the studied species have their main flowering season on early spring; nevertheless the different phenological phases vary among species, sites, and years depending on the bioclimatic characteristics and fluctuations [8].

4. Allergenicity

Birch, followed by alder and hazel, has the greatest allergenic potency in this group of allergenic trees. In Central Europe, these tree pollens are the second most common cause of allergic conditions after grass pollen. In the case of birch, the major allergen is Bet v1, and the percentage of subjects with a positivity skin prick test to birch allergens ranges from 5% in the Netherlands to 54% in Zurich (Switzerland) [17, 21].

In recent years, the popularity of *Betula* as an ornamental plant loved by architects has caused a significant increase in allergic sensitization to this allergen [22, 23]. In a large study of cross-sensitization between allergenic plants in adult patients with asthma or rhinitis, it was found that sensitization to birch pollen allergens was frequently associated with other allergens, that it induced mostly nasal symptoms, and that respiratory symptoms started at about 30 years of age [14].

Pollen from the common alder, major pollen allergen *Aln g 1*, is an important cause of pollen allergy. This pollen has similar physicochemical properties than the pollen of birch, hazel, hornbeam, and oak. The joint presence of these pollen grains in the atmosphere makes difficult to separate out their individual effects [24].

Hazel is well distributed in Europe, and it typically has a flowering occurring from winter to early spring. The major allergen is *Cor a 1*, cross reactive with *Bet v1* [25]. In the case of *Corylus* pollen, a recent study performed in Poland revealed that ~11% of allergy patients had positive skin reactions to *Corylus* pollen allergens, and most of these (94.4%) reacted to pollen allergens from other members of the Betulaceae family—alder or birch [26].

Beech trees are related to oaks. These trees are considered as low allergenic [27]. The European beech sheds much more pollen than the American species, but both have been reported to have minor allergenic importance. Despite the large amounts of pollen grains detected in the European atmosphere, *Quercus* pollen, which is a stenopalynous pollen type for all the genera, does not provoke actual allergy problems [8].

Although willows elicit strong allergic responses from individuals in allergy tests, willows tend to be pollinated more by insects than by wind and therefore present fewer people with the allergenic challenge than other tree types [28]. In fact, the impact of the increase in *Salix* atmospheric pollen upon asthma admissions is insignificant [29, 30].

Mulberry pollen grains cause allergenic symptoms such as rhinitis, conjunctivitis, and asthma [31, 32]. A study from Tucson, Arizona, USA, concluded that it is an important allergen for children raised in a semiarid environment [33]. In other climate areas, Mulberry tree pollen has been revealed as an important aeroallergen. This is the case of the tropical area of Caracas, Venezuela [34], the Mediterranean area [35, 36], and the Atlantic temperate climate of Argentina [37].

The most important allergenic species revised here, birch, alder, and hazel, have their main pollen emission time mostly in early spring although the exact time depends on the response of these trees to climate [8].

5. Effects of climate changes on phenology of all tree taxa

Different phenological studies are showing a clear link between anthropogenic climate change, warming winter and spring temperatures, and changes in phenology, especially earlier flowering times and late leaf fall in autumn [8, 10, 17, 18, 21]. This occurs in a wide variety of tree species including the early spring species that are analysed here (**Table 1**).

There is considerable variation in these studies that reflects the time examined and regional differences in temperature, etc.; however, for all tree species examined, flowering is now occurring, on average, approximately 2 weeks earlier than it did relative to the mid-twentieth-century temperature average [38–41].

Some studies have shown the impact of climate change on phenology and pollen and therefore on aeroallergens and allergic diseases describing the influence on the amount, distribution, allergenicity, and pollen season of pollen grains [8, 10, 17, 18, 21]. A global comparative study of the International Phenological Gardens in Europe (covering 69–42°N to 10°W–27°E) of current data compared and early

Taxa	Country	Time period (a-b)	Start (a)	Start (b)	Difference	Reference
<i>Fraxinus</i>	The Netherlands	1970–1990s	92	88	–3	[38]
<i>Betula</i>	Belgium	1982–2000	102	84	–18*	[39]
<i>Betula</i>	Finland	1975–2004	130	118	–12*	[40]
<i>Betula</i>	The Netherlands	1970–1990s	106	94	–10*	[38]
<i>Betula</i>	Switzerland	1982–2000	105	85	–20*	[39]
<i>Quercus</i>	The Netherlands	1970–1990s	135	117	–18***	[38]
<i>Quercus</i>	Spain	1970–1990s	89	78	–11	[41]
<i>Corylus</i>	The Netherlands	1970–1990s	84	66	–18**	[38]
<i>Salix</i>	The Netherlands	1970–1990s	82	70	–12*	[38]

Table 1.

Statistically significant differences in start date between the start and the end of the time are indicated with * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

1960s phenological data indicated the advance of spring events, such as flowering (+6 days), whereas autumn phenophases have been delayed by 4.8 days [42].

Speaking about early spring species, in the case of *Corylus avellana*, an earlier flowering onset was observed at 80% of the studied localities of the Iberian Peninsula, earlier fruit ripening at all sampling sites, and earlier fruit harvesting at 75% of them [43]. *Salix alba* presented a trend towards earlier budburst and earlier leaf unfolding at 67% of the studied Iberian localities. In the case of autumn phases, delay in leaf fall at all sampling sites [40]. Holm oak is suffering a strong advance in the flowering start, as it was previously indicated in the Iberian Peninsula [41]. Northern species such as birch, poplar, or willow are also showing the impact of climate change on phenology [38, 39].

As it was demonstrated by [41, 43] among others, the relationship between the phenological observations and weather is so clear for tree species and especially for early spring species. The statistical analyses show that in the 55% of the studied localities of the Iberian Peninsula, the temperature is influencing these trees' phenology. In 58% of the sites affected by temperature, the correlation between phenology and minimum temperatures was negative, which is provoking an advance in phenology. The mean temperature results showed negative correlation in 54% of the sites, although different behaviour was observed depending on species and phenophases.

On average, the length of the growing season in Europe increased by 10–11 days during the last 30 years. Trends in pollen amount over the latter decades of the 1900s increased according to local rises in temperature [8, 44–46]. The increased CO₂ concentration can be affecting pollen production as it has been demonstrated in experimental conditions [47, 48]. Regarding the pollen season length, it is also extending especially in late spring and summer flowering species [49]. Moreover, temperature is influencing towards stronger allergenicity in tree pollen [17, 50].

An earlier pollen season starts, and peak is being more pronounced in early spring flowering species [43]. Due to this earlier onset, the seasons are more often interrupted by adverse weather conditions in late winter/early spring [51].

Finally, changes in climate appear to have altered the spatial distribution of pollens. New patterns of atmospheric circulation over Europe might increase the number of long-distance transport episodes of allergenic pollen, increasing the risk of new sensitizations among the allergic population [52]. On the other hand, the temperature increases, and the changes in rainfall regime are provoking the

geographical spread of some vegetal species to new areas. In the future the effect of the expected rate of warming (0.5°C per decade) could increase this geographical migration although the effect on pollen distribution is expected to be less pronounced than the effect of changes on land as well as international transport of plant species [53].

6. Conclusions

The review made about the recent response of the phenology of different species of anemophilous trees to climate change reveals that, apart from the field phenology data, aerobiological pollen data are a valuable tool to obtain reproductive phenological information of wind-pollinated species.

The response to climate of each studied taxon was different; most of the revised species and sites presented an advance of the early spring phenophases, especially budburst. The statistical analyses of the revised studies indicate that phenological advances are a consequence of the increasing temperature trend—minimum temperature being one of the most influential factors. The increase of temperature influenced that leaf unfolding and flowering dates showed a general advance expressed by negative correlations with temperature data, whereas the leaf colour change and leaf-fall presented positive correlations due to the delay of the colder temperatures.

On the contrary, some studies detected a delay in the autumn vegetative phases, especially on leaf-fall events. Both, leaf colour change and leaf-fall events showed positive correlations with temperature due to the delay of the colder temperatures.

The phenological revised results can be considered as reliable and valuable bio-indicators of the impact of the recent climate change in the Northern Hemisphere and especially in the Central and Southern Europe.

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References

- [1] Schwartz MD, editor. *Phenology: An Integrative Environmental Science*. Netherlands: Springer; 2013
- [2] Meier U, Bleiholder H, Buhr L, Feller C, Hack H, Heß M, et al. The BBCH system to coding the phenological growth stages of plants—history and publications. *Journal für Kulturpflanzen*. 2009;**61**(2):41-52
- [3] Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, et al. IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. United Kingdom: Cambridge University Press; 2013
- [4] Walther GR, Post E, Convey P, Menzel A, Parmesan C, Beebee TJ, et al. Ecological responses to recent climate change. *Nature*. 2002;**416**(6879):389-395
- [5] Schlichting CD. The evolution of phenotypic plasticity in plants. *Annual Review of Ecology and Systematics*. 1986;**17**(1):667-693
- [6] Peñuelas J, Filella I, Comas P. Changed plant and animal life cycles from 1952 to 2000 in the Mediterranean region. *Global Change Biology*. 2002;**8**(6):531-544
- [7] De Rigo D, Caudullo G, Houston Durrant T, San-Miguel-Ayanz J. The European atlas of Forest tree species: Modelling, data and information on forest tree species. In: San-Miguel-Ayanz J, de Rigo D, Caudullo G, Houston Durrant T, Mauri A, editors. *European Atlas of Forest Tree Species*. Luxembourg: Publications Office of the European Union; 2016. p. e01aa69+. Available from: <https://w3id.org/mtv/FISE-Comm/v01/e01aa69>
- [8] D'amato G, Cecchi L, Bonini S, Nunes C, Annesi-Maesano I, Behrendt H, et al. Allergenic pollen and pollen allergy in Europe. *Allergy*. 2007;**62**(9):976-990
- [9] Chuine I, Cambon G, Comtois P. Scaling phenology from the local to the regional level: Advances from species-specific phenological models. *Global Change Biology*. 2000;**6**(8):943-952
- [10] Beggs PJ. *Impacts of Climate Change on Aeroallergens and Allergic Diseases*. United Kingdom: Cambridge University Press; 2016
- [11] NOAA 2015 Annual Global Climate Report. Available from: <https://www.ncdc.noaa.gov/news/2015-annual-global-climate-report> [Accessed: 15 November 2017]
- [12] Hartmann DL, Tank AMK, Rusticucci M, Alexander LV, Brönnimann S, Charabi YAR, et al. Observations: Atmosphere and surface. In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, et al, editors. *Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. United Kingdom: Cambridge University Press; 2013. pp. 159-254
- [13] Collins M, Knutti R, Arblaster J, Dufresne JL, Fichet T, Friedlingstein P, et al. Long-term climate change: Projections, commitments and irreversibility. In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Midgley PM, editors. *Climate Change 2013: The Physical Science Basis. IPCC Working Group I Contribution to AR5*. Eds. IPCC. Cambridge: Cambridge University Press; 2013. pp. 1029-1136

- [14] Tutin TG, editor. Flora Europaea. United Kingdom: Cambridge University Press; 1964
- [15] Nabors MW, editor. Introduction to Botany. USA: Pearson; 2004
- [16] Ebner C, Hirschwehr R, Bauer L, Breiteneder H, Valenta R, Ebner H, et al. Identification of allergens in fruits and vegetables: IgE cross-reactivities with the important birch pollen allergens bet v 1 and bet v 2 (birch profilin). Journal of Allergy and Clinical Immunology. 1995;**95**(5):962-969
- [17] Spieksma FTM, Emberlin JC, Hjelmroos M, Jäger S, Leuschner RM. Atmospheric birch (*Betula*) pollen in Europe: Trends and fluctuations in annual quantities and the starting dates of the seasons. Grana. 1995;**34**(1):51-57
- [18] D'amato G, Spieksma FTM. Allergenic pollen in Europe. Grana. 1991;**30**(1):67-70
- [19] García-Mozo H, Galán C, Aira MJ, Belmonte J, de la Guardia CD, Fernández D, et al. Modelling start of oak pollen season in different climatic zones in Spain. Agricultural and Forest Meteorology. 2002;**110**(4):247-257
- [20] Barbour JR, Read RA, Barnes RL, Morus L. Mulberry. The Woody Plant seed manual. AGRIC. 2008;**727**:728-732
- [21] Frei T, Leuschner RM. A change from grass pollen induced allergy to tree pollen induced allergy: 30 years of pollen observation in Switzerland. Aerobiologia. 2000;**16**(3-4):407
- [22] Ciprandi G, Comite P, Ferrero F, Bignardi D, Minale P, Voltolini S, et al. Birch allergy and oral allergy syndrome: The practical relevance of serum immunoglobulin E to bet v 1. Allergy and Asthma Proceedings. 2016;**37**(1):43-49
- [23] Lavaud F, Fore M, Fontaine JF, Pérotin JM, de Blay F. Birch pollen allergy. Revue des Maladies Respiratoires. 2014;**31**(2):150-161
- [24] Niederberger V, Pauli G, Grönlund H, Fröschla R, Rumpold H, Kraft D, et al. Recombinant birch pollen allergens (rBet v 1 and rBet v 2) contain most of the IgE epitopes present in birch, alder, hornbeam, hazel, and oak pollen: A quantitative IgE inhibition study with sera from different populations. Journal of Allergy and Clinical Immunology. 1998;**102**(4):579-591
- [25] Żbikowska-Gotz M, Józwiak J, Rędowicz JM, Kuźmiński A, Napiórkowska K, Przybyszewski M, et al. Assessment of cross-reactivity in patients allergic to birch pollen by immunoblotting. Food and Agricultural Immunology. 2013;**24**(4):445-456
- [26] Grewling L, Janerowicz D, Nowak M, Polanska A, Jackowiak B, Czarnecka-Operacz M, et al. Clinical relevance of *Corylus* pollen in Poznan, western Poland. Annals of Agricultural and Environmental Medicine. 2014;**21**(1):64-69
- [27] Mothes N, Horak F, Valenta R. Transition from a botanical to a molecular classification in tree pollen allergy: Implications for diagnosis and therapy. International Archives of Allergy and Immunology. 2004;**135**(4):357-373
- [28] Sofiev M, Bergmann KC, editors. Allergenic Pollen: A Review of the Production, Release, Distribution and Health Impacts. Netherlands: Springer; 2013. p. 159
- [29] Eriksson NE, Wihl JA, Arrendal H, Strandhede SO. Tree pollen allergy. II. Sensitization to various tree pollen allergens in Sweden. A multi-Centre study. Allergy. 1984;**39**(8):610-617

- [30] Dales RE, Cakmak S, Judek S, Coates F. Tree pollen and hospitalization for asthma in urban Canada. *International Archives of Allergy and Immunology*. 2008;**146**(3):241-247
- [31] Navarro AM, Orta JC, Sanchez MC, Delgado J, Barber D, Lombardero M. Primary sensitization to *Morus alba*. *Allergy*. 1997;**52**(11):1144-1145
- [32] Targow AM. The mulberry tree: A neglected factor in respiratory allergy in Southern California. *Annals of Allergy*. 1971;**29**(6):318
- [33] Tiwari GPK. Impacts of climate variability and change on aeroallergens and their associated health effects: A preliminary review. In: *Proceedings of the Symposium on Sustainable Development*. 2010. p. 194
- [34] Hurtado I, Riegler-Goihman M. Air sampling studies in a tropical area. Four year results. In: *Advances in Aerobiology*. Birkhäuser: Basel: Springer; 1987. pp. 49-53
- [35] Bilisik A, Yenigun A, Bicakci A, Eliacik K, Canitez Y, Malyer H, et al. An observation study of airborne pollen fall in Didim (SW Turkey): Years 2004-2005. *Aerobiologia*. 2008;**24**(1):61-66
- [36] Gonianakis MI, Baritaki MA, Neonakis IK, Gonianakis IM, Kypriotakis Z, Darivianaki E, et al. A 10-year aerobiological study (1994-2003) in the Mediterranean island of Crete, Greece: Trees, aerobiologic data, and botanical and clinical correlations. *Allergy and Asthma Proceedings*. 2006;**27**(5):371-377
- [37] Nitiu DS. Aeropalynologic analysis of La Plata City (Argentina) during a 3-year period. *Aerobiologia*. 2006;**22**(1):79-87
- [38] Van Vliet AJ, Overeem A, De Groot RS, Jacobs AF, Spieksma F. The influence of temperature and climate change on the timing of pollen release in the Netherlands. *International Journal of Climatology*. 2002;**22**(14):1757-1767
- [39] Emberlin J, Detandt M, Gehrig R, Jaeger S, Nolard N, Rantio-Lehtimäki A. Responses in the start of *Betula* (birch) pollen seasons to recent changes in spring temperatures across Europe. *International Journal of Biometeorology*. 2002;**46**(4):159-170
- [40] Yli-Panula E, Fekedulegn DB, Green BJ, Ranta H. Analysis of airborne betula pollen in Finland; a 31-year perspective. *International Journal of Environmental Research and Public Health*. 2009;**6**(6):1706-1723
- [41] García-Mozo H, Galán C, Jato V, Belmonte J, de la Guardia CD, Fernández D, et al. *Quercus* pollen season dynamics in the Iberian Peninsula: Response to meteorological parameters and possible consequences of climate change. *Annals of Agricultural and Environmental Medicine*. 2006;**13**(2):209-212
- [42] Huynen M, Menne B. Phenology and human health: Allergic disorders. In: *WHO Meeting 2003; 16-17 January 2003; Rome, Italy: Health and Global Environmental Series*. EUR/03/5036791. Copenhagen: World Health Organization; 2003. p. 55
- [43] Hidalgo-Galvez MD, García-Mozo H, Oteros J, Mestre A, Botey R, Galán C. Phenological behaviour of early spring flowering trees in Spain in response to recent climate changes. *Theoretical and Applied Climatology*. 2018;**132**(1-2):1-11, 263-273
- [44] Corden JM, Millington WM. The long-term trends and seasonal variation of the aeroallergen *Alternaria* in Derby, UK. *Aerobiologia*. 2001;**17**(2):127-136

- [45] Fitter A, Fitter RSR. Rapid changes in flowering time in British plants. *Science*. 2002;**296**(5573):1689-1691
- [46] García-Mozo H, Oteros JA, Galán C. Impact of land cover changes and climate on the main airborne pollen types in southern Spain. *Science of the Total Environment*. 2016;**548**:221-228
- [47] Wayne P, Foster S, Connolly J, Bazzaz F, Epstein P. Production of allergenic pollen by ragweed (*Ambrosia artemisiifolia* L.) is increased in CO₂-enriched atmospheres. *Annals of Allergy, Asthma & Immunology*. 2002;**88**(3):279-282
- [48] Leakey AD, Uribe Larrea M, Ainsworth EA, Naidu SL, Rogers A, Ort DR, et al. Photosynthesis, productivity, and yield of maize are not affected by open-air elevation of CO₂ concentration in the absence of drought. *Plant Physiology*. 2006;**140**(2):779-790
- [49] García-Mozo H, Mestre A, Galán C. Phenological trends in southern Spain: A response to climate change. *Agricultural and Forest Meteorology*. 2010;**150**(4):575-580
- [50] Ahlholm JU, Helander ML, Savolainen J. Genetic and environmental factors affecting the allergenicity of birch (*Betula pubescens*) pollen. *Clinical and Experimental Allergy*. 1998;**28**:1384-1388
- [51] García-Mozo H, Hidalgo P, Galán C, Gómez-Casero MT, Dominguez E. Catkin frost damage in Mediterranean cork-oak (*Quercus suber* L.). *Israel Journal of Plant Sciences*. 2001;**49**(1):42-47
- [52] Cecchi L, Malaspina TT, Albertini R, Zanca M, Ridolo E, Usberti I, et al. The contribution of long-distance transport to the presence of ambrosia pollen in central northern Italy. *Aerobiologia*. 2007;**23**(2):145-151
- [53] Riotte-Flandrois F, Dechamp C. New legislation from the Politique Agricole commune passed in 1994 and its impact on the spread of ragweed. The public health laws are the responsibility of the mayor, the health department, the general council and the state council. *Allergie et Immunologie*. 1995;**27**(9):345-346