



The impact of climate change on selected pollen allergies and some allergic diseases

Wpływ zmian klimatu na wybrane alergie pyłkowe oraz niektóre choroby alergiczne

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■ Abstract

Introduction and Objective. Pollen can reflect changing climate. In Europe, pollen types are increasing season duration and an earlier onset is being experiencing. The reason for this includes a lack of change in some monthly meteorological variables or change in land-use, such as grassland being replaced by urban areas or woodland. The review presents the background of climate change, impact of the pollen season, and duration of symptoms in patients with allergic diseases.

Brief description of the state of knowledge. Climate change has important effects related to environmental pollution and the origin of hypersensitivity and pollen allergy. This causes an increase in the production of pollens and an increase in their allergenic properties. Climate change can affect plant growth which can be altered so that the new pollens produced are modified and affect health. As a consequence, an increase in the incidence of allergic diseases caused by pollens is expected in the medium and long-term.

Summary. The education of the population in preventing environmental pollution and climate change is a matter of urgency worldwide. Adaptation and mitigation measures can be undertaken to limit the impact of climate change on the pollution induced by chemical agents and pollen. Mitigation addresses the causes of climate change, whereas adaptation addresses its impact. Adaptation will be not able to eliminate all negative impacts and mitigation is crucial to limit changes in the climate system. Extreme weather phenomena, such as thunderstorms, trigger exacerbations of asthma with an important socio-economic impact. Allergic patients should be educated about the risk of asthma exacerbation during a thunderstorm or pollen season.

■ Key words

allergy, climate change, pollen allergy, pollen season

■ Streszczenie

Wprowadzenie i cel pracy. Celem pracy jest zwięźle przedstawienie aktualnej wiedzy na temat wpływu zmian klimatu na stan pylenia roślin i znaczenia tych zmian dla zdrowia osób cierpiących na choroby alergiczne wywołane pyłkami, ze szczególnym uwzględnieniem ambrozji. W pracy omówiono także wpływ gwałtownych burz i wyładowań atmosferycznych na przebieg alergicznej choroby podstawowej.

Opis stanu wiedzy. W całej Europie, jak i w Polsce obserwuje się wzrost zachorowania na choroby alergiczne. Główną przyczyną chorób o przebiegu sezonowym jest obecność w powietrzu pyłków roślin. Wraz z ocieplaniem klimatu zmieniają się okresy pylenia. Są one coraz dłuższe, zaczynają się wcześniej i charakteryzują się gwałtownością. Zmiany te oraz odmienności w uprawach oraz wyładowania atmosferyczne wpływają na zaostrzenie przebiegu dotychczas łagodnych chorób oraz stwarzają śmiertelne niebezpieczeństwo dla osób z ciężkim przebiegiem choroby.

Podsumowanie. Ze względu na zachodzące zmiany klimatyczne istnieje potrzeba nie tylko edukowania społeczeństwa i chorych uczulonych na pyłki na temat zachowania w nowych warunkach, ale również uświadamiania organom rządzącym oraz instytucjom zarządzającym ochroną zdrowia, że zmiany klimatyczne oraz zmiany profilu pylenia roślin zwiększą liczbę chorych, czego efektem jest zwiększona liczba wizyt lekarskich oraz hospitalizacji. A gwałtowne, silne burze oraz wichury powodują niekontrolowane zaostrzenia nawet dość łagodnie przebiegających dotychczas chorób.

■ Słowa kluczowe

alergia, zmiany klimatu, pyłki, sezon pylenia

INTRODUCTION

Climate change affects human health, and allergy appears to be at the frontline of the sequelae of climate change, in addition to infectious and cardiovascular diseases. Allergic diseases are becoming an increasing health problem in many

countries worldwide [1]. According to the World Allergy Organization, in 2050 there will be 4 billion allergy sufferers worldwide. Currently, in Europe, allergy symptoms have already been found in 30% of the population, among whom 20% are severe cases, and 50% remain undiagnosed. The European Academy of Allergy and Clinical Immunology [EACCI] predicts that by 2030, 50% of Europeans will be affected by some type of allergy [1]. In Poland, there has also been a significant increase in the number of people with allergic diseases and, in particular, over the past dozen or so

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years, there has been a rapid increase in incidents of allergic rhinitis and asthma [2]. According to research within the project 'Epidemiology of Allergic Diseases in Poland' [ECAP 2019], 40% of the Poles are allergic, and the observed rate of increase in the number of people suffering from allergies and asthma will soon be equal to the number of healthy people [2]. It was found, among other things, that allergic diseases of the respiratory system in particular are a significant and growing problem in the Polish population. In over 18.5 thousand people examined, over 40% had positive skin prick test results for common allergens, and almost 50% had one or more allergy symptom, e.g. allergic rhinitis, wheezing, or asthmatic dyspnoea [2]. In Poland, the incidence of asthma is very high, and a significant percentage of patients are unaware of the diseases.

A significantly higher frequency of allergic diseases was found among children aged 3–16 living in large cities compared to those from rural areas. The corresponding values were 16.4 and 2.0% for bronchial asthma and 38.8 and 10.8% for allergic rhinitis [2]. The results of a study conducted in Kraków in 2008–2017 in group of over 70 thousand children and adolescents, as part of the 'Municipal Prevention Programme for Asthma and Allergic Diseases of Children and School Youth', indicate that the occurrence of allergic rhinitis and asthma among the students of Kraków was more frequent compared to the results of nationwide studies [3]. The authors suggest that air pollution in Kraków and its immediate vicinity is the main cause of this phenomenon. The ECAP report also stated that allergy in children, adolescent and young adults, among whom the incidents of morbidity is the highest, significantly impairs their quality of life and is a significant problem for educational and professional efficiency [ECAP 2007] [4].

Today, at the beginning of the 21st century, the effects of climate change are clearly being felt. The frequency of among others very mild winters, hot summers, long-term droughts, and heavy rainfall is increasing. The significant increase in air temperature and weather variability, and in the longer term, the climate change being observed today has been influenced on the time and concentration of grains and spores of fungi causing allergic diseases. In Poland, patients with pollen allergy most often react to grasses and birch, then alder and hazel, and in summer and autumn, mugwort and ragweed. Climate change is likely to affect allergic diseases, and the view of clinical experts is that these diseases will increase under climate change, in part because of the impact on allergic plant species [5]. Impacts on allergens may be one of most important consequences of climate change for human health [6]. Climate change has already been identified as one factor contributing to the rising prevalence of allergic asthma [6]. Pollens are the primary cause of symptoms in individuals with allergic diseases, but there is no quantitative evaluation of how future climate change might influence pollen allergy levels in humans due to the complex nature of climate effects [7]. For instance, changing climate conditions will impact the distribution of allergenic species, as well as the timing and duration of the pollen season, and increased carbon dioxide [CO₂] levels may boost plant growth and pollen production [6]. Climate change may also influence the timing of pollen release and its atmospheric dispersion [5], the overall effect of which will be changes in the timing and intensity of pollen seasons, leading to altered exposure levels. Comprehensive modelling of all these factors is necessary to evaluate the

consequences of climate change on pollen-related allergic diseases.

Current knowledge is based on experimental and epidemiological research on the relationships between allergic respiratory diseases, asthma, and environmental factors, such as meteorological variables, airborne allergens, and air pollution, while there remains a lack of studies on how climate change affects respiratory allergies [1, 2, 4, 5]. Urbanization, characterized by high levels of vehicle emission and a westernized lifestyle, has been linked to the increasing prevalence of respiratory allergic diseases and bronchial asthma observed over recent decades in most industrialized countries [1, 5, 6, 8]. Climatic factors, including thunderstorms, temperature, humidity, and wind speed, can influence both components of these interactions. The patterns of climate change will vary regionally, depending on factors such as latitude, altitude, rainfall and storms, land-use patterns, urbanization, transportation, and energy production. The magnitude of climate change and the associated rise in allergic diseases will depend on how rigorously greenhouse gas mitigation strategies are implemented [1]. Carbon dioxide (CO₂), mainly produced by burning fossil fuels, is the predominant greenhouse gas; other greenhouse gases include methane (CH₄), nitrous oxide (NO₂), and fluorinated gases [9]. Studies on plant responses to elevated atmospheric CO₂ levels have shown enhanced photosynthesis, reproductive changes, and increased pollen production. Additionally, these climate conditions modify the protein composition and metabolites in pollen grains, enhancing their allergenic potential. Elevated CO₂ levels specifically increase the expression of allergenic proteins in pollen, making them more potent in triggering allergic immune responses. This results in more frequent, intense, and prolonged allergic symptoms in sensitized individuals, as well as a higher risk of new sensitizations. Consequently, climate change contributes to a rise in the prevalence and severity of pollen-related allergies, such as seasonal allergic rhinitis and pollen-food allergy syndrome [9]. Human activities have increased the natural concentration of carbon dioxide in the atmosphere, intensifying the earth's natural greenhouse effect. In 1870, before the industrial revolution, carbon dioxide levels were 280 ppm, and by January 2019, had risen by 2.87 parts per million to 409.92 ppm (Tab. 1) [10, 11].

Climate change is causing an increase in the number of days with concentrations of ragweed, grasses, and birch pollen that trigger clinical allergy symptoms. Higher temperatures and rising carbon dioxide levels lead to an earlier start and lengthening of the pollen season for these plants; as a result,

Table 1. Impact climate change on allergy and allergic diseases

Factor	Impact on Allergy/Health
Climate change	Earlier, longer, more intensive pollen seasons; higher pollen counts, more potent allergens, greater range of pollen
Environmental pollution	Increases airway inflammation and risk of asthma/allergies, worsens symptoms (particular in children)
Air pollution	Triggers/exacerbates asthma, allergic rhinitis, eczema, enhanced allergenicity of pollen
Allergic diseases	Increasing prevalence and severity due to environment changes/pollution
Health impact	More frequent/severe symptoms, longer allergy seasons; higher healthcare burden; reduced quality of life; increased demand of treatment

there are more days when pollen concentrations reach levels capable of causing allergic symptoms. Additionally, ragweed pollen produced at higher temperatures and elevated CO2 contains more of the major allergen Amb a 1, which can provoke stronger allergic reactions. Similarly, birch growing in warmer conditions produces pollen with higher amounts of the allergen Bet v 1, increasing its allergenic potential. The grasses' pollen season is also changing under climate influence, with summer weather conditions significantly affecting their pollen production [12].

The impact of climate change on alterations in wind patterns, timing and intensity of rainfall, and rising temperatures, can influence the frequency and severity of air pollution episodes, as well as anthropogenic emissions, such as increased energy demand for cooling or heating spaces [1]. The urban heat island effect can elevate certain pollutants like ozone, and indirectly increase natural sources of air pollutant emissions, including forest fires, vegetation degradation, vehicle emissions, and soil erosion. Tropospheric ozone (O3) forms in the presence of strong sunlight through reactions between volatile organic compounds (VOC) and nitrogen oxides (NOx), which come from both natural and human-produced sources. Birch pollen exposed to elevated ozone levels causes larger wheals in skin prick tests, compared to pollen exposed to lower ozone concentrations, indicating an allergenic effect of ozone [13, 14].

The increasing occurrence of allergic respiratory symptoms triggered by inhalation of pollen grains, along with the related growing economic burden, makes pollen allergy a concern for public health. Between 10–35% of young adults in Europe have serum IgE antibodies against grass pollen allergens [1]. Alterations in pollen patterns can lead to allergies that cause difficulties in working, disabilities, medical visits, and treatment needs, significantly impacting healthcare costs [15, 16]. During natural pollination, mature pollen grains dry out when released from the anthers at the time of dispersion, and upon contacting a wet surface the pollen grains rehydrate and undergo rapid metabolic changes. Afterwards, when pollen grains come into contact with the conjunctival, nasal or oral mucosa, the pollen allergens are quickly released, triggering pollinosis symptoms in the eyes and respiratory tracts of sensitized individuals [1, 6]. Pollen grains can burst due to osmotic shock, releasing cytoplasmic allergens into the air. Specifically, fresh birch pollen can rupture under conditions of high humidity, emitting an aerosol composed of pollen cytoplasm fragments within microdroplets [17]. The particles released, include fragmented pollen cytoplasm, and form an ultrafine aerosol. Grass anthers serve as the site where pollen breaks and are a source of fine particle aerosols containing pollen allergens [15, 18, 19]. There are numerous connections between exposure to allergens, inflammation in both the upper and lower respiratory tracts, and clinical symptoms. In allergic individuals, symptom severity is influenced by the amount of allergenic pollen; however, other factors, in addition to allergens, appear to play a role. Although pollen grains enter the upper respiratory tract, they seldom reach the bronchi because their size is consistently larger than 10 µm in diameter [1]. Still, bronchial asthma and related conditions, such as irritative cough, are frequently observed in patients allergic to pollen.

While it is commonly thought that rain clears pollen from the air, certain studies have demonstrated that allergens can be released from the pollen surface within seconds upon

contact with water. The hypothesis suggests that during thunderstorms and rainfall, pollen releases allergens attached to particles much smaller than the original pollen grains. These tiny granules, measuring 1–5 µm and derived from other pollen tissues, carry allergens that might contribute to allergic asthma [1, 19]. Thunderstorm-related asthma is a phenomenon posing a significant health risk, and thunderstorms during pollen seasons have been reported to trigger severe asthma attacks, and even deaths, among pollen-allergic individuals [17, 19]. The term ‘thunderstorm asthma’ refers to the surge in acute bronchospasm cases following thunderstorms in a given area. Asthma exacerbations caused by thunderstorms are marked by a sharp rise in emergency hospital visits for asthma at the onset of a storm [18, 19]. Even patients without prior asthma symptoms but with seasonal rhinitis, can experience asthma attacks. A recent systematic review examined the link between grass pollen and thunderstorm asthma, by analysing 20 studies; of these, 15 found some association between grass pollen and thunderstorm asthma, and nine demonstrated an effect occurring within four days following an increase in grass pollen concentration, which was linked to a higher risk of thunderstorm asthma [20].

In 2017, a team of scientists from a European country carried out quantitative assessments of the potential effects of climate change on pollen allergy in humans, concentrating on common ragweed (*Ambrosia artemisiifolia*) in Europe [21]. According to their estimates, sensitization to ragweed is expected to more than double by 2041–2060, with populations across most of Europe likely to be affected. Their forecasts show that sensitization will continue to rise in countries where ragweed is already an issue, but the largest proportional increases are expected in regions where ragweed sensitization is currently relatively rare. Much of the predicted change results from the anticipated northward expansion, which has already been observed in the United States. These projections suggest that ragweed-sensitized persons may suffer more severe symptoms due to increased pollen concentrations and an extended pollen season lasting into September and October across much of Europe. The anticipated changes are mainly linked to climate and related land-use changes [2], but they also involve the spread of this invasive plant through Europe even without climate change. The reference plan: invasion scenario assumes the common hypothesis that seed dispersal is inversely proportional to the square of the distance [22]. Therefore, it strongly implies that controlling ragweed is vital for public health, and as a strategy to adapt to climate change impacts (Tab. 2).

However, managing existing plants is challenging due to the long-lasting seeds of ragweed, its ability to develop

Table 2. Ambrosia Pollen Season Duration in Poland Over the Last 30 Years [30, 31, 32]

Period	Ambrosia Pollen Season Length	Notes
1990s	Late August – mid-September (~20–25 days)	Shorter season, fewer pollen counts
2000–2010	Late July – early October (~30–40 days)	Longer season, expansion of ragweed
2010–2020	Early August – late September/October (~50–60 days)	Noticeable lengthening, higher pollen levels
2020–2025	Late July – late October (up to ~70 days)	Longest recorded season

herbicide resistance, and its capacity to regrow after cutting [23]. Ragweed proliferates in frequently disturbed land [24]. Controlling long-distance seed dispersal is also crucial for preventing the spread of the plant, which is mainly linked to human activities. Consequently, regulating contaminated seed and monitoring areas vulnerable to ragweed invasion are essential components for limiting its expansion. Beyond climate change, plant invasion, and population dynamics, other factors may influence ragweed allergy in the future. By 2041–2060, ozone pollution levels across Europe are projected to decrease [23], which may reduce the allergenicity of ragweed pollen [24]. In contrast, ragweed pollen allergenicity might increase due to elevated atmospheric CO₂ levels and intensified drought conditions. Including variations in allergenicity is a priority for forthcoming research [25, 26]. By 2041–2060, the median age of the European population is expected to rise from 38 to 52 years [1] and ragweed allergy is more difficult to manage in older populations because of challenges in diagnosis and limited treatment options stemming from comorbidities and ongoing medication use [27].

Future demographic changes in Europe suggest smaller effects in countries with declining populations, such as Germany, Poland and Romania, and greater impacts in countries with growing populations like France and the United Kingdom [1]. Proper management and use of medication can significantly alleviate allergy symptoms [28]. Such management may also be economically advantageous; thus, the overall effect of rising ragweed allergy will depend on the adaptive capacities of individuals and healthcare systems across Europe. It has been claimed that the ability of healthcare systems to adjust to climate change will rely on the development trajectories chosen by individual countries [29].

SUMMARY

Climate change has significant effects related to environmental pollution and the development of hypersensitivity and pollen allergies. This leads to an increase in pollen production and changes in their characteristics that enhance their allergenic potential. Due to the effects of climate change in the future, plant growth may be altered so that newly produced pollens are modified and impact human health. As a result, an increase in the occurrence of allergic diseases caused by pollens is anticipated in the medium and long-term. Educating the public and implementing governmental policies to prevent environmental pollution and climate change are actions urgently needed worldwide. Adaptation and mitigation strategies can be implemented to reduce the effects of climate change on pollution caused by chemical agents, pollen, and moulds.

Mitigation targets the causes of climate change, while adaptation addresses its impacts. However, adaptation alone will not be sufficient to eliminate all adverse effects, making mitigation essential to limit changes in the climate system. Extreme weather events, such as thunderstorms, can trigger asthma attacks that have significant socio-economic consequences. Patients with pollen allergies should be informed about the risk of asthma exacerbations and specifically warned about the dangers of being outdoors without proper treatment for their chronic rhinitis and asthma during thunderstorms or pollen seasons.

CONCLUSIONS

- Climate change leads to earlier onset, longer duration, and increased intensity of pollen seasons due to higher temperatures and elevated CO₂.
- Increased CO₂ heightens allergen protein expression in pollen, exacerbating allergic responses.
- Ragweed sensitization is projected to more than double in Europe by 2041–2060, driven by northward expansion and climate effects.
- Climate-related changes in pollen coincide with air pollution and urbanization, further worsening allergic respiratory diseases.
- The ability of healthcare systems to adapt to climate change will influence future allergy burden outcomes.
- Effective management and public health strategies are crucial for mitigating the growing impact of allergies linked to climate change.

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