International Journal of Genetic Engineering 2025, 13(6): 133-137
DOI: 10.5923/j.ijge.20251306.10

Chronological Analysis of International Aeropalynological Research and Its Prospects for Development in Uzbekistan

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Abstract This article presents a comparative analysis of the stages of development in aeropalynological research and the study of allergenic anemophilous flora across various regions of the world, including North America, Europe, Russia, Asian countries, Australia, Africa, Central Asia, and Uzbekistan. Five main stages of scientific progress are identified — from initial botanical and floristic observations to the implementation of molecular and digital monitoring methods. It is established that countries in North America, Europe, and East Asia are global leaders in this field, with highly developed scientific and technical infrastructures. At the same time, countries in Central Asia, including Uzbekistan, are mostly at the second and third stages of development. Based on this analysis, the article emphasizes the need to modernize aeropalynological research in Uzbekistan through the adoption of advanced technologies and the expansion of international collaboration.

Keywords Aeropalynology, Anemophilous flora, Allergenic pollen, Stages of development, Molecular diagnostics, Digital monitoring, Uzbekistan, International experience, Pollen season forecasting

1. Introduction

Today, global issues such as climate change, environmental pollution, and the growing prevalence of allergic diseases pose serious threats to human health and ecological stability [1].

Pollinosis is an allergic disease caused by the body's sensitivity to airborne pollen. A significant portion of the population suffers from this condition. For example, in Russia, approximately 20–30% of the population is affected by pollinosis; in southern regions, this figure reaches 25–30%, and in the Krasnodar Krai, it exceeds 40% [2].

To ensure effective prevention, diagnosis, drug development, and treatment strategies for this disease, it is essential to study the anemophilous flora of each region, identify the taxonomy of plants producing allergenic pollen, analyze the phenology of their flowering, investigate the dynamics of airborne allergenic pollen concentrations, and conduct research at the molecular level.

Aeropalynology, the study of airborne plant pollen, is becoming an increasingly important field of research worldwide. It plays a significant role not only in the prevention of allergic diseases but also in disciplines such as agrometeorology, ecology, and urban planning [3,4].

Scientific studies in this field are being conducted on a large scale and with high technological support in countries such as the United States, Germany, France, Spain, Japan, Poland, India, and many others. Each country has established specific pollen monitoring systems tailored to its own climatic conditions and national needs. For instance, in European countries, the Pollen Monitoring Network operates; in Japan, there is an Aeroallergen Monitoring System; and in the United States, the National Allergy Bureau serves this function [5].

In these countries, the study of allergenic anemophilous flora and aeropalynological research has a long-standing scientific foundation and is carried out using high-tech equipment and advanced analytical methods. In Uzbekistan, this direction has only begun to emerge in recent years and still requires a comprehensive and systematic development approach.

This article analyzes studies on allergenic anemophilous flora and aeropalynological research conducted in various countries, highlighting both their commonalities and regional distinctions. The main focus is placed on identifying global development trends and scientific approaches in this field through a review of international experience. This analysis is intended to provide a scientific foundation for future research and the development of aeropalynology in emerging regions.

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Received: Jun. 12, 2025; Accepted: Jul. 8, 2025; Published: Jul. 11, 2025
Published online at http://journal.sapub.org/ijge

2. Materials and Methods

This article analyzes the chronological development of aeropalynological research worldwide. The geographical regions included in the study are: North America (primarily the United States), Europe (the United Kingdom, Germany, France, Poland, Spain, and others), Russia, Australia, Africa, as well as Asia (Japan, China, India) and the countries of Central Asia.

The sources of data included monographs and reports from pollen monitoring centers and agencies, as well as scientific articles published over the last 125 years that are indexed in databases such as Scopus, Web of Science (WoS), and PubMed.

The research methodology was based on the following approaches:

Chronological analysis — scientific achievements in each region, from the earliest studies of allergenic anemophilous flora and aeropalynology to the present, were systematically classified.

Comparative analysis — methodological, technological, and organizational aspects were examined and compared across regions.

Scientific data for each region were collected and analyzed in chronological order, based on the date of the initial study, the methodology employed, the equipment used, key findings, as well as the achievements and limitations encountered. The duration of developmental stages in each region was also evaluated.

3. Results and Discussion

During the study, scientific articles indexed in Scopus, Web of Science, and PubMed databases for the period from 1900 to 2025 were reviewed, along with monographs and reports from pollen monitoring centers and agencies [32].

As a result of the chronological analysis, the following developmental stages of research on allergenic anemophilous flora and aeropalynology were identified in countries of North America, Europe, Russia, Australia, Africa, Asia, and Central Asia:

Stage I – Initial Phase: Characterized by the study of anemophilous flora and the identification of correlations between allergenic wind-pollinated plants and allergic diseases.

Stage II – Period of Systematic Research: Involving basic pollen collection, identification, seasonal distribution analysis of allergenic pollen, and determination of major allergens.

Stage III – Phase of Intensive Research: Marked by active pollen capture using traps, publication of pollen atlases, and application of immunological methods.

Stage IV – Expansion and Geographic Growth: Integration of molecular biology methods with Stage III approaches and the beginning of international scientific collaboration.

Stage V – Modern Methods and Innovations: Development of digital monitoring systems and predictive modeling techniques.

North America (USA) is recognized as a leading region in aeropalynological research [6].

The first stage began in the 1910s, followed by the second stage in the 1930s–1950s [7,8], and the third stage during the 1950s–1980s [9].

The fourth and fifth stages have rapidly evolved from the late 20th century into the early 21st century. Today, the USA has achieved significant technological progress in the field, including molecular-level allergen diagnostics, digital monitoring, real-time forecasting models, and AI-based systems for aerobiological applications [10,11].

In European countries, the first stage began in the 1920s [12]. The second stage started around the 1950s, while stages II and III were significantly intensified during the 1960s–1980s [13].

After 1990, the fourth stage was introduced, marked by the publication of annual pollen atlases in many countries [14]. Since 2000, digital monitoring systems and forecasting technologies have been implemented, marking the onset of the fifth stage of development.

In Russia, initial observations and the compilation of lists of anemophilous flora (Stage I) were conducted during the 1930s–1950s [15]. Microscopic analyses in laboratory conditions and local aerobiological monitoring (Stages II–III) were carried out during the 1950s–1980s [16].

Table 1. Distribution of countries by chronological stages of development of aeropallinology

Countries	1900-1930	1930-1950	1950-1980	1980-1990	1990-2010	2010 - present
North America	I	II	III	IV	IV-V	IV-V
Europe	I	I-II	II-III	III	IV-V	IV -V
Russia	-	I	I-II-III	I-II-III	III-IV	IV-V
East Asia	-	-	I-II	III-IV	III-IV-V	IV-V
Australia	-	-	I-II	III-IV	III-IV	IV-V
Africa	-	-	I	I-II	I-II-III	II-III
Kazakhstan, Kyrgyzstan	-	-	I	I-II	I-II	III-IV
Uzbekistan	-	-	I	I-II	I-II	I-II-III

These stages expanded in the 1980s–1990s, with experimental application of immunological methods in certain regions. Molecular studies and computer-based monitoring were introduced — albeit in a limited scope — between the 1990s and 2010s (Stages III–IV–V). The fourth stage has been under development since 2010, and Stage V has been progressing from 2020 to the present; however, methodological limitations remain in several regions [17,18].

In Asian countries, including Japan, China, and India, Stage I began in the 1950s, based on foundational floristic research [19].

Stage II started in the 1970s, focusing on the phenological analysis of flowering in anemophilous plants and the seasonal dynamics of airborne allergenic pollen. Stage III began in the 1990s, incorporating molecular and immunological methods [20].

From 2000 to the present, Stage IV has gradually transitioned to the use of AI-based monitoring systems and predictive modeling technologies (Stage V) [21].

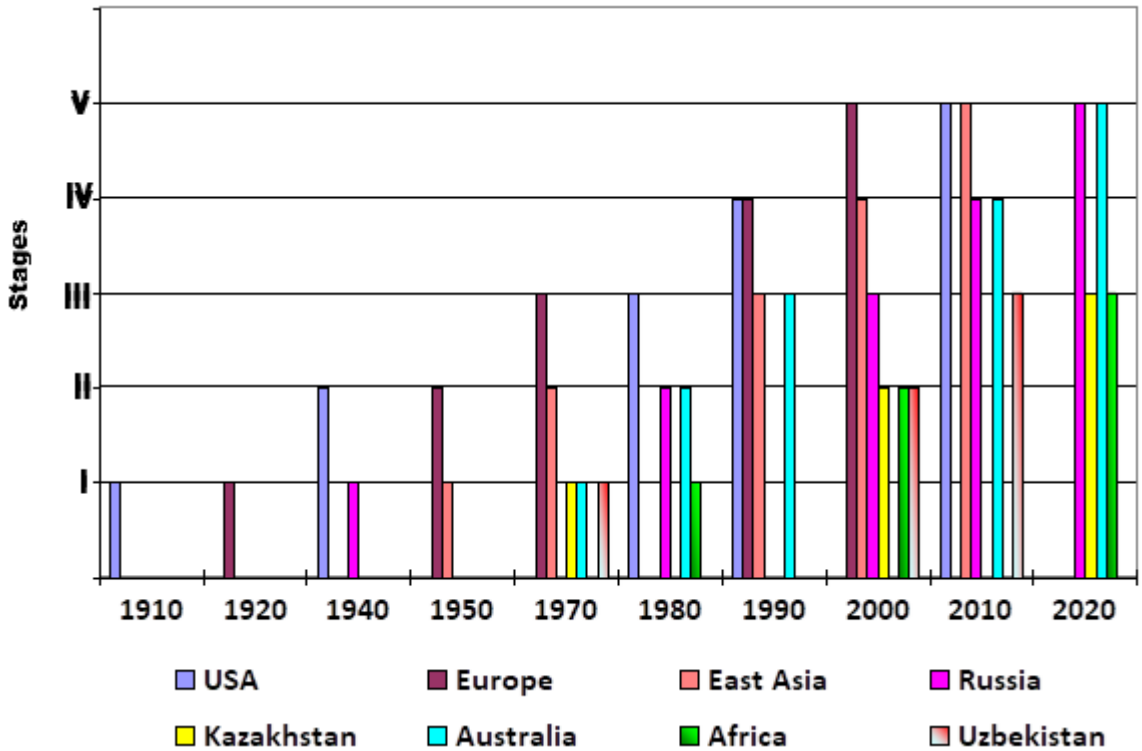
In Japan and China, systems for identifying allergenic plants and conducting regional monitoring based on molecular techniques are currently in place [20].

Research in Australia and Africa began relatively late [22,23]. While Australia is approaching Stage V [24,25], most parts of Africa remain in Stages II–III [26]. The main challenges include the lack of qualified specialists, technical infrastructure, and stable monitoring systems.

In Kazakhstan, Stage I research was conducted between the 1950s and 1980s, based on foundational botanical investigations. In the 1990s–2010s, Stage II studies focusing on seasonal allergen monitoring were established. Stage III began in the 2000s, with the development of modern laboratories and the initiation of publications in international journals [27]. Currently, some studies are being carried out using molecular and immunological methods.

The study of anemophilous flora and allergenic plants in Uzbekistan is currently at Stages I–II–III [28,29]. Although aeropalynological monitoring is carried out in some major cities (e.g., Tashkent, Samarkand), technical and organizational capabilities for transitioning to Stages IV–V remain limited. However, scientific activity has intensified in recent years.

The results of the study revealed that the stages of development in the field of aeropalynology vary significantly across regions. North America, especially the United States, stands out as a region that has made rapid progress in this area (see figure 1). Since the 20th century, specialized studies have been conducted there, and today advanced molecular biology methods and digital monitoring systems are widely used. The scientific infrastructure, laboratories, and international collaborations in this region are very well developed.



I – Stage I: Initial studies of allergenic anemophilous flora (link between flora and allergic diseases).
II – Stage II: Pollen collection, identification, and seasonal analysis.
III – Stage III: Pollen atlases, immunological analyses, and laboratory methods.
IV – Stage IV: Molecular biology, genetic research, and international collaboration.
V – Stage V: Digital monitoring, AI-based forecasting models, and real-time data systems.

Figure 1. Development of Aeropalynological Research: Global Perspective and the Position of Uzbekistan

In European countries, systematic work on the identification and monitoring of anemophilous flora has been carried out since the 1920s. Aeropalynological research in Europe was also systematized in the mid-20th century, and over the past 30 years, significant progress has been made in the implementation of molecular and digital technologies. The stages of development in Europe and North America are similar, and they have influenced each other through international scientific exchange and technology transfer.

Aeropalynological studies in Russia and the Central Asian countries (especially Kazakhstan and Kyrgyzstan) have been actively conducted since the 1950s. However, their scientific development occurred later and has been somewhat more limited compared to North America and Europe. While molecular methods and international collaboration have been actively utilized in Russia since the 1990s, certain local challenges and a lack of resources have slowed the scientific progress. In Central Asian countries, although research is developing rapidly, digital monitoring and high-tech solutions have yet to be widely implemented.

Aeropalynological research in East Asia (Japan, China) and India began in the 1950s, and since the 1990s, advanced technologies—including molecular biology and immunology—have been actively applied. In recent years, China, Japan, and South Korea have implemented digital monitoring and forecasting systems, positioning the region among the global leaders in this field.

In Australia and Africa, aeropalynological studies developed relatively late, and in Africa in particular, research in this area remains limited. While Australia began its investigations in the 1970s, Africa has seen a surge in activity over the past 30 years. Efforts are also underway in these regions to adopt molecular and digital technologies.

Aeropalynological research in Uzbekistan began in the 1960s [30,31], but the systematization and expansion of scientific studies has become more evident in the past 20–30 years. This delay can be attributed to the lack of scientific infrastructure, a shortage of qualified specialists, and limited access to essential equipment.

At the same time, opportunities for conducting modern and comprehensive research tailored to local climatic and geographical conditions are beginning to emerge. Based on global experience, a major priority for Uzbekistan is the advancement of high technologies in aeropalynology, particularly molecular diagnostics, digital monitoring systems, and international collaboration. This will not only strengthen the country's scientific capacity, but also support the development of effective strategies for the prevention and treatment of allergic diseases.

4. Conclusions

The comparative analysis of the stages of development in aeropalynological research and the study of allergenic anemophilous flora across various world regions has revealed a significant disparity in scientific progress. The leading regions in this field are North America (especially the United States), Europe, and East Asia (Japan, China, and Korea), where research spans all five stages of development — from the initial identification of allergenic plants to the implementation of molecular diagnostics, digital monitoring, and AI-based predictive models.

In Russia, Central Asia, and South Asia (e.g., India), a steady pace of scientific advancement is observed; however, the transition to high-tech approaches is still limited by infrastructural and human resource constraints. In Africa and parts of Central Asia, research remains predominantly at the second and third stages, despite a recent surge in scientific activity.

In Uzbekistan, aeropalynological research began as early as the mid-20th century, but systematic organization and scientific development have only gained momentum over the past two decades. Given the current climate challenges and the increasing prevalence of allergic diseases, Uzbekistan's priority tasks include strengthening its scientific research base, adopting molecular techniques, implementing digital monitoring systems, and fostering international collaboration. These steps will enhance the effectiveness of allergy diagnosis and prevention, and enable Uzbekistan to integrate into the global scientific community in the field of aerobiology.

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