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Review Article

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Human Exposure to Air Pollution by Particulate Matter, Aeroallergens (Common Ragweed) and Viruses (COVID-19)

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Abstract

Atmospheric air pollution, according to the World Health Organization (WHO), can be caused either by changes in the values of air components, or by the presence of various natural compounds not normally found among air components, or by anthropogenic influence, including particulate matter [PM], in particular [$PM_{2,5}$]/[PM_{10}]. Results from the literature, published in recent years, have demonstrated the link between air pollution with particulate matter and increased allergenicity of some plants (common ragweed), and also the link with the spread of some viruses (SARS-CoV-2). There are results of studies which consider that particulate matter, constantly present in the atmospheric air, in values which may or may not exceed the maximum permissible concentration (MAC), can act as a source of aeroallergens (common ragweed) and viruses (SARS-CoV-2). The size of respirable particulate matter [PM_{10}] and, in particular by their composition, [$PM_{2,5}$] are considered to be the most aggressive at alveolar level. However, larger sedimentable particles, once deposited at ground level, are also considered to have a direct relationship with the spread of aero-allergens and viruses, depending on the degree of atmospheric air pollution and climatic conditions (e.g. radiation inversions). In addition, climate change, through the steady increase in atmospheric air temperature in recent decades, changes in air humidity, changes in wind direction and speed, increased concentration of [CO_2], leads to a long-range spread of respirable and sedimentable particulate in the environment. Thus, it is considered that both short- and long-term exposure of the population to [PM] may be associated with reduced resistance to infection in exposed individuals. This research aimed to identify a possible association between [PM] air pollution, aeroallergens (common ragweed) and viruses (SARS-CoV-2). The research method used was a systematic review of literature, scientific databases. Both studies that considered a direct, important link in terms of the role of particulate matter in the spread of aeroallergens and viruses under the influence of climate change and studies that did not demonstrate a link between them were identified. The results obtained from the selected studies underlying this research are important both in terms of identifying long-term population exposure to air pollution by respirable and sedimentable [PM], which can have a significant impact on human health, at lung, cardiovascular and gastrointestinal levels, and in terms of exposure at certain times of the year to significant amounts of aeroallergens and viruses (SARS-CoV-2), when the aeroallergen season precedes/overlaps the influenza season.

Keywords: Air Pollution, Particulate Matter (Respirable, Sedimentable); Aeroallergens; Common Ragweed; Viruses; SARS-CoV-2; COVID-19.

1. Introduction

In the last decade, in Europe, the change in atmospheric air quality through pollution, natural and/or anthropogenic, is considered to pose the greatest risk to human health, through the variety of adverse effects that can occur in either short-term or long-term exposures: respiratory diseases (from respiratory infections to chronic obstructive pulmonary disease), allergic respiratory or dermatological diseases (allergic rhinitis, bronchial asthma, atopic dermatitis), ischaemic heart disease, inflammatory digestive diseases, diabetes mellitus and obesity, etc., which are on the increase worldwide. (M. De Sario et al., Parry ML et al.).

The World Health Organization considers air pollution by particulate matter [$PM_{2,5}$]/[PM_{10}] to be the most serious urban air pollution problem (in particular). There are epidemiological studies and WHO reports that mainly associate exposure to [$PM_{2,5}$], and less exposure to [PM_{10}], with increased morbidity and mortality from lung and cardiovascular diseases.

Climate change in recent decades, through continuous and constant increase in temperature, changes in seasons and the presence of heat waves, alternating periods of increased rainfall and periods of severe drought, accompanied by changes in air humidity, changes in wind speed, as well as changes in CO_2 concentrations, etc., together with atmospheric air pollution with [$PM_{2,5}$]/[PM_{10}], contribute to the more rapid growth of aeroallergenic plants, increased intensity, flowering time and pollen potency of these plants, as well as the long-distance spread of aeroallergenic plant pollen (common ragweed). Thus, for an increasing number of people, pollens are having a significant negative impact on human health through the development or exacerbation of allergic respiratory diseases (allergic rhinitis, bronchial asthma).

Several epidemiological studies carried out in recent years, from 2020 to the present, have assessed the link between air pollution with particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] and the incidence and severity of infectious respiratory diseases, including the new SARS-CoV-2 coronavirus (responsible for the appearance, symptoms and severity of COVID-19), trying to correlate the increase in the spread of the virus (SARS-CoV-2) with an increased number of confirmed cases.

The current research aimed to determine - through a study of the literature - the associations between atmospheric air pollution with particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] and soil pollution with sedimentable particles, aeroallergenic plant pollens (common ragweed), viruses (SARS-CoV-2) and exposure of people living in urban areas, where the incidence of respiratory allergic and viral diseases is thought to be increased (compared to lower incidence in rural areas) under climate change (considered as a co-factor for the occurrence and spread of respiratory allergic diseases as well as respiratory viral diseases).

The possible combined influence of all these factors on human health, through pulmonary, cardiovascular and gastrointestinal effects, is a public health concern. These, once identified, could be associated with clinical measures, accompanied by appropriate treatment by health professionals. On the other hand, at local and regional level, urgent measures to improve air quality by reducing particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] pollution and measures to reduce the number of people exposed to aeroallergenic plant pollen and viral diseases, such as COVID-19, are important.

2. Materials and Methods

In our research, we used a thorough systematic review of the available scientific literature/databases according to the PRISMA-ScR - Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, meaning books and scientific articles.

We conducted searches and they were analysed: ELSEVIER (Environmental Pollution, Environmental Research, Sustainable Cities and Society) and PubMed databases, The Allergy Asthma Immunology Journal, The European Respiratory Journal, The Atmosphere Journal (MDPi), The Microorganism Journal (MDPi), The International Journal of Environmental Research and Public Health (MDPi), The Paediatria Journal, The Chinese Medical Journal 2020, The Science Advances Journal, The Lancet Regional Health Europe, The European Journal of Inflammation, The British Medical Journal (BMJ) - Nutrition, Prevention and Health, The European Parliamentary Research Service (EPRS) - The Scientific Foresight Unit (STOA), The Proceedings of the National Academy of Sciences of the United States of America (PNAS or PNAS USA), The Allergologia et Immunopathologia, The Journal of Health Inequality, The World Allergy Organization Journal, The Georgian Medical News.

In the selection of the studies, which were the basis of our research, we used the recommendations of the PRISMA-ScR Guidelines, which were useful, helpful and guided us in the smooth conduct of our research and in achieving results in line with the purpose of the research. To carry out this work, we used the following key search terms: atmospheric air pollution, particulate matter (airborne respirable, sedimentable); aeroallergens; common ragweed; viruses; SARS-CoV-2; COVID-19 and we considered only those scientific articles and books that had a direct link with the proposed purpose of the research.

The information, which we subsequently used as references for research design, was selected based on responses to several questions (used as inclusion criteria): (Q_1) does air pollution with particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] correlate with an increase and spread of aeroallergens (common ragweed) and higher rates of viral infection (SARS-CoV-2)? (Q_2) Does atmospheric air pollution with particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] and soil pollution with sedimentable particles correlate with an increase in the spread of viruses (SARS-CoV-2) and higher rates of confirmed cases? (Q_3) is there a correlation between air pollution with particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}], airborne pollen concentration (co-risk factor) and higher rates of viral infection (SARS-CoV-2)? (Q_4) are there additional environmental factors (co-risk factors) that may influence the concentration and spread of environmental pollen (common ragweed) and viral infection (SARS-CoV-2)?

We chose as inclusion criteria all available epidemiological studies that aimed to identify any temporal and spatial association with the proposed aims, following the use of the question set. The information selected as reference was subject to further assessment, both qualitatively and in terms of its relevance to the development of this paper, before being used in this research. Finally, we only used articles that we considered relevant and that answered, even partially, the 4 control questions. All those articles that we did not consider to be directly related to our research were excluded.

The database search found 90 scientific articles and books, a large part published in the last 4 years, from 2020 - the year of the COVID-19 pandemic to the present, from which we selected both general information on air pollution with particulate matter, aeroallergens (common ragweed) and viruses (SARS-CoV-2) and specific, quantifiable information that answered our set of questions.

Of these, a subset comprising 62 scientific articles and books was used as a reference based on the inclusion criteria. Note that we eliminated, after the first selection stage, all duplicate studies.

Subsequently, a checklist was useful in assessing the quality of the documents. This checklist included questions to assess the quality of the selected documents as well as simple answers: (Q_1) the selected document contains information on air pollution with particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}], and aeroallergens (common ragweed): (+1) yes/(+0) no; (Q_2) the selected document contains information on air pollution with particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}], and/or soil pollution with sedimentable [PM] and the spread of viruses (SARS-CoV-2): (+1) yes/(+0) no; (Q_3) the document specifies a correlation between increased concentrations of particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}], airborne aeroallergenic plant pollen and higher rates of viral infection (SARS-CoV-2): (+1) yes/(+0) no; (Q_4) the document describes, even partially, additional environmental factors (co-risk factors) and their influence on the concentration and spread of pollen (common ragweed) and viral infection (SARS-CoV-2): (+1) yes/(+0) no.

Figure no. 1. contains a summary description of the steps we followed to select the information from the databases, following the flow chart according to PRISMA 2020[15] . The description includes, in turn: the initial step - selection, the screening step, the eligibility step of the documents and the final step - the final selection.

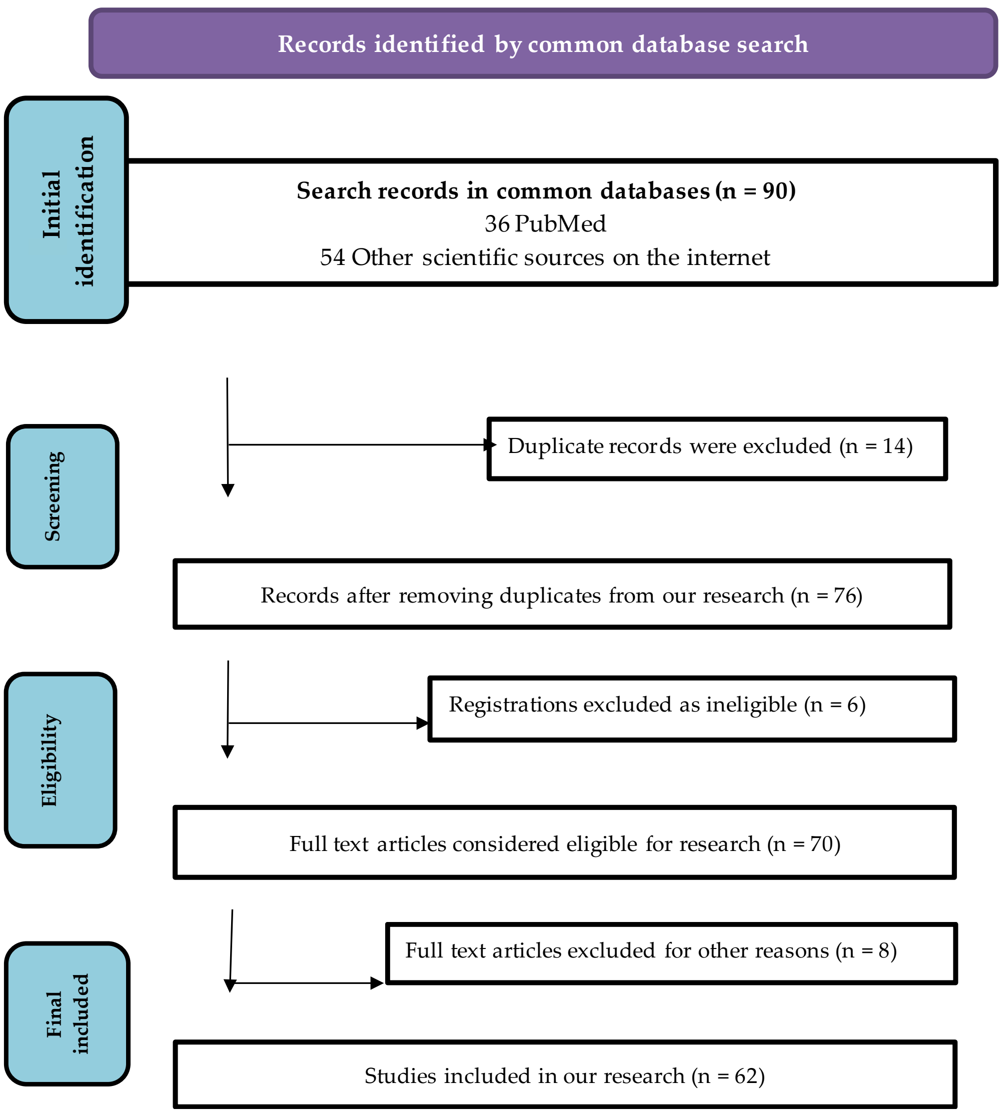

Figure 1. Search, Identification, Screening, Eligibility and Selection in Scientific Databases

Results and discussions

General information about matter particles and their effects on the human body

Particulate matter [PM] is considered to be a mixture of several pollutants; basically, it consists of liquid droplets, dry solid fragments and solid nuclei (inert carbonate core) with liquid shells. Particulate matter have different origin, size, shape and chemical composition. Depending on the particle size - diameter (Ø), there are several classifications in the literature, of which the best known is the Gibbs classification (classical): a) [PM] with Ø >10 μm (Ø between 100 and 10 μm), referred to as sedimentable [PM], which due to their large size settle on surfaces (soil, vegetation, water, streets, buildings, etc.) and permeate environmental factors, are nuisances and, in particular, have a global ecological impact; (b) [PM] with Ø between 0,1 and 10 μm, referred to as suspended [PM], which diffuse into the air and, due to their very small size, are moved by air currents over long distances; these airborne respirable [PM] reach and are retained at different levels in the respiratory tree, depending on their diameter; of these, the most aggressive at alveolar level is considered to be respirable [PM] with Ø ≤ 2.5 μm [$PM_{2,5}$], which have a different composition, with a higher content of water and acid radicals (sulphates, nitrates), as well as heavy metals, organic compounds, inorganic ions, elemental carbon; they may also include: plant pollen, viruses, bacteria, endotoxins, mycotoxins, mite debris, mould spores, etc; c) [PM] with Ø < 0.1 μm (Ø between 0.1 and 0.001 μm), which have Brownian movements, move by collision, diffuse a lot and do not sediment in still air, are respirable and reach the alveolar level, but are mostly eliminated with the exhaled air from the lung.

Long-term exposure to particulate matter is expected to be accompanied by significant adverse effects on human health. Because of their reactivity and toxic potential, their ability to reach the human body up to the level of different organs, even at the mitochondrial level, where they bring significant amounts of potentially inflammatory and allergenic toxins, [PM] are considered to be a cause for concern for human health effects. Epidemiological studies, conducted over time, have shown that respirable particles have an effect on the respiratory (mainly), cardiovascular and digestive systems.

At the respiratory level, environmental pollution by particulate matter acts on the ground already sensitised by endogenous factors and favours the development of pulmonary (bronchial) pathology. In hyper-reactive, sensitised individuals, pollen-scented particulate matter can favour the onset of allergic rhinitis and bronchial asthma; it can increase the reactivity of asthmatic patients to the action of allergenic pollutants, to which they are highly sensitive.

In the cardiovascular system, environmental pollution by particulate matter acts and can induce cardiac conduction and repolarisation disorders, with heart rhythm disturbances; pulmonary and systemic inflammation, with aggravation of atherosclerosis. Results of epidemiological studies have shown that exposure to [PM] with Ø between 0.1 and 10 μm (in particular, [$PM_{2,5}$] by their particular chemical structure) can lead to increased respiratory and cardiovascular morbidity and mortality.

A number of epidemiological studies in recent years have shown that exposure to a particulate matter polluted environment may also be associated with an increased incidence of inflammatory bowel disease (IBD). It is considered that particulate matter can reach the intestinal tract via several pathways: (1) respirable [PM], with Ø between 0.1 and 10 μm, after inhalation and passage into the bloodstream or via mucociliary transport, which clears them from the lungs after reaching the alveolar level during respiration, (2) sedimentable [PM], with Ø between 100 and 10 μm, after ingestion of contaminated food and water. Once in the gut, they are thought to alter the gut microbiota, inducing acute and chronic inflammatory reactions in the gut.

The results of an epidemiological study showed that there are seasonal differences in the airborne presence of certain particulate matter airborne respirable: [$PM_{2,5}$] increases in winter and decreases in summer; [PM_{10}] increases in winter and spring and decreases in summer and autumn. According to the authors of this study, the association between increased average daily concentrations for [$PM_{2,5}$]/[PM_{10}]. and the high number of total new daily cases during the 2nd, 4th and 5th wave of COVID-19 (in a European capital such as Bucharest) has been demonstrated, proving the harmful effects of particulate matter airborne respirable [$PM_{2,5}$]/ [PM_{10}] on the incidence and lethality of COVID-19.

The European Environment Agency reported in its *"Air quality in Europe - 2022 report"* that the majority of urban dwellers in Europe were exposed in 2020 to concentrations of particulate matter airborne respirable ticles with Ø ≤ 2.5μ [$PM_{2,5}$] and Ø ≤ 10μ [PM_{10}] with increased values above the WHO recommended maximum allowable concentrations, although following the COVID-19 pandemic, through lock-down, the value of particulate matter airborne respirable decreased over certain periods of time.

"In 2020 in the European Union, 96% of the urban population was exposed to levels of fine particulate matter above the health-based guideline level set by the World Health Organization. In 2020, exposure to concentrations of fine particulate matter above the 2021 World Health Organization guideline level resulted in 238,000 premature deaths in the EU-27. Air pollution also causes morbidity, whereby people live with disease - entailing both personal suffering and significant health care costs." (https://www.eea.europa.eu/publications/air-quality-in-europe-2022

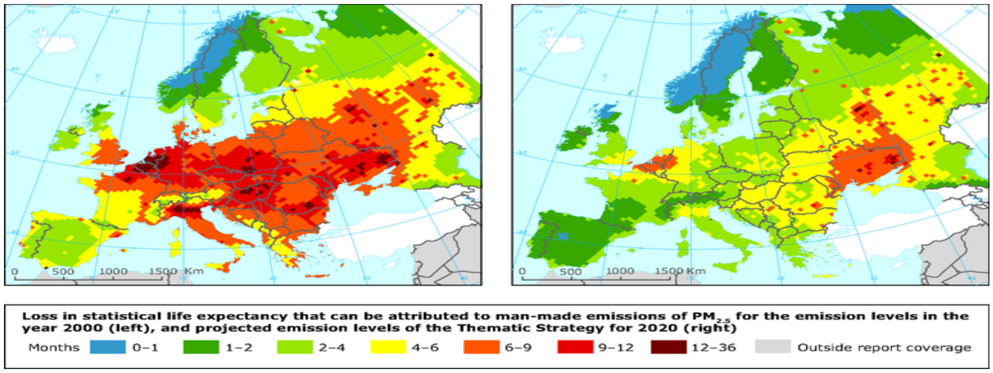

Figure 2: *Loss in statistical life expectancy that can be attributed to man-made emissions of $PM_{2,5}$ for the emission levels in the year 2020 (left), and projected levels of the Thematic Strategy for 2020 (right)*

General information about ragweed and its effects on the human body

Common ragweed is an annual plant, which under the influence of atmospheric pollution and climate change can produce large and important quantities of pollen - between 3 000 and 6 000 seeds on a single plant. The pollination period of common ragweed peaks in August-September, but the pollination season can start earlier (May/June) and last longer (October/November).

In recent years, climatic changes, with rising temperatures and decreasing air humidity (hot and dry summers), as well as strong winds, have been favourable for the long-distance spread of the weed's pollen. According to epidemiological studies in recent years: *"a concentration of suspended pollen <30 pollen grains/m³ of air is considered sufficient to induce an allergic reaction; highly sensitive individuals may also experience symptoms from as little as 1-2 pollen grains/m³ of air"*. (Pearce N et al, D'Amato G et al).

Research in recent years has demonstrated a direct link between particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}], which can contain and carry pollen grains, as well as other allergen-carrying plant particles and mould spores, and the spread of aeroallergenic plant pollen (common ragweed) (Alberto González Ortiz et al, Kuan-Wei Chen et al).

Pollen grains generally belong to the coarse fraction of particulate matter airborne respirable (Ø ≤ 10µm [PM_{10}]). However, there are also fragments of pollen grains that are found in respirable airborne particles with Ø ≤ 2.5µm, [$PM_{2,5}$]. Particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] once inhaled, can penetrate deep into the respiratory tract, down into the lower airways, into the alveolar regions of the lungs, and cause the onset or aggravation of allergic respiratory diseases (bronchial asthma) (Kuan-Wei Chen et al, Sarah Cunze et al., Essl F).

On the other hand, a causal link has also been demonstrated between short- and long-term exposure to sedimentary particulate matter pollution at elevated ground-level concentrations associated with the presence of particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] in the air and the occurrence of seasonal respiratory diseases, as well as exacerbation of respiratory system symptoms, through inflammation of the upper and lower airways, decreased lung function and respiratory symptoms (allergic rhinitis, bronchial asthma, seasonal influenza, viral diseases - such as COVID-19, severe acute respiratory syndrome, etc.).

Zoran M. et al, Romania, 2023, considers that environmental conditions were also associated with the aggravation or worsening of symptoms: local or regional weather conditions, sometimes only seasonal (heavy rains, strong winds, changes in air humidity associated with high temperatures), but also conditions related to human health: immune system damage, comorbidities, age.

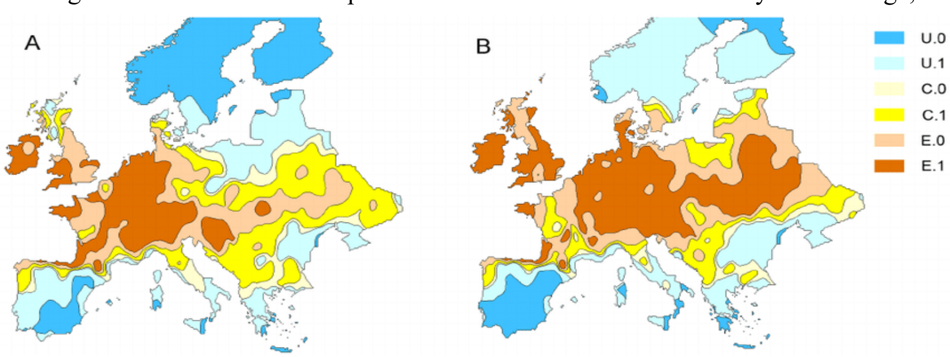

Figure 3: *Distribution of Ambrosia artemisiifolia (common ragweed) in Europe under climate change as predicted by the process based model. A. Using HadCM3 (A1B) scenarios for near future 2010-2030 and B. long-term future 2050-2070. The categories are: U.0 - highly unsuitable, U.1 - unsuitable, C.0 - casual (less likely), C.1 - casual, E.0 - established, E.1 - well established. doi:10.1371/journal.pone.0088156.g003.*

General information about SARS-CoV-2 and effects on the human body

SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2), considered a new type of coronavirus, initially (in December 2019) caused an outbreak of pneumonia in China (Wuhan, Hubei province), named COVID-19 disease. A few months later, in spring 2020 (11th of March 2020), WHO declared COVID-19 disease a pandemic.

The most common current symptoms of Covid-19 disease were considered: fever, dry cough, fatigue. Other less common symptoms are: loss of taste and smell, conjunctivitis nasal congestion, headache, myalgia, nausea, vomiting, diarrhea, chills, dizziness, decreased or loss of appetite, confusion, persistent pain or chest pressure, increased temperature (>38°C). Other rare symptoms: irritability, confusion, impaired consciousness associated with seizures, anxiety, depression, sleep disturbances, neurological complications - strokes, encephalitis, delirium and neuronal damage. In severe forms: respiratory failure, multiple organ failure, acute respiratory distress syndrome (ARDS), pneumonia and death have been described. (Huang et al, 2020, Jiang at al, 2020).

The spike protein of SARS-CoV-2 is thought to have hydrophobic properties and thus COVID-19 viral infection would mainly be transmitted from person to person via close contact (~2 meters), via respirable virus-laden aerosol particles in the air with Ø < 5 µm (https://www.who.int/), via direct contact with SARS-CoV-2 infected persons, via the fecal-oral route etc (Zoran M. et al, 2023).

Role of aeroallergenic plant pollen in the risk of SARS-CoV-2 viral infection

There are several hypotheses that have been considered regarding a possible role of aeroallergenic plant pollen (such as common ragweed) on the risk of viral infections (in our case, the new SARS-CoV-2 coronavirus, which caused the COVID-19 pandemic). Since 2020, so far, meta-analyses and clinical trials have been published with completely different results and conclusions: pollen may increase, polen may decrease or polen may have no effect on the risk of viral infection.

However, before discussing these issues in turn, it is important to discuss the type and dispersal of aeroallergenic plant pollen and the viruses that may attach to them. Damialis et al. - Germany, 2020 concluded *"the observed correlation between airborne pollen and infections did not depend on the allergenic nature of the pollen types present in the air during the study period."* Both: their physical transport over short distances and especially over long distances under the influence of atmospheric factors (air temperature and humidity, wind speed and direction, sunlight, increased CO2 concentration, etc.) and possible changes concerning the biological effectiveness of pollen-virus particles during the dispersion period are considered important.

Visez et al., 2020, following different results on the role of aeroallergenic plant pollen (such as common ragweed) on the risk of viral infection, investigated whether the type of plant pollen is important and whether or not it can affect virus attachment to the pollen grain. The amount of virus that can attach to a single pollen grain was also investigated, with a subsequent effect on the risk of viral infection. The viability and viral load required for the transfer of viral infection are also considered important. There are researchers (Solomon et al., 2002) who believe that *"particles adhering to pollen grains could interact with aeroallergens and absorb proteins from pollen grains, thus favouring their dispersion into the respirable fraction of particles in the atmospheric air"*.

In experimental studies, conducted over the last 4 years and over time (Santarpia, Rivera et al., 2020, Singh et al., 2010, Van Doremalen, Bushmaker et al., 2020, Chen et al., 2020a,b), pollen particle-virus association has been examined, considering the possible presence of virus inside the pollen grain (where it can penetrate) or considering the possible binding of virus to the outer surface of the pollen grain, where viruses can remain lodged and persist in the atmospheric air.

Researchers have shown that a virus can survive in respirable aerosol particles in the air for several hours (~3 hours) and on their surface for up to several days, while retaining its infectious potential. Thus, it is demonstrated that viruses can spread through the air from the source (droplets evaporate rapidly and remain in suspension, and can disperse into the air; they can contain microorganisms - including viruses from infected people, dissolved in mucus). It has been found that droplets formed, containing virus, can travel up to 10 meters at concentrations of $[PM_{2,5}] < 20$ µg/m³ of air.

It is believed that viruses can be transported by particulate matter airborne respirable, together with pollen grains, under climatic conditions that favour this, over shorter or longer distances. However, during transport, the pollen grain may undergo physical and biochemical changes. Essl F et al., 2015 concluded that *"under the influence of harsh environmental conditions (e.g. very low temperatures and sunlight, including UV radiation) the viability of pollenvirus particles can be greatly reduced and the time they persist in the environment can be reduced, limiting the distances they can reach in a viable state so as to transmit respiratory diseases"*.

The WHO, as far back as 2014, defines the airborne pathway of viruses as *"the spread of an infectious agent caused by the release of droplet nuclei which, if suspended in the air, remain infected over a long distance and time."*

Some researchers have examined the association between pollen-virus particles and their long-distance transport/dispersion, which is thought to be the way both allergic respiratory diseases and viral respiratory diseases spread more rapidly. In an epidemiological study by Selcuk, Gormus and Guven - Turkey, 2021 the potential impact of wind pressure and wind speed (by changing local and regional patterns) and wind direction on the spread of COVID-19 was examined; the results of the study reported a positive correlation between the rapid spread of SARS-CoV-2 coronavirus, increased number of new cases and transmission rates of COVID-19 in crowded urban areas and wind speed/direction. It is therefore possible that changing wind speed/direction may act as a co-factor in the spread of pollen-virus particles, with pollen acting as a carrier for viruses (including SARS-CoV-2 coronavirus). Ahmadi et al. - Iran, 2020 conducted a similar study and obtained the opposite results, finding no significant correlation between wind speed/direction and COVID-19 outbreak.

Change in atmospheric air quality by increasing [CO_2] concentrations (higher increases of [CO_2] are described in the literature in urban areas during daytime compared to rural areas), increase in air temperature (predominantly in urban areas, in urban areas compared to rural areas) has over time also been accompanied by changes in aeroallergenic plants (under the influence of [CO_2], they grow in a shorter period of time, have a different structure they are more vigorous and much taller, but are therefore also much more difficult to eradicate). The duration of pollen periods and pollen production also increases (by up to 115% in urban areas and 60% in rural areas by doubling the concentration of [CO_2]), but so does the allergen potency of the pollen in question (it increases in highly anthropised areas), leading to a significant increase in the severity and prevalence of allergic respiratory diseases (allergic rhinitis, bronchial asthma), particularly in urban areas.

According to studies, the increase in global average ambient air temperature over the earth's surface is thought to be directly related to increased plant allergenicity. In a warm and dry climate, under the influence of increased [CO_2] concentration, the pollen season starts earlier and the peak pollination periods move earlier in the calendar. It has also been found that in urban areas, aeroallergenic plants have an earlier flowering period by several days (on average 4 days) compared to the flowering period in rural areas. However, some researchers Ahmadi, Sharifi, Dorosti, Ghoushchi, & Ghanbari - Iran, 2020; Briz-Redo´n & Serrano-Aroca - Spain, 2020; Hoang & Tran - Korea, 2021; Iqbal et al - China, 2020; Shahzad et al. - China, 2020 did not show a consistent correlation between temperature increase and COVID-19 outbreaks in urban areas.

Studies carried out in recent years have shown a direct link between increased air humidity and precipitation (heavy rainfall), which contribute to increased proliferation of aeroallergenic plants (common ragweed), exacerbation of bronchial asthma attacks and hospitalisations. Low air humidity, associated with high temperatures, under the influence of winds, can act as a co-factor in the spread of pollen particles. However, in their studies, researchers Ahmadi et al. - Iran, 2020; Selcuk et al. - Turkey, 2021; Shi, Dong et al. - China, 2020; Shi, Gao et al. - China, 2020; Yuan et al. - China, 2020 did not show a consistent correlation between changes in air humidity and COVID-19 outbreaks in urban environments.

Selcuk et al., 2021, in Turkey, reported a positive correlation between rainfall (heavy rainfall) increased and SARS-CoV-2 coronavirus transmission, reporting an increase of 56 new cases of COVID-19 per day for each centimetre of rainfall per day. Another study, conducted in Italy, also reported a positive correlation between increased rainfall (heavy rainfall) and SARS-CoV-2 coronavirus transmission. However, two other studies by Ahmadi et al., 2020, in Iran, and Tosepu et al., 2020, in Indonesia, reported no significant correlation between new cases of COVID-19 per day and increased rainfall in the respective urban areas.

Researchers (Moriyama, Hugentobler and Iwasaki - USA, 2020) also observed that there is a seasonality in the occurrence of influenza epidemics, which was fully confirmed in the case of the COVID-19 epidemic: the first influenza wave produced by the SARS-CoV-2 coronavirus was of shorter duration, followed by several multi-seasonal waves. Thus, influenza circulation patterns had their onset and predominance during the winter in the northern hemisphere, migrating in spring (April-May) to the southern hemisphere; in autumn or the following winter returning to the northern hemisphere and then following the cycle described above.

Another important aspect to discuss is the human factor. In sensitised individuals with respiratory allergic diseases (allergic rhinitis, bronchial asthma), aeroallergenic plant pollen is considered to be the main trigger. In Europe, there are two peak seasons for pollen: spring (predominantly tree pollen) and autumn (predominantly weed pollen, such as common ragweed). According to retrospective analyses, published in 2019 and 2022, in European countries, the highest concentrations of common ragweed pollen are reported in Hungary, Romania, France (Rhône Valley region), Italy (north-western area of Milan and southern area of Varese), Germany, Switzerland, Austria, northern Portugal, Montenegro, Bosnia and Herzegovina, Croatia, Serbia, Slovenia, Slovakia, Greece, predominantly in urban areas. In all these European countries, the presence of high concentrations of aeroallergenic plant pollen is associated with an increase in respiratory allergic diseases (allergic rhinitis and bronchial asthma) in the exposed population and with an impairment of the quality of life of these patients. Allergic rhinitis may occur in childhood (and persist throughout life) or later in life (and be a co-factor of chronic respiratory diseases, including bronchial asthma).

In the context described above, a limited number of studies have looked at the effect of concurrent exposure to pollen and respiratory viruses. A number of studies have been conducted previously that have demonstrated a direct link between long-term exposure to air pollution and an increase in a person's susceptibility to respiratory viral infections.

The upper respiratory tract is the site of entry for pollen grains, which act from the nasal epithelium, where they inhibit anti-viral λ-IFN responses (15), but can also be a reservoir for viruses. Thus, it is considered that the effect of aeroallergenic plant pollen on upper airway epithelia may increase susceptibility to SRs-CoV-2 coronavirus infection.

The respiratory effect of pollen particles on the airway epithelium (upper and lower) occurs mainly through an inflammatory response (increased cytokine secretion, increased lymphocyte secretion, increased oxidative stress, increased levels of free radicals, increased production of reactive oxygen species at cellular level, infiltration of neutrophils, increased number of Th17 cells). Thus, through long-term (sometimes lifetime) exposure to air pollution and seasonal co-exposure (aeroallergenic plant pollen and atmospheric air pollution), the sensitivity and susceptibility of people with allergic respiratory diseases (allergic rhinitis and bronchial asthma) to respiratory viral infections increases, bronchial asthma may be triggered or exacerbated (in sensitised and non-sensitised individuals) and pre-existing respiratory symptoms may worsen. In addition, researchers have shown that respiratory tract damage following overexposure to air pollution can increase the activity of angiotensin-converting enzyme (ACE-2), which plays an important role in the colonisation of SARS-CoV-2 corornavirus in respiratory epithelial cells.

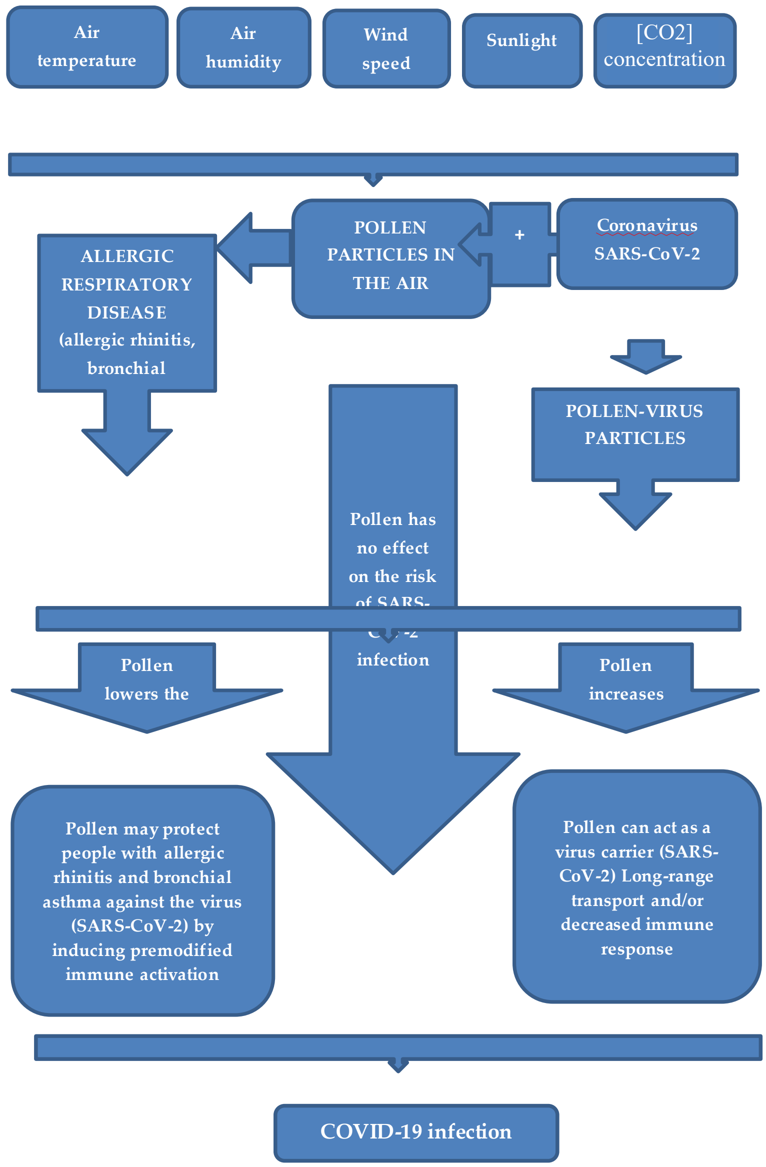

Figure 4: *Mode of action of airborne pollen-virus particles in the human body and determination of SARS-CoV-2 (COVID-19) coronavirus infection*

a) Aeroallergenic plant pollen may increase the risk of SARS-CoV-2 viral infection

In spring 2020, when the COVID-19 pandemic was announced worldwide, it was tree pollen season in the northern hemisphere. Based on the number of reported cases in those areas, the variability of infection rates from day to day and the total number of positive tests, a team of researchers from the Department of Medicine at the Technical University of Munich, Germany, led by Athanasos Damialis, investigated whether there could be a demonstrable causal relationship between the increased amounts of pollen in the air during that period and SARS-CoV-2 infestation, considering that *"pollen in the air weakens the immune response of the human body and can be a significant environmental factor influencing viral infection rates by acting as a carrier."*

Damialis et al. - Germany, 2020, used data from 5 continents, from 31 countries. The researchers concluded that *"airborne pollen can explain, on average, 44% of the variation in infection rates"*.

According to the results of the study, the variation in infection rates was also influenced by certain co-factors, such as weather conditions (change in air humidity associated with higher than average annual temperatures in the areas concerned). The types of isolation chosen in the countries included in the study (early isolation, late isolation, no isolation) were also monitored during the study. The team of researchers found that *"during the intervals without isolation regulations, infection rates were on average 4% higher per 100 grains of pollen/m³/day increase"*. They also studied the daily variability in the number of new cases diagnosed in some German cities, correlated with increases in pollen grains/m³/day and found that *"infection rates were 20% higher when there was an increase of up to 500 pollen grains/m³/day"*. The team of researchers concluded that when the concentration of pollen grains in the air increases and they become inhaled together with virus particles (in the form of pollen-virus particles), less antiviral interferons will be generated and the inflammatory response will be impaired, especially in people with allergies, allergic rhinitis or bronchial asthma, compared to people in an apparently healthy state. Thus, they cautiously concluded that *"environmental factors, which include pollen particles in the atmospheric air, may be responsible for some of the shift in the number of SARS-CoV-2 viral infections from spring 2020."* However, the results of the epidemiological study do not fully clarify the exact correlation between cause and effect, and the question remains as to the causal relationship between particulate matter airborne respirable and the increase in SARS-CoV-2 viral infections.

Hoogeveen et al. - The Netherlands, 2022 conducted similar research and investigated whether environmental conditions (including increased daily pollen concentrations, incidence of allergic rhinitis, increasing temperature, changing humidity, exposure to solar radiation, etc.) and mobility trends correlated with the seasonality of influenza illness could also explain the seasonality of COVID-19 in the Netherlands. In this study an average of 69.2 pollen grains/m3/day was considered, but daily pollen concentrations were not included in the combined model. The researchers used an inverse linear regression model and showed that the combined pattern of increased incidence of allergic rhinitis cases (moderately to highly correlated pollen and allergic rhinitis), increased atmospheric air temperature, exposure to solar radiation and exposure of people in indoor recreational places could be directly related to 87.5% of the variation in COVID-19 reproduction number (Rt). If data on increasing pollen concentrations were also used in this study, the authors would have obtained results similar to those in the study by Damialis et al. - Germany, 2020.

Even with this result, findings from studies conducted by Damialis et al., 2020 and Hoogeveen et al., 2020 suggest that environmental factors (increased pollen concentrations, increased air temperature and altered air humidity), may act together and explain susceptibility to SARS-CoV-2 (COVID-19) coronavirus infection.

Contini and Costabile - Italy, 2020; Domingo and Rovira - Italy, 2020 reported that an increase in concentrations of air pollutants (particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}], ozone [O_3], nitrogen oxides [NO_2], sulphur oxides [SO_2], carbon dioxide [CO]) is associated with an increase in the number of COVID-19 positive cases confirmed daily, increasing the related mortality rate (Wu, Nethery et al., 2020).

In the autumn of 2020, when the 2nd wave of the COVID-19 pandemic was in full swing, affecting more and more countries around the world as well as countries in Europe, with the most SARS-CoV-2 infections on record, this wave overlapped the common ragweed pollen season (in Europe). At the same time, according to the European Environment Agency's *"Air quality in Europe - 2020 report"*, after a decrease in respirable particle concentrations, attributed to lockdown restrictions, until April 2020, a change was followed by a further increase in respirable particles [$PM_{2,5}$]/[PM_{10}] in the air during the rest of the year.

Coccia et al. - Italy, 2020, determined the key role of atmospheric air pollution with particulate matter airborne respirable [$PM_{2,5}$/PM_{10}] in the dynamics of COVID-19 infection transmission. At the end of the study, the researchers reported that "*the rapid and global spread of COVID-19 infection may be associated with days when the maximum allowable concentration for particulate matter airborne respirable [PM_{10}] is higher than the daily threshold value of 50 µg/m3 air, set by European Union legislation*. Setti, Passarini et al. - Italy, 2020, in an experimental study, demonstrated that virus RNA may be present on particulate matter respirable [PM_{10}] in the air under stable atmospheric conditions and when the concentration of particulate matter airborne respirable [PM_{10}] exceeds the daily maximum allowable concentration. Thus, the researchers suggest that *"concentrations of respirable particulate matter [PM_{10}] can be used as an indicator for a high potential for infection with SARS-CoV-2 coronavirus."*

Setti et al. - Italy, 2020a, reported, by experimental evidence, the presence of SARS-CoV-2 virus on the surface of particulate matter airborne respirable [PM_{10}], under conditions of strong atmospheric stability and high levels of particulate matter respirable concentrations [PM_{10}], in areas of the Po Valley, Italy. Setti et al. - Italy, 2020a,b, confirmed the presence of SARS-CoV-2 virus RNA on the surface of particulate matter airborne respirable [PM_{10}] at the peak of the COVID-19 epidemic in Italian cities in the northern part of the country, suggesting that it could coagulate with particulate matter airborne respirable [PM_{10}] in the ambient environment and increase the longevity of SARS-CoV-2 in the atmosphere.

Martelletti and Martelletti - Italy, 2020 reported areas in Northern Italy as having the highest concentrations of particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] and the increased number of cases in those areas (most people affected by COVID-19) due to the much faster diffusion of COVID-19.

Setti, Passarini et al. - Italy, 2020c, consider that the presence of SARS-CoV-2 virus on the surface of particulate matter airborne respirable [PM_{10}] could be a potential early indicator for COVID-19 infection and that may enhance airborne viral transmission - particulate matter airborne respirable [$PM_{2,5}$] are strongly associated with the risk of COVID-19 infection.

In particular, the increased air pollution in Italy, especially in the Lombardy area, has led to research on possible mechanisms of diffusion of SARS-CoV-2 coronavirus into the atmospheric air, using particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] as a vector. Lombardy (which includes the city of Milan) is considered the area (in Northern Italy) most affected by air pollution, influenced by the long-range transport of air pollutants, as well as by seasonal pollen pollution from aeroallergenic plants (common ragweed) - according to reported data.

Thus, the researchers concluded that SARs-CoV-2 can find suitable transport vectors among particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] in the air and increases susceptibility to viral infections. According to the study, the high average number of people infected with SARS-CoV-2 was found in cities where previously the highest concentrations of particulate matter airborne respirable [PM_{10}] were reported, exceeding the EU limits for more than 100 days. At the same time, the lowest average number of infected people was recorded in cities with less than 100 days of air pollution. Setti, Passarini et al. - Italy, 2020 consider that *"SARS-CoV-2 may use a type of "highway" composed of particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}], which enhance its indirect transport."*

Conticini, Frediani et al. - Italy, 2020, from the analysis of the data collected, concluded that the regions of the country with the highest pollution with particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] are in the northern area, where a high level of lethality caused by SARS-CoV-2 infection has been reported. In contrast, the regions of the country with the lowest levels of particulate matter airborne respirable [$PM_{2,5}$/PM_{10}] pollution are located in the south.

Wu, Nethery et al. - USA, 2020, at the end of an epidemiological study, estimated that at an increase of 1 μg/m3 air in the concentration of particulate matter airborne respirable [$PM_{2,5}$], there was an 8% increase in SARS-CoV-2 coronavirus-induced mortality in the USA. Yao, Pan et al - China, 2020a, 2020b reported a positive correlation between particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] concentration with the mortality rate of SARS-CoV-2 virus-induced cases in Wuhan, China.

Stoian M.I. et al. - Romania, 2020, conducted an epidemiological study in which included 43 cities (41 of these cities being county capitals and 2 localities in Ilfov county), to assess exposure to particulate matter airborne respirable [PM_{10}] and nitrogen dioxide [NO_2] in the atmospheric air, in relation to the cumulative number of confirmed cases of COVID-19 until 28 September 2020, in Romania. For this purpose, the annual average concentration of [PM_{10}] and [NO_2], collected from monitoring stations in the 43 cities, was calculated. The annual values over a five-year period were then averaged. Finally, the annual average concentration of [PM_{10}] and [NO_2] was obtained for each city. The cumulative incidence/hour per 1000 inhabitants on 28 September 2020 was used, taking into account the population size of each city included in the study, reported on 1 January 2020, according to data from the National Institute of Statistics. On 28 September 2020, there were 123,944 confirmed cases of COVID-19. At the end of our study, we found a positive correlation between the average level of particulate matter [PM_{10}] in atmospheric air, over a five-year period, and the cumulative incidence of cases caused by SARS-CoV-2 per 1000 inhabitants, in 43 localities in Romania; the positive correlation being more evident for the Municipality of Bucharest. Basically, the results of the study showed that exposure of the population to low levels of respirable particles [PM_{10}] in the atmospheric air, below the limit values allowed at EU level (50 μm/m³ air), but for a long period of time (in our case five years, between 2015-2019), can have negative effects on the health status of the population exposed in large cities, a population that becomes much more vulnerable to external agents (e.g. viruses, such as SARS-CoV-2).

Zoran M. et al. - Romania, 2023, carried out a large epidemiological study in the Municipality of Bucharest, performing a complex statistical analysis (with data provided by websites for the period 26 February 2020 - 31 March 2022, when the 5 waves of COVID-19 were recorded in the Municipality of Bucharest), suggesting that exposure to high levels of particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] in the air, as potential carriers of the SARS-CoV-2 coronavirus, could increase the transmission and severity of COVID-19 viral infection (through aerosol clusters, which can affect the integrity of the upper and lower respiratory tract, forming condensation nuclei to which the SARS-CoV-2 coronavirus can attach). SARS-CoV-2 is thought to be able to spread by air and over long distances. The researchers concluded that the inactivation of this viral transmission via respirable particles [PM_{10}] in the atmospheric air can be achieved under the influence of meteorological conditions - air temperature, air pressure, relative humidity, average wind speed, solar radiation - for the Municipality of Bucharest.

Population exposure to elevated levels of particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] in atmospheric air has been positively correlated with incidence and mortality from COVID-19 infection. The results of this research show direct positive correlations of atmospheric air concentrations of particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] and the derived mean ratio [$PM_{2,5}$]/[PM_{10}] with new daily COVID-19 cases and deaths throughout the pandemic period. Researchers consider the variability of particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] concentrations as an important indicator of the degree of air pollution in large cities (such as Bucharest). However, the value of the derived average ratio [$PM_{2,5}$]/[PM_{10}] is intended to quantify the capacity of respirable particles to affect human health on the one hand and atmospheric processes on the other; if it is <0.5, fine particles in atmospheric air are considered to have more negative effects on human health than coarse particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}].

The results of this study also showed a negative correlation between atmospheric air temperature, solar radiation, incidence and severity of COVID-19 infection; COVID-19 infection is thought to spread more easily during the colder months of the year. The researchers, analysing the climatic variables investigated, showed that a change in relative humidity can lead to an increase in the spread of particulate matter airborne respirable in the atmospheric air and that a sudden change in atmospheric air temperature can activate COVID-19 infection in the temperate climate of Municipality of Bucharest. Also, another conclusion of the study was that severe fog episodes have a significant negative impact on SARS-CoV-2 virus transmission and human health, related to atmospheric inversions in the autumn/winter period (reflecting synergistic effects caused by interactions between local and regional air masses, physico-chemical atmospheric processes, anthropogenic factors - emissions and viral transport via particulate matter airborne respirable [PM_{10}]).

This study proved the harmful effects of particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] from atmospheric air and sedimentable particles from ground level on the incidence and lethality of COVID-19 in the Municipality of Bucharest, the result being consistent with previous studies [81-83]. Researchers considered that respirable and sedimentable particles can be considered as a vector for SARS-CoV-2 coronavirus in large cities.

Marco Travaglio et al - UK, 2021, suggested that *"long-term exposure to poor quality air will increase the risks of COVID-19 infection and increase mortality from this viral infection, in the UK."* The final results of the study link increased levels of air pollutants (such as particulate matter airborne respirable [$PM_{2,5}$/PM_{10}] and nitrogen oxides [NOx]), COVID-19 infection and mortality from SARS-CoV-2 in the UK (regional and sub-regional). The authors believe that prolonged exposure to these air pollutants may also increase the risk of a severe outcome of COVID-19 infection. A one unit increase in the long-term average of particulate matter airborne respirable [$PM_{2,5}$] was found to be associated with a 12% increase in COVID-19 cases. Similarly, for particulate matter airborne respirable [PM_{10}] for one-unit increase was associated with an 8% increase in COVID-19 cases.

Young-Jin Choi et al - Korea, 2022 conducted a 5-year study in which they aimed to determine the link between air pollutants, increased amounts of pollen during the two flowering periods of the year and the prevalence of respiratory viral infection (tests for human coronavirus, human rhinovirus, adenovirus, parainfluenza virus, respiratory syncytial virus type A and B were performed). Only children, aged 0-18 years, hospitalized for respiratory symptoms (cough, fever, dyspnea) were selected in the study, of which only children with confirmed respiratory viral infections were selected. Both air pollutant and aeroallergen pollen concentrations were measured at both times of the year (spring and autumn). The researchers used multiple linear regression analyses to determine the factors with the greatest influence on the growth of viral infections. They also determined the time that had the greatest influence, using a cross-correlation coefficient (comprising measured weekly values of pollen and viral infections). A correlation was basically made between confirmed respiratory viral infections, the average concentration of measured air pollutants and the concentration of aeroallergenic plant pollens measured in that week. The results obtained in this study show that following co-exposure to air pollution ([$PM_{2,5}$], [PM_{10}], [O_3], [NO_2], [SO_2]) and an increased concentration of tree pollen (spring: February - June) in those spring weeks, as well as co-exposure to air pollution ([$PM_{2,5}$], [PM_{10}], [CO_2]) and an increased concentration of weed pollen - common ragweed (autumn: August - November) in those autumn weeks, there was an increase in respiratory viral infections in Korean children included in the study.

b)Aeroallergenic plant pollen may lower the risk of SARS-CoV-2 viral infection

Results from other epidemiological studies suggest that pollen from aeroallergenic plants may act as an inhibitory factor for viral infections and decrease the number of SARS-CoV-2 viral infections (by decreasing ACE-2 in the epithelial cells of the upper and lower airways), regardless of the severity of the condition (allergic rhinitis or bronchial asthma).

Researchers have found that pollen particles in the air can protect people with allergic respiratory diseases (allergic rhinitis and bronchial asthma) against infection with the SARS-CoV-2 coronavirus. In another epidemiological study of adults diagnosed with mild bronchial asthma, who were not receiving control treatment, after exposure to airborne common ragweed pollen particles, a decrease in ACE-2 in lower airway epithelial cells was observed. However, other factors (such as Toll-like receptor-4, which may bind to the spike protein of SARS-CoV-2 with a higher affinity than ACE-2) that may have influenced the decreased risk of SARS-CoV-2 viral infection need to be studied.

Martjin j. Hoogeveen et al. - The Netherlands, 2020, in another epidemiological study, conducted over the period 2016-2020 (5 years), concluded that *"exposure to aeroallergenic plant pollen had inverse correlations with the risk of influenza infection"*. In this study they tested the seasonality of the timing of viral respiratory diseases (influenza and influenza-like illnesses) in direct correlation with the periods of increased pollen concentrations, atmospheric temperature and solar radiation threshold (as environmental factors that could influence the occurrence of viral respiratory diseases). The study period also overlapped with the first year of the COVID-19 pandemic, which dominated the tail end of the 2019-2020 influenza season in the Netherlands, and the respective Dutch researchers suggested that *"exposure to aeroallergenic plant pollen might be protective against SARS-CoV-2 viral infection"* The respective researchers considered that *"pollen particles are independent, discrete factors that may be involved in decreasing or inhibiting the incidence of viral respiratory diseases, including COVID-19"*. They also set a threshold value for aeroallergenic plant pollen grains (≥100 pollen grains/m^3/week, whereas the first symptoms may occur in the range of 1-50 pollen grains/m³/week), considering this threshold to represent both the early and late periods of the life cycles of moderate influenza epidemics (including, COVID-19).

The researchers also considered that an increase in air temperature only influenced early pollen flowering, but had no predictive value for the incidence and seasonality of influenza periods. Solar radiation (exposure to UV light) acted as a co-inhibitor, through immuno-activation, protecting together with pollen against respiratory viral diseases. A composite variable (total pollen, allergenic pollen, solar radiation) was considered as a useful predictor of the incidence and seasonality of influenza periods.

At the end of another epidemiological study, the researchers concluded that *"aeroallergenic plant pollen was able to increase protection against viruses, regardless of the allergy status of the individuals concerned."*

E. Bontempi - 2020, Italy analyses, for the first time, the link between exposure to air pollution with particulate matter airborne respirable [PM_{10}] (which exceeded, for several days, the maximum allowed concentration of 50µg/m³ air) in Lombardy (e.g. Brescia and Bergamo) and Piedmont (on the border with Switzerland and France), based on the idea that *"respirable particles in the air act as a virus carrier"* (the mechanism of airborne virus transmission - according to Sterpeti - 2020, Italy) and the increased number of cases in those areas due to the much more rapid spread of COVID-19.

During the study period, the cities in the Piedmont area (the cities of Turin and Alessandria) reported (according to the Lombardy Environmental Protection Agency - "ARPA Lombardia", which collected the data from both areas) the most serious pollution events with [PM_{10}] compared to the pollution events recorded, during the same period, in the cities of the Lombardy area. However, they showed a lower number of cases of SARS-CoV-2 coronavirus viral infections detected (compared to the Lombardia area - cities of Brescia and Bergamo) in the 20 days before the medical crisis in that area. In contrast, in the Lombardia area (city of Bergamo), where the maximum concentration allowed for particulate matter airborne respirable [PM_{10}] - 50µg/m³ air was exceeded only a few times, a much higher number of SARS-CoV-2 coronavirus viral infections were detected.

In practice, the results of this study did not allow a correlation between the mechanisms of diffusion of SARS-CoV-2 coronavirus in the atmospheric air and the increased concentrations of particulate matter airborne respirable [PM_{10}] used as a vector, leaving an invalid assessment of the risk to human health. From the data collected and reported at the end of the study, it was considered that the contagious area spread in the proximity areas (preferentially) in the cities of northern Italy (Lombardia area and Piemonte area).

Conclusions

In Europe, the change in atmospheric air quality and its pollution with particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}], varies widely from country to country, with many areas where annual average concentrations of respirable particulate matter are exceeded on a significant number of days per year. In addition, seasonal (spring and autumn) pollution with aeroallergenic plant pollens (such as common ragweed) affects the quality of life of people living in these areas. Overlaying the maps showing the areas most affected by respirable particle pollution and aeroallergenic plant pollen pollution shows that in many areas they are overlapping. Thus, the emergence of the COVID-19 pandemic at European level has occurred at a time when an increasing proportion of the population is exposed to poor air quality in the short term and especially in the long term.

A first conclusion of our study, although the results of epidemiological studies conducted in the last 4 years may be contrary, is that the vast majority of these studies show a link between air pollution with particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}], the presence of pollen of aeroalegeneous plants (such as common ragweed) and the SARS-CoV-2 virus.

Another conclusion is that particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] as well as sedimentable particles at ground level, can be considered a vector for SARS-CoV-2 coronavirus, especially at urban level (in large cities). There is growing evidence of this, but the mode of transmission of SARS-CoV-2 coronavirus is still being studied and considered controversial, according to public health policy agencies. However, epidemiological studies have not reported significant correlations between virus concentration and the diameter of particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}].

It can also be concluded that the population in urban areas, exposed for a long period of time to increased levels of particulate matter airborne respirable [$PM_{2,5}$]/[PM_{10}] or, sometimes, even to levels below the EU limit values (e.g. 50 µm/m³ air for [PM_{10}]), can have negative effects on the human body, affecting health and becoming more vulnerable to external agents (e.g. viruses such as SARS-CoV-2).

Another conclusion was that most epidemiological studies to date have considered it important to study atmospheric factors (air temperature and humidity, wind speed and direction, sunlight, increased [CO_2] concentration, etc.) in direct relation to particulate matter pollution, aeroallergenic plant pollen and SARS-CoV-2 coronavirus transmission.

Thus, we can conclude that most studies have shown that air pollution contributed to the spread of SARS-CoV-2 infection in patients with additional exposure to aeroallergenic plant pollen. However, further, additional epidemiological studies that could link air pollution with respirable particles, aeroallergenic plant pollen-induced respiratory disease population, increased morbidity and mortality by COVID-19 in that population are recommended to be conducted further.

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