# Does airborne pollen influence COVID-19 outbreak?

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ABSTRACT

The fast spread of SARS-CoV-2 presented a worldwide challenge to public health, economy, and educational system, affecting wellbeing of human society. With high transmission rates, there are increasing evidences of COVID-19 spread via bioaerosols from an infected person. The current review was conducted to examine airborne pollen impact on COVID-19 transmission and to identify the major gaps for post-pandemic research. The study used all key terms to identify revenant literature and observation were collated for the current research. Based on existing literature, there is a potential association between pollen bioaerosols and COVID-19. There are few studies focusing the impact of airborne pollen on SARS-CoV-2, which could be useful to advance future research. Allergic rhinitis and asthma patients were found to have pre-modified immune activation, which could help to provide protection against COVID-19. However, does airborne pollen acts as a potent carrier for SARS-CoV-2 transport, dispersal and its proliferation still require multidisciplinary research. Further, a clear conclusion cannot be drawn due to limited evidence and hence more research is needed to show how pollen bioaerosols could affect virus survivals. The small but growing literature review focuses on searching for every possible answer to provide additional security layers to overcome near future corona-like infectious diseases.

## 1. Introduction

On 31st December, pneumonia-like cases of unknown etiology were reported in Wuhan, China associated with Huanan Seafood Market. The causative agent identified behind the pneumonia-like cases was subsequently named Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) by the Chinese Centre for Disease Control and Prevention (CCDC) as reported by Lei et al. (2020). On 30th January 2020, with a surge in the number of coronavirus cases, the World Health Organization (WHO) announced the outbreak of SARS-CoV-2 as Public Health Emergency of International Concern posing various countries at high risk (Sohrabi et al., 2020). The global spreading of coronavirus diseases in 2019 caused by SARS-CoV-2 presented an unprecedented challenge to the international public health, trade, economy and educational system affecting human society's welfare (Lippi, Henry, Bovo, &

Sanchis-Gomar, 2020). On the contrary, the outbreak has posed a huge positive impact on the pollution level, wildlife and nature (Biswal, Singh, Singh, Ravindra, & Mor, 2020; Biswal, Singh, Singh, Kesarkar et al., 2020; Mor et al., 2021). As all human activities came to a halt, a reduction in the level of particulate matter in the air, lowering $NO_2$ and $CO_2$ emissions, was reported (Habib, Xia, Fareed, & Hashmi, 2020; Ravindra, Singh, Biswal, Singh, & Mor, 2021; Wang & Li, 2021). By 10th January 2021, the pandemic of COVID-19, as labeled by WHO, has reported more than 11.1 crores cases of COVID-19 globally, with more than a 2.5 million deaths and 87 million recoveries spontaneously (WHO Report, 2020).

The high transmission rate of coronavirus and vaccines unavailability led governments to enforce social distancing, compulsory use of facial masks and related measures. Thus, the basic purpose of maintaining social distancing (at least 1.8 m) is to slow down/minimize and

eventually prevent the spread of novel coronavirus by reducing its possibility of transfer among infected persons to non-infected persons (CDC, 2007; Jin et al., 2020). Initially, scientists tried to solicit factors such as temperature, relative humidity and sunlight to explain novel coronavirus spread mainly in countries experiencing cold climates. However, meteorological variables do not completely explain disease occurrence variation (Liu, Zhi, & Ying, 2020; Liu, Zhou et al., 2020; Wu et al., 2020). The exact pathogenesis of coronavirus is not decoded yet, but it is well-known that the virus has the ability to spread via dispersal of bioaerosols from an infected person.

Airborne pollen constitute a significant fraction of bioaerosols and serve as carriers for various bacteria and viruses (Card, Pearson, & Clover, 2007). They are greatly influenced and triggered by meteorological factors (such as temperature, relative humidity, rainfall and wind, etc.) (Beggs, 2004) and jointly can explain the effect on COVID-19 (Hoogeveen, 2020; Hoogeveen, van Gorp, & Hoogeveen, 2020). As highlighted by Hoogeveen et al. (2020), the ability of SARS-CoV-2 to persist in the environment can cause eventual exposure to pollen bio-aerosols, which can further alter the transmission rate and seasonality of coronavirus. The overview of airborne pollen effect, meteorological parameters on COVID-19 has been summarized in Fig. 1. This review explains that there is a possibility of the pollen-virus complex may diffuse into the atmosphere and can be transported to long-distances from their original site. This could be one of the possible reasons for the rapid spread of COVID-19.

Contrary to this, studies have found that pollen bio-aerosols are one of the independent factors involved in reducing or inhibiting flu-like epidemics incidences since 1889 and COVID-19. Typically, airborne pollen are considered major triggers of respiratory allergies causing allergic rhinitis (hay fever/pollinosis) and asthma. And theoretically, allergic rhinitis and asthmatic patients should have increased severity and susceptibility towards COVID-19, but surprisingly an unexpected low prevalence of asthmatic and allergic rhinitis is shown in existing studies. This suggests that pollen bio-aerosols may lead to pre-modified immune activation, which seems to protect against COVID-19. Hence, this review examines the existing scientific evidence to better understand the linkage between the pollen bioaerosols, COVID-19, meteorological parameters and anticipated risk in the severity of allergic rhinitis and asthma.

## 2. COVID-19, bio-aerosols and its spread

Among different symptoms showed by COVID-19 patients includes sore throat, cough, diarrhea, fever, loss of taste and smell, breathlessness accompanied with fatigue; with extreme conditions resulting in respiratory failure, multiple-organ failure, acute respiratory distress syndrome (ARDS), pneumonia, and even death (Huang et al., 2020; Jiang et al., 2020). On 18th February 2020, the National Health Commission (NHC) of People's Republic of China published guidelines for effective diagnosis and treatment of COVID-19 infection (NHC, 2020). With a major focus on the transmission route, the guidelines show that apart from droplets produced by an infected person, aerosols transmission was considered one of the major routes of coronavirus transmission (Wang & Du, 2020). Aerosols are the suspension of fine solid or liquid particles (industrial dust particles, soil particles, bacteria, pollen grains and other components) dispersed or suspended in the air. In contrast, bioaerosols are solid and liquid airborne particles of biological origin (pollen, fungi, bacteria).

It is well-known that SARS-CoV-2 can spread via the dispersion of bio-aerosols by an infected person. Viruses exerted by an infected person upon speaking, sneezing, or coughing get dissolve with the aerosols suspended in the atmosphere and become bio-aerosols (Guzman, 2020). The bio-aerosol particles generally range from 0.3 to 100 μm in diameter, whereas primary concerns remain on a respirable fraction of size 1.0–10 μm. Generally, bio-aerosols in the size range of 1.0–5.0 μm persist in the ambient air, whereas heavier/ larger particles tend to settle down on surfaces. Whereas the particle size of a droplet of saliva released by a human upon speaking, sneezing, wheezing, or coughing generally varies between 1–5 mm and tend to spread in the vicinity of around 1–2 m from the source of infection as shown in Fig. 2 (Adhikari et al., 2019; Jones & Brosseau, 2015; Tellier, Li, Cowling, & Tang, 2019; Velraj & Haghighat, 2020). Moreover, both the aerosols and bioaerosols could travel hundreds/thousands of meters or more (Killingley and Nguyen-Van-Tam, 2013).

Varieties of the bacterial pathogens, namely *Bordetella pertussis, Neisseria meningitides* and *Bacillus anthracis,* are known to be transmitted through bioaerosols collapsing respiratory system (GBD, 2013). Some of the pathogenic fungi, such as *Fusarium moniliforme, Aspergillus fumigatus* and *Mucorales sp,* are also known to be transmitted through bioaerosols and caused various respiratory abnormalities, hypersensitivity and system organ infection (Jung, Lee, Lee, Kim, & Lee, 2009). Similarly, bio-aerosols have proven to be a transmission route in spreading the
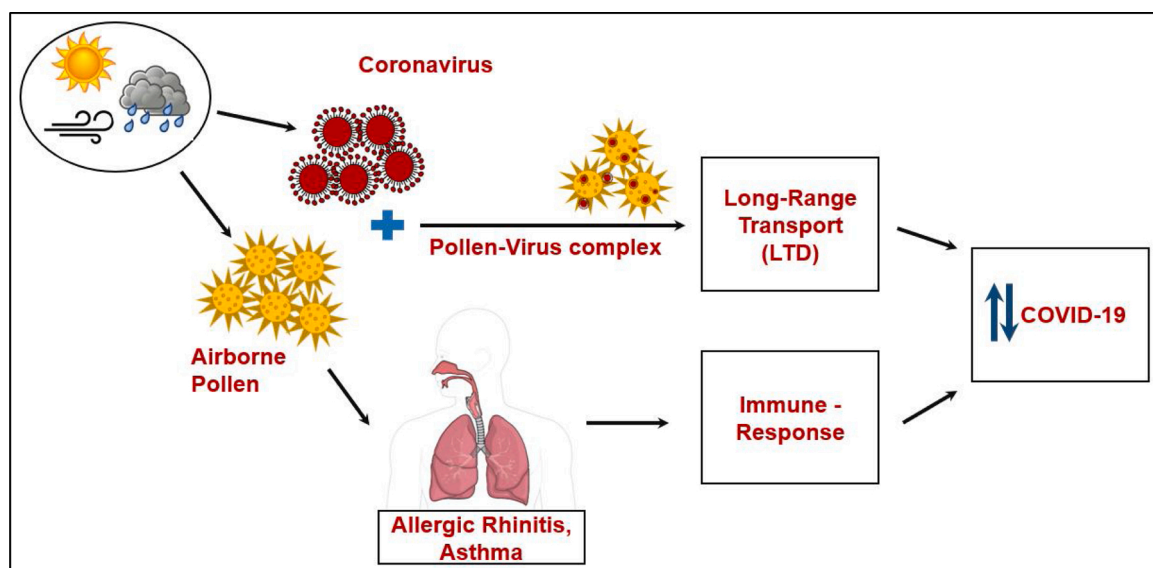
**Fig. 1.** Overview summarizing the effect of pollen aerosols along with meteorological parameters on COVID-19.
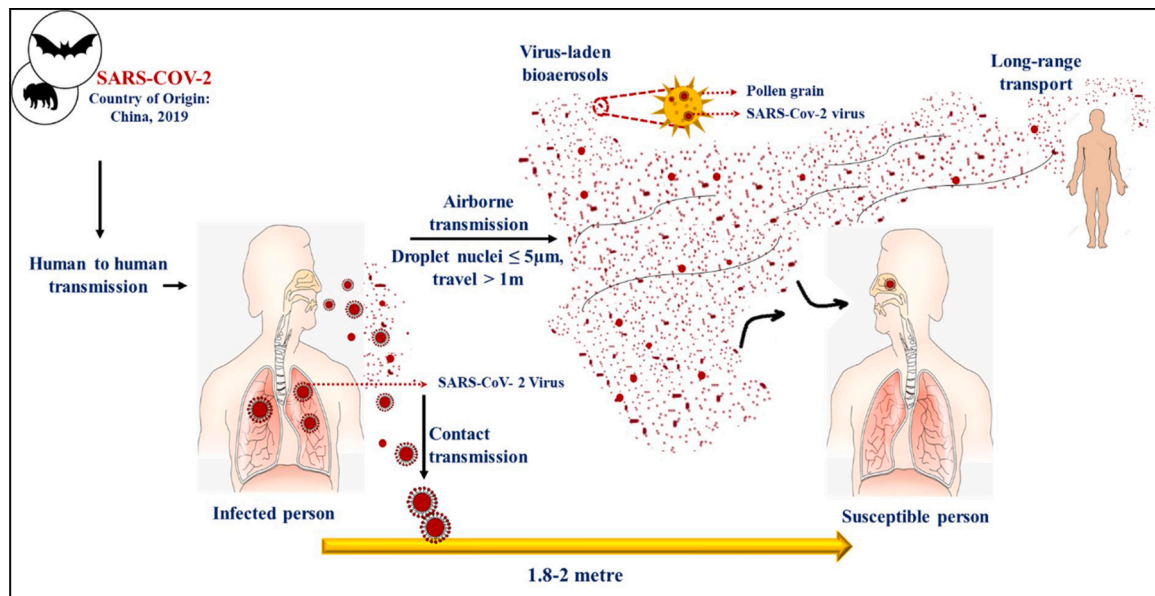
**Fig. 2.** Modes of transmission and dispersal of COVID-19.

Middle East respiratory syndrome (MERS), H1N1, SARS-CoV and some other diseases (Li, Huang, Yu, Wong, & Qian, 2005; Zayas et al., 2012; Zhang et al., 2013). Airborne pollen are considered a major vector for various bacteria and viruses (Card et al., 2007; Verreault, Moineau, & Duchaine, 2008). More than 40 viruses belonging to 16 genera are identified as pollen-transmitted and the majority of them belong to *Ilarvirus, Nepovirus, Potyvirus* and *Sobemovirus* genera (Bhat & Rao, 2020; Card et al., 2007). However, understanding the transmission route in response to pathogens is an urgent need for public health.

### 3. Airborne pollen and virus interaction

From anther dehiscence to release in the atmosphere, airborne pollen come in contact with various atmospheric particles (Knox et al., 1997; Sedghy et al., 2017). Airborne pollen constitute a major fraction of bioaerosols and serve as carriers for various pathogens, including viruses (Jones & Harrison, 2004; Shiller, Lebas, Horner, Pearson, & Clover, 2010; West, 2014). This will affect the prevalence and occurrence of diseases linked to pollen exposure. Distribution patterns of pollen grains have suggested a relationship between pollen source areas and pollen transport factors such as ocean currents and wind patterns (Hooghiemstra, Lézine, Leroy, Dupont, & Marret, 2006). Due to regional climate change, pollen grains are dispersed and transported from one place to another, exposing the people to new and novel allergens to which they are not exposed previously (Poole et al., 2019). Regional and local wind patterns are considered critical factors associated with the spread of airborne pollen and diseases in the following ways: they influence the dispersal pattern and behavior of disease vector; affect the human susceptibility of diseases; their correlation with vector abundance (Parham, Christiansen-Jucht, Pople, & Michael, 2011). Chen et al. (2010) suggested that highly pathogenic avian influenza virus (H5N1) and influenza virus may be subjected to long-distance transport (LDT) due to Asian dust storms.

The introduction of a tracer transport approach integrated with models to predict infectious disease prevalence provides better insights on disease transport. This approach mainly works for the diseases that are transported along long-distances environmentally. These include infectious diseases caused by fungi (Prank, Kenaley, Bergstrom, Acevedo, & Mahowald, 2019), Aspergilli and Coccidioides (Sprigg et al., 2014) and pollen-borne viruses (Duhl et al., 2013; Zhang et al., 2014). To motivate discussion of the interplay of pollen and disease spread,

various exemplars representing key long-range transmission: Zhang et al. (2014) integrate the STaMPS (Simulator of Timing and Magnitude of Pollen Season) pollen transport model into the WRF (Weather Research Forecasting) and CMAQ (Community Multiscale Air Quality) regional air-quality modeling system to simulate the variation of temporal-spatial patterns for different species of pollen under several meteorological parameters. Similarly, CESM (Community Earth System Model) is used to model the emission and long-range transport of fungal spores, the most relevant vector for the spread of crop diseases. Several studies examine the emission pattern and long-range transport of airborne pollen, leading to the spread of infectious disease. A survey conducted by Ye, Fu, Mao, and Shang (2016) showed that children who suffered from Respiratory Syncytial Virus infection (RSV) in China were promoted by particle-based transport.

Similarly, Selcuk, Gormus, and Guven (2021) examined the potential impact of wind speed changes on COVID-19 and reported a positive correlation between wind speed and crowd in cities with high COVID-19 transmission rates. This could be one of the possible reasons for the rapid spread of COVID-19. However, there are multiple studies events known where spores or the fungi spreading diseases from one continent to another via the atmospheric pathway, even crossing oceans, have been confirmed (Brown & Hovmøller, 2002). Therefore, it is possible that airborne pollen might behave as an effective carrier for viruses, including SARS-CoV-2 transport, dispersal and its proliferation.

In order to apprehend the actual biological relevance of virus-pollen dispersion, it is also necessary not only to study the physical transport but also to understand the changes that occur in biological effectivity during the period of dispersal. In the vicinity of pollen a question arises that does pollen type affect virus attachment? Moreover, how much virus can attach to single pollen grain, viability, and viral load required for transferring infection is still unanswered. Airborne pollen releases sticky cytoplasm containing moisture, which behaves as a perfect carrier for the virus and its viability. There are four possible processes known for pollen-particle interaction: sticking of particles during another dehiscence, pollen-particle coagulation; dry and wet scavenging of pollen-particles; co-deposition of pollen and particle (Visez et al., 2020). Particles are defined as any small bits of material or droplets, either organic or non-organic, viable or non-viable, that can become airborne (Salvaggio, 1994). Pollen-particles complexes are well-documented in the outdoor environment but highly-complex to examine (Behrendt et al., 1991). For instance, pollen allergens from grass were shown to

bind diesel exhaust particles in vitro experiments (Knox et al., 1997; Namork, Johansen, & Løvik, 2006). Similarly, Ormstad (2000) found soot particles carried Birch pollen on their surface. In addition, the release of proteins by pollen grains has been shown to be enhanced in the presence of particles on their surface (Behrendt, Becker, Friedrichs, Darsow, & Tomingas, 1992; 1997). Particles adhered to pollen grains could interact with allergens and uptake proteins from pollen grains, thus favoring their dispersal in the respirable fraction of atmospheric aerosols (Solomon, 2002). Similarly, viruses have the potential to be absorbed on the pollen outer surface, i.e., exine and may remain in the atmosphere for hours, weeks, or days. During a study, Singh et al. (2010) examined pollen-virus association and suggested that there is a possibility that the virus is not only attached to the surface but instead present inside the pollen grain.

It is well- known that pollen undergo physical and biochemical modification while traveling in the lower troposphere (Sénéchal et al., 2015). During transport, pollen, spores, or fungi are subjected to harsh environmental conditions, including sunlight and subfreezing temperatures, which reduces their viability and time to persist in the environment and thus limiting the distances a pathogen or viruses can be transmitted in a viable state. However, a perfect example has been provided by Schueler, Schlünzen, and Scholz (2005) and Maddison and Manners (1973), where both examined that spectrum of UV radiation has detrimental effects on the viability of pollen and spores are crucial for gene transport patterns. Although, the magnitude of pollen-virus interaction is poorly understood and the extent of pollen pollution caused by viruses is substantially undetermined. The complexity of the coronavirus with aspects of bioaerosol transmission still requires further examination.

## 4. Role of airborne pollen and weather conditions in explaining COVID-19

Virologists observed different circulation patterns of influenza or flu-like illnesses (FLI) that prevails in winters and "leave in May" in the Northern hemisphere while emerging in the Southern hemisphere and return in next autumn or winter (Moriyama, Hugentobler, & Iwasaki, 2020). Every flu-like epidemic since 1889 occurred at the tail-end of every flu-season in the Northern hemisphere, as shown in Fig. 3 (Fox, Miller, & Meyers, 2017). Moreover, Fox et al. (2017) revealed that most flu-like epidemics occur in multiple waves, while the initial wave is typically short-lived. This suggests that coronavirus is also subjected to similar multi-seasonal waves (Kissler, Tedijanto, Goldstein, Grad, & Lipsitch, 2020). The dispersal or distribution pattern followed by COVID-19 is consistent with earlier flu-like behavior incidences (Fox et al., 2017; Sajadi et al., 2020). Various studies conducted tried to

explain the inconsistent association of flu-like illness with meteorological parameters, i.e., sunlight including UV radiation, humidity and temperature (Schuit et al., 2020; Shaman, Goldstein, & Lipsitch, 2011; Chong et al., 2020). Similarly, numerous studies across the world aimed to exemplify the impact of different weather parameters on COVID-19 cases. An exclusive reflection of some studies on each parameter is shown in Table 1. Although inconsistent correlation is witnessed among COVID-19 and temperature (Ahmadi, Sharifi, Dorosti, Ghoushchi, & Ghanbari, 2020; Briz-Redón & Serrano-Aroca, 2020; Hoang & Tran, 2021; Iqbal et al., 2020; Shahzad et al., 2020) and equally inconsistent among COVID-19 and humidity (Ahmadi et al., 2020; Selcuk et al., 2021; Shi, Dong et al., 2020; Shi, Gao et al., 2020; Yuan et al., 2020). Selcuk et al. (2021) reported a positive correlation between precipitation and COVID-19 transmission for each average inch per day of rainfall and an increase of about 56 cases/day was observed. Contrary to this, a study conducted by Ahmadi et al. (2020) and Tosepu et al. (2020) reported a non-significant correlation between rainfall and COVID-19 cases, respectively. Very limited studies are available that have shown the relationship between wind and COVID-19 transmission. Selcuk et al. (2021) examined the influence of wind on the transmission of COVID-19 and reported a positive correlation between wind speed and crowd in cities with high COVID-19 transmission rates. Whereas another study carried out in Iran by Ahmadi et al. (2020) showed extremely opposite results. Therefore, none of the environmental factors thoroughly explains the association of meteorological parameters with COVID-19.

Pollen bioaerosols present in the environment depend upon the surrounding vegetation and weather conditions. Nonetheless, meteorological parameters are associated with flower maturating, pollen ripening, and dispersion (Poole et al., 2019). Variations in climatic parameters influence pollen grains production, affecting their occurrence, duration and concentration in the atmosphere. Increased $CO_2$ concentration and temperature are the major factors directly linked to increased pollen production, increased duration of pollen seasons, changes in pollen morphology and increased allergenicity of pollen. Pollen distribution greatly depends on weather conditions such as wind pressure, wind speed, wind direction, precipitation, humidity etc. and also on the micro and macro topography that exist within the area (Beggs, 2004). Factors such as sunlight and temperature trigger the flower and pollen maturation while the rain has a contrasting effect, i.e., lowers the formation of pollen bio-aerosol (Gatz & Dingle, 1963; Rahman et al., 2019; Sousa et al., 2008). Whereas relative humidity has a detrimental effect on pollen (Pacini, Guarnieri, & Nepi, 2006), it provides additional information that why flu-like illness is higher in the rainy season in tropical countries than in the rest of the year.

Dutch researchers recognized pollen bio-aerosols as one of the independent/discrete factors involved in reducing, waning or inhibiting
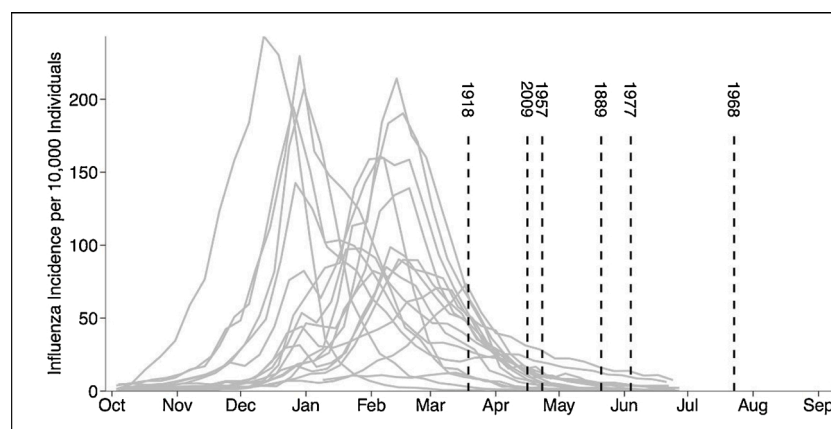


**Fig. 3.** Historical flu-like epidemics emerged at the tail-end of every flu-season. Where grey curves indicate the occurrence of different flu-seasons of that year and vertical dash-lines depict the emergence of historical pandemics from 1889-2015 in the Northern hemisphere. (Image taken from- Fox et al., 2017).

**Table 1**
Effect of various meteorological parameters on COVID-19 cases.

| Meteorological parameter | Country | Key findings | References |
|---|---|---|---|
| **Temperature** | China | Asymmetric nexus between temperature and COVID-19 in 10 affected provinces, three shows positive, two negatives and five mixed trends | Shahzad et al. (2020) |
| | Iran | No significant correlation between temperature and COVID-19 outbreak | Ahmadi et al. (2020) |
| | China (Wuhan) | No significance of an increase in temperature is observed to slow down the COVID-19 cases | Iqbal et al. (2020) |
| | Korea | Significantly non-linear relationship between temperature and COVID-19 cases | Hoang and Tran (2021) |
| | Spain | Insignificant impact between temperature on COVID-19 transmission | Briz-Redón and Serrano-Aroca (2020) |
| | "Belt and Road" countries | Non-linear correlation between temperature and COVID-19 in 127 countries | Yuan et al. (2020) |
| **Relative humidity** | Turkey | Negative correlation between humidity and number of COVID-19 cases (81 provinces) | Selcuk et al. (2021) |
| | Iran | Reverse relationship between humidity and COVID-19 | Ahmadi et al. (2020) |
| | "Belt and Road" countries | Non-linear correlation between relative humidity and COVID-19 in 127 countries | Yuan et al. (2020) |
| | China | No significant relationship between COVID-19 and absolute humidity | Shi, Dong et al. (2020a) and Shi, Gao et al. (2020b) |
| **Precipitation** | Italy | Positive correlation between precipitation and COVID-19 transmission | Sobral, Duarte, da Penha Sobral, Marinho, and de Souza Melo (2020) |
| | Jakarta (Indonesia) | Rainfall was not significantly correlated with COVID-19 | Tosepu et al. (2020) |
| | Iran | No correlation between rainfall and COVID-19 cases | Ahmadi et al. (2020) |
| **Wind speed** | Turkey | Shows a positive correlation between wind and COVID-19 cases | Selcuk et al. (2021) |
| | Iran | Significant inverse relationship between wind and COVID-19 infection rate | Ahmadi et al. (2020) |

flu-like illness incidences in the Netherlands over the time-period of 2016–2019 (Hoogeveen, 2020). They considered pollen as an anti-viral substance having anti-influenza effects. The study reports a highly significant inverse correlation between allergic pollen concentration and flu-like incidences, including COVID-19. Further, when the threshold value of allergenic pollen grains exceeds 100grains/m$^3$ per week, it marks the onset and ending of moderate flu-like epidemics lifecycles, including COVID-19 and therefore might be used as a predictor. The indirect explanation is based on the fact that pollen bioaerosols are influenced and triggered by meteorological factors and jointly can explain the inverse effect on the seasonality of FLI. Moreover, pollen bio-aerosols and UV radiation lead to immune-activation, which seems to protect against flu-like pandemics.

A study conducted by Hoogeveen et al. (2020) tested Pollen Flu Seasonality theory (2016–2020) based on changes in pollen concentration, allergic pollen, FLI incidences and solar radiation threshold. They found a highly inverse correlation of flu-like incidences with an average threshold of solar radiation threshold of 510 J/cm$^2$, 610 total pollen/m$^3$, and 120 allergenic pollen/m$^3$ every week. Moreover, the persistent observation over past years showed that passing these pollen thresholds in week 10 ± 5 and week 33 ± 2 each year corresponds to the peak of flu-like epidemic and the beginning of the new flu season, respectively. While the solar radiation was a co-inhibitor of FLI and temperature marks no effect. Therefore, this explains that pollen grains, solar radiation and humidity effects flu-like pandemics, including COVID-19.

## 5. COVID-19, allergic rhinitis and asthma

Pollen are considered as one of the primary triggers of respiratory allergies, causing 'pollinosis'. Allergic rhinitis (Hay fever/Pollinosis) has been recognized by the World Allergy Organisation (Pawankar, Holgate, Canonica, Lockey, & Blaiss, 2013) as one of the global health issues. It affects about 10–30 % of the worldwide population (Pawankar, 2014). Allergic rhinitis can start in early childhood and persist throughout life or can later develop risk factors for exacerbation of asthma and chronic obstructive pulmonary diseases (COPD) in susceptible individuals (Cecchi et al., 2010). Whereas coronaviruses are well-known respiratory pathogens and SARS-CoV-2 is also identified to infect the upper and lower respiratory tract. COVID-19 exhibits various distinct clinical manifestations varying from asymptomatic to symptomatic, i.e., mild and severe or uncontrolled disease. The US Centers for Disease Control and Prevention (CDC) listed asthma as one of the risk factors for novel coronavirus illness, given those respiratory pathogen are known to cause serious illness in patients with chronic airways diseases, but allergies are not classified as a risk factor.

However, Global Initiative for Asthma (GINA) provided a guideline on special allergy care during COVID-19. In contrast, the American Academy of Allergy, Asthma & Immunology (AAAAI), European Respiratory Society (ERS) and other prestigious national societies recommend continuing the usual treatment for asthma patients to prevent further exacerbations (Morais-Almeida et al., 2020). Interestingly, asthma and pre-existing respiratory allergies have not been identified as substantial risk factors among coronavirus patients (Shi, Dong et al., 2020; Shi, Gao et al., 2020). Patients with allergic diseases do not seem to develop any distinct symptoms or an increased risk of severe disease. Moreover, allergic diseases are underreported as a co-morbid condition among coronavirus patients (Dong et al., 2020; Zhang et al., 2020).

Consequently, multiple consistent studies have identified that asthma or allergic rhinitis do not seem to increase the risk against SARS-CoV-2 as shown in Table 2. Surprisingly, despite the prevalence of 4.2 % and 9.7 % asthma and allergic rhinitis were not listed as co-morbidities in Wuhan, China, with 140 hospitalized COVID-19 patients (Zhang et al., 2020). Another study conducted in China revealed no physician-diagnosed asthma among 1590 COVID-19 patients (Guan et al., 2020). Similar findings were also reported by Carli, Cecchi, Stebbing, Parronchi, and Farsi (2020) in Italy, where a low prevalence of asthmatic patients admitted among COVID-19 patients, i.e., 3 out of 275 individuals, only one requiring ICU. These reports were theoretically conflicting with the well-known pattern of viral infections, which exacerbate asthma and other allergic diseases.

**Table 2**

Summary of studies in relation to allergic rhinitis, asthma and COVID-19.

| Country | No. of COVID-19 cases | Key findings | Reference |
|---|---|---|---|
| China | 1590 | No asthmatic patient involved among 1590 COVID-19 patients | Guan et al. (2020) |
| Wuhan, China | 140 | No patients were found to have asthma or allergic rhinitis | Zhang et al. (2020) |
| New York, USA | 737 | Pre-existing eosinophils found in asthmatic patients, protective against COVID-19 with decreased mortality | Ferastraoaru et al. (2021) |
| China | 138 | With a prevalence of 1.1 %–2.9 %, chronic obstructive pulmonary diseases (COPD) are less common in COVID-19 cases | Wang et al. (2020) |
| Prato, Italy | 275 | Very low prevalence of asthmatics patients among admitted COVID-19 patients | Carli et al. (2020) |
| China | 2143 | No asthmatic patient among pediatric cases of COVID-19 | Dong, Mo et al. (2020) |
| China | 110 | Ratio of asthma and allergic rhinitis were far lower than those of domestic morbidity among COVID-19 patients. | Shi, Dong et al. (2020a) and Shi, Gao et al. (2020b) |
| Italy | 12,055 | allergic children have higher counts of eosinophils and no symptom of dyspnea than COVID-19 patient | Licari et al. (2020) |

Therefore, there arises a question that what could be the possible features of allergic diseases or asthmatic patients that are found related to reduced potential for the severity of COVID-19 disease.

Pollen grains are known to be allergenic (Basak et al., 2019; D'Amato et al., 2007; Schmidt, 2016) and plays a vital role in immune system activation (Janeway et al., 1999; Plötz et al., 2004). They are considered anti-viral substances and have also shown anti-influenza effects (Hoogeveen, 2020; Lee et al., 2016). Elucidating this, Licari et al. (2020) showed that allergic children have higher counts of eosinophils and no dyspnea symptoms than COVID-19 patients, where eosinophils are disease-fighting cells that help to recover from certain viral infections, including COVID-19 (Lindsley, Schwartz, & Rothenberg, 2020). Moreover, patients medicated with systematic steroids or patients on the oral dosage of corticosteroids (allergy treatments) may have increased susceptibility or severity to COVID-19 due to pre-modified immune response with evidence of cytokine-storm formation (Brough et al., 2020). However, direct evidence is still lacking, but some observations provide indirect evidence.

A study conducted by Jackson et al. (2020) found that allergic and allergen exposure have an inverse relation with angiotensin-converting enzyme 2 (ACE-2) expression, where COVID-19 requires this receptor to enter the host body (Ou et al., 2020; Wan, Shang, Graham, Baric, & Li, 2020). Furthermore, histamine and Immunoglobulin E (IgE) serum levels are found to be elevated in allergic rhinitis and asthmatic patients, which can down-regulate certain anti-viral responses, i.e., hyper-inflammation that mark the severity of various respiratory diseases, including COVID-19 (Carli et al., 2020). Like various other respiratory diseases, coronavirus might worsen asthmatic symptoms in severe or uncontrolled patients but owing to Th2-skewed immunity (pertaining to the allergic and interferon-mediated response), which drives anti-immune response may protect against COVID-19 diseases (Liu, Zhi et al., 2020; Liu, Zhou et al., 2020). Certain types of immune-responses, accumulation of eosinophils, lower ACE-2 receptors expression, Th-2 skewed immunity and elevated histamine, immunoglobin E (IgE) serum levels and systematic steroids are the possible features of allergic diseases or asthma patients that are found associated

with reduced potential for the severity of COVID-19 as shown in Fig. 4. Collectively, they indicate that allergic rhinitis and asthma may not be aggravating factors towards novel coronavirus. These observations were quite interesting and contrasting according to the theoretical knowledge, where allergic diseases and asthma are known to increase with viral infections. This inverse correlation might support the idea that the triggering of immune responses by airborne pollen (i.e., hay fever) makes it difficult for COVID-19 to penetrate a new host. Moreover, this gives substantial sense to the idea that an activated-immune system seems to protect against COVID-19 viruses. Although studies are limited but based on literature review, there is currently no clear evidence of elevated risk or fatal outcome of allergic rhinitis or asthmatic patients due to COVID-19.

## 6. Direction for future research

The current study examines the relationship between airborne pollen, meteorology and COVID-19. Based on the existing evidence, the study identifies the following gaps and challenges covered below:

Firstly, very few studies are available that have proved a highly significant inverse correlation between allergic pollen concentration, UV light, humidity and flu-like incidences, including COVID-19. But, the magnitude of pollen count differs at various geographic locations in response to meteorological variables. So, identifying whether the same inverse correlation between pollen count, meteorological parameters including UV light, temperature, humidity and COVID-19 also prevails in other countries at a large scale are not precisely estimable. The central question that pollen aerosols inhibit or increases the SARS-CoV-2 propagation and seasonality still remains unsolved.

Secondly, airborne pollen and spore counts are limited, especially long duration time series are completely hard to find. Continuous aerobiological monitoring is required to collect pollen and spores so that long-time-series data can be developed and compared with flu-like incidences. Thirdly, pollen allergic diseases and the mechanisms of respiratory disease disorders caused by them are highly complex and somewhere shown to protect against SARS-CoV-2. But the relationship between pollen allergies and COVID-19 patients is hard to be modeled or quantified due to inadequate patient data. Further work must understand how pollen aerosols provide a pre-active immune system for the low prevalence of allergic diseases in COVID-19 patients.

Interdisciplinary research and collaboration need to be promoted to better understand the mechanism underlying the linkage between pollen aerosols and these viruses. Further, there is a need to understand the impact of the pollution-pollen-virus complex on COVID-19 survivability and transmission at the global hotspots of ambient and indoor air pollution including the impact of air pollution reduction interventions (Singh, Ravindra et al., 2020; Singh, Biswal et al., 2020; Ravindra, Kaur-Sidhu et al., 2021). The complexity of the coronavirus with aspects of bioaerosol transmission still requires further examination. Moreover, extensive research is needed for determining projected variations in human health.

## 7. Conclusion

The recent COVID-19 outbreak led to a global health emergency affecting millions of people worldwide. It is unambiguously representing a major environmental, socio-economic threat faced by the human community. SARS-CoV-2 has the ability to spread through the dispersal of bioaerosols from an infected person. There is a possibility that airborne pollen can serve as an effective carrier for SARS-CoV-2. But this raised several important questions due to the highly complex nature of coronavirus and its association with airborne pollen. It is quite difficult to assess the impact of pollen bioaerosol and weather parameters on COVID-19 but the seasonality of previous flu-like pandemics and recent studies, indicates that airborne pollen is an anti-viral substance having anti-influenza effects and can act as an inhibiting factor towards COVID-
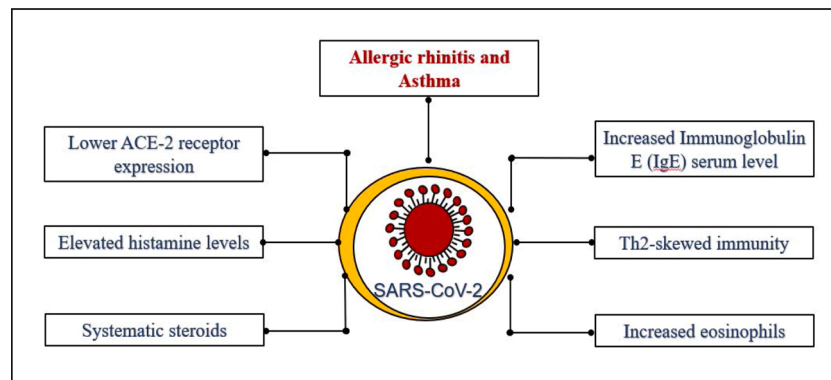
**Fig. 4.** Possible features of allergic diseases or asthma patients that are found associated with reduced potential for the severity of COVID-19.

19. However, future research is required to understand how pollen bioaerosols affect viruses altogether. Moreover, the clinical observations collectively suggest that there is some probable mechanism of the impaired anti-viral response in allergic rhinitis and asthma patients. During the course, observations were found surprisingly and theoretically conflicting with the well-known paradigm, where asthma and allergic disease worsen with viral infections. However, it is quite difficult to draw a conclusion based on the association between allergic rhinitis, asthma and COVID-19, but it provides hints and references for future research.

## Declaration of Competing Interest

The authors report no declarations of interest.

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