Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Inactivation of airborne SARS-CoV-2 by thyme volatile oil vapor phase

 Çağrı Şakalar , Murat Ertürk *

Antimikrop Ar-Ge ve Biyosidal Analiz Merkezi, Nasuh Akar Mah. Süleyman Hacıabdullahoğlu Cad. No: 37/1, Çankaya, Ankara, Turkey

A B S T R A C T

Background: The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) caused a global pandemic mainly through air transmission. Novel variants are emerging and thus innovative methods of air disinfection still warrant exploration. Essential oils with virucidal properties may be an alternative to known air disinfectants.

Objectives: Analysis of virucidal potential of thyme oil vapor phase against airborne SARS-CoV-2.

Materials and methods: Chemical composition of thyme oil was analyzed by Gas chromatography–mass spectrometry. Thyme oil was tested in solution in different dilutions against soluble SARS-CoV-2. For air disinfection analysis, different volumes of thyme oil were placed in a container with hot water and its vapor phase was tested against airborne/aerosolized SARS-CoV-2 in a 30 m³ room. The aerosolized virus was collected in a gelatine filter using a vacuum system after the test and the collected virus was quantified utilizing inoculations of serial dilutions into 96-well plates with VERO E6 cells.

Results: The main component of thyme oil was carvacrol. Thyme oil had virucidal action both in solution and in the air. Thyme oil at 1/1000 dilution (volume/volume, final concentration) in a solution eliminated more than 99.99% of SARS-CoV-2 in 60 min. In air disinfection tests in 30 m³ room, vapor phase of 40 ml of extracted thyme oil eliminated more than 99.99% (> 4 LOG10) of airborne SARS-CoV-2, and vapor phase of 20 ml of thyme oil resulted in elimination of 90.88% (1.04 LOG10) airborne SARS-CoV-2 in 60 min.

Conclusion: We have shown that vapor phase of thyme oil inactivates more than 99.99% of airborne SARS-CoV-2 in a room for the first time to the best of our knowledge. This finding may have implications on the use of thyme oil as a potential air disinfectant against SARS-CoV-2.

1. Introduction

The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is the virus that causes the coronavirus induced disease in 2019 (COVID-19). This virus is an enveloped, single-stranded RNA coronavirus of the betacoronaviridae family (del Rio and Malani, 2020). SARS-CoV-2 has a lower fatality rate compared to SARS-CoV-1, however it caused a global pandemic since its transmission rate is much higher and it has led a tremendous threat to public health and economic system with more than 400 million cases in 2020, and with more than 590 million reported infection cases and 6.4 million deaths worldwide, recently (Helmy et al., 2020). New variants of SARS-CoV-2 are emerging, SARS-CoV-2 B.1.1.529 (Omicron) Variant is one of the latest variants of SARS-CoV-2 and it has an increased transmission rate (Team, 2021). With its higher transmission rate, Omicron variant became the dominant variant in COVID-19 patients and caused a dramatical increase of COVID-19 cases (Elliott et al., 2022).

Although vaccines are available, these new variants indicate that COVID-19 still poses a threat for public health. In addition to efficient vaccines and several drugs, antiviral potential of several herbal components and extracted volatile oils against SARS-CoV-2 were also explored and potent candidates were demonstrated through in vitro and in vivo studies (Jan et al., 2021; Lionis et al., 2021). Among these, thyme oil has long been known for its anti-microbial and anti-viral properties and is a volatile oil studied for its activity (Kowalczyk et al., 2020).

Since new SARS-CoV-2 variants have a higher transmission rate, inactivation of airborne virus needs more attention. Air ventilation, HEPA filters and UV-C disinfection have been utilized to eliminate viruses in the air (Nardell and Nathavitharana, 2020). On the other hand, there are very few studies on the impact of essential oils against airborne SARS-CoV-2. In this study, we have focused on the vapor phase of thyme oil and studied virucidal activity of vapor phase of thyme oil against airborne SARS-CoV-2 in a 30 m³ room. To the best of our knowledge, this is the first study demonstrating the impact of thyme oil vapor against airborne SARS-CoV-2 in a real volume of a room.

2. Materials and methods

2.1. Chemical analysis of thyme oil

Thyme oil was obtained commercially (Mecit Efendi Bitkisel Ürünler Gıda Sanayi ve Tic. Ltd. Şti., İzmir, Turkey). Chemical composition of
2.2. Preparation of SARS-CoV-2 virus stock solution

Experiments were performed in biosafety level 3 (BSL3) facilities of Antimikrop Research and Biocidal Analysis Laboratories which is accredited by Ministry of Health of Turkey. In this laboratory, biocidal analysis tests were routinely performed using SARS-CoV-2. BSL3 virology laboratory is fully equipped with negative pressure vacuum systems, air-lock systems, HEPA filters and biosafety cabinets with HEPA filters and vacuum, and a 30 m³ test room designed for air disinfection tests (http://www.antimikrop.com.tr/ana-sayfa) (Antimikrop AR-GE ve Biyoidal Analiz Merkezi). Air disinfection analyzes regarding SARS-CoV-2 were routinely performed in our laboratory for air disinfection devices such as UV-C devices, UV-C attached air conditioners and ventilators and ozone generators. In all routine analysis, a stock suspension of SARS-CoV-2 strain (Clinical isolate, Gen Bank No: MT955161.1) was used. SARS-CoV-2 virus stock was prepared by inoculating the Vero E6 cell line in Dulbecco's modified Eagle's medium (DMEM-10). DMEM-10 containing supplements (10% fetal bovine serum, 2 mM/L glutamine, 100 U/ml penicillin, 100 mg/ml streptomycin, and 0.5 mg/ml fungizone (Amphotericin B)) was added to the flask, and the cells were incubated at 37 °C for 72 h. The supernatant was collected, clarified by centrifugation, and stored at –80 °C. TCID<sub>50</sub> titer was determined by the Spearman- Kärber method as described (Hubert, 1984).

2.3. Virucidal test

Virucidal test was performed based on EN 14476 standard (Chemical disinfectants and antiseptics - Quantitative suspension test for the evaluation of virucidal activity in the medical area - Test method and requirements (Phase 2/Step 1)) (European Standards, 2019). Various dilutions of thyme oil (1/1000, 1/4000 and 1/16000 final volume/volume concentrations) was prepared in DMSO as 1/10 dilution of virus stock solution and BSA (Bovine Serum Albumin: 0.3 g/l) was mixed with different concentrations of thyme oil or PBS in clean conditions and incubated for 60 min. Neutralization was started by 1/10 dilution in DMEM-10. Then, LOG<sub>10</sub> dilutions (from 10<sup>-3</sup> to 10<sup>-7</sup>) of test and control solutions were prepared and inoculated in 96-well plates containing VERO E6 cells. Therefore, at the end of the virucidal treatment, thyme oil/virus solution mix was further diluted 1/100 for neutralization and then, inoculated into the cell culture, and thyme oil did not show any cytotoxicity at tested concentrations. Cells were visualised under inverted microscope at 72–96-hours incubation period and cytopathic effect (CPE) was scored. LOG<sub>10</sub> TCID<sub>50</sub> titer was determined for test and control solutions by the Spearman- Kärber method as described (Hubert, 1984).

2.4. Experimental setup for the inactivation of airborne SARS-CoV-2 by thyme oil

The experimental system was shown in Fig. 2. In the method, an air compressor provided air flow with a rate of approximately 0.72 m<sup>3</sup>/h (12 L/min). An air flow meter (RST Measurement Control Tech., Istanbul, Turkey) was used to measure the air flow rate. A nebulizer (M102, Jiangsu Yuyue Medical Equipment & Supply Co., Ltd., Danyang Jiangsu, China) was used to aerosolize the virus liquid with a nebulization rate of approximately 0.5 ml/min, and an average particle size of 3.7 μm. A venturi injector was used to mix the aerosolized virus to the air flow through the system. Venturi injector was connected to the room through a pipe and ball valve. Air was pumped into the venturi injector through a compressor (12 liter/minute). The nebulizer was connected to the venturi injector from the side part and nebulized virus from the nebulizer was mixed to air flow inside venturi injector and then, the air was given to the test room. The aerosolized virus was given into the 30 m³ test room through a leakproof plastic pipeline controlled with a ball valve. A fan (its diameter was approximately 75 cm and it was run at minimum speed settings) was run inside the test room during virus nebulization period to provide air circulation. To collect the virus from the test room, a polycarbonate filter holder with a gelatin membrane filter (Sartorius, Göttingen, Germany) was connected to a separate leakproof plastic pipeline controlled with a ball valve. An approximately 1 m³ air was passed through gelatin membrane filter using a vacuum instrument (MD8 Airscan, Sartorius, Göttingen, Germany) to collect airborne SARS-CoV-2 on the filter.

Test room was supplied with various volumes of thyme oil in 3.5 liters of hot water (90–95 °C) in a glass container and this container was placed in the middle of the room. In each experiment, different volumes of thyme oil (20 ml, 40 ml and 60 ml) was added into the glass container. Thyme oil was not solubilized in air disinfection experiments. Thyme oil was directly added into the 3.5 l of hot water (90–95 °C). In the control experiment only hot water was placed in the middle of the test room. Suspension of the SARS-CoV-2 was nebulized into the venturi injector and mixed with the compressor’s air before entering 30 m³ test room. Virus was nebulized into the room in 15–18 min and incubation period was 60 min. Then, virus collected into the gelatine filter. Gelatine filter was dissolved in PBS (Phosphate Buffered Saline) in 10 min at 37 °C. LOG<sub>10</sub> dilutions of virus stock solution and solution obtained from the filter was prepared and inoculated in 96-well plates containing VERO E6 cells. TCID<sub>50</sub> titers of virus stock solution and solution obtained from the filter in control and test experiments were determined by the Spearman- Kärber method as described (Hubert, 1984).

Table 1: Chemical Composition of Thyme Oil.

| Chemical Component | Percentage (%) |
|--------------------|----------------|
| ( + ) Bornesol     | 0.70           |
| Alpha Terpinen     | 0.66           |
| Alpha Thujen       | 0.73           |
| Beta Bisabolene    | 1.25           |
| Beta Myrecene      | 0.74           |
| Camphene           | 0.15           |
| Carvacrol          | 84.63          |
| Delta 3 Caren      | 0.22           |
| Gamma Terpinen     | 2.98           |
| Linalool           | 3.68           |
| Para Cymen         | 2.27           |
| Terpinen-4-ol      | 0.48           |
| Thymol             | 0.83           |
| Trans Caryophyllene| 0.67           |

Chemical composition of thyme oil indicated that Carvacrol was the most abundant chemical in thyme oil and it constituted approximately 85% of the volatile oil (Table 1). The other abundant chemicals were linalool (3.68%), gamma terpinen (2.98%), para cymen (2.27%) and beta bisabolene (1.25%). Full list of chemicals in thyme oil were given in Table 1.

The virucidal activity of thyme oil in solution was tested based on an adaptation of EN 14476 standard. Different volume to volume dilutions of thyme oil was prepared and incubated with 1/10 dilution of SARS-CoV-2 stock solution for 60 min. 1/1000 dilution of thyme oil demonstrated a strong virucidal impact and eliminated more than 99.99% of the virus in solution (R<sup>-4,75 LOG</sup>/99.99%) (Fig. 1, Table 2). Other dilutions of thyme oil were 1/4000 and 1/16000. These dilutions had a very moderate activity and resulted in about 44% inhibition of SARS-CoV-2 (R<sup>-0.25 LOG</sup>/43.77%) (Fig. 1, Table 2).
In the table, virus titers were given as Log_{10} TCID_{50} values. SARS-CoV-2 in test suspension was incubated with different volumes of thyme oil (T.O.) for 60 min and the remaining virus titer in test suspension was analyzed based on EN 14476 standard. In the control experiment, the remaining virus titer in suspension was analyzed without T.O. after 60 min. R is the reduction in viral load, C is an average of TCID_{50} of the control groups, and T is the TCID_{50} values of the test groups.

| TEST                          | Log TCID_{50} ± SD | Result (LOG Reduction/ Percent Inhibition) |
|-------------------------------|--------------------|------------------------------------------|
| Control                       | 5.25 ± 0.25        | –                                        |
| Thyme Oil (1/1000 in T.O.)    | 0.5 (2 replicates) | R – Log C – Log T 99.99%                 |
| Thyme Oil (1/4000 in T.O.)    | 5 ± 0.45 (2 replicates) | R – Log C – Log T 43.77%                |
| Thyme Oil (1/16000 in T.O.)   | 5 ± 0.57 (2 replicates) | R – Log C – Log T 43.77%                |
| Stock Virus Suspension        | 7.49 ± 0.22        | –                                        |

Finally, virucidal impact of thyme oil vapor phase against airborne SARS-CoV-2 was analyzed. Vapor phase of thyme oil was obtained by mixing the volatile oil with hot water (95 °C) in a container. Test was performed in 30 m^3 room designed for air disinfection tests with SARS-CoV-2 (Fig. 2). Thyme oil was placed in the middle of the room and aerosolized SARS-CoV-2 was released into the room and virus was collected and quantified after 60 min of test time. Different volumes of thyme oil including 20 ml, 40 ml and 60 ml were tested. 40 and 60 ml of thyme oil eliminated more than 99.99% (>4 Log_{10}) of airborne SARS-CoV-2, and 20 ml of thyme oil resulted in elimination of 90.88% (1.04 Log_{10}) airborne SARS-CoV-2 (Table 3, Fig. 3).

4. Discussion

In this study, we focused on virucidal potential of thyme oil against airborne SARS-CoV-2. We tested different volumes of thyme oil in a 30 m^3 room containing nebulized SARS-CoV-2 and we demonstrated that vapor phase of thyme oil can inactivate more than 99.99% of SARS-CoV-2 in 1 h.

Volatile oil of Thymus vulgaris is well known for its antimicrobial properties. Further, antiviral properties of thyme oil have been studied and has been shown to have antiviral activity against viruses such as HIV-1, influenza virus, HSV-1 and HSV-2 (Kowalczyk et al., 2020). Oil extracted from Thymus vulgaris was tested against HIV-1 and has been shown to reduce virus transcription by 52% through inhibition of the function of Tat protein (Perioto et al., 2018). In another study, thyme extract was tested against rhinoviruses and influenza viruses. It was demonstrated that thyme extract reduced cytopathic effect caused by influenza viruses but not rhinoviruses at non-cytotoxic doses (Walther, Bing, and Schmidike, 2020).

In addition, there are studies focusing on coronaviruses and SARS-CoV-2. In a study with feline coronavirus, antiviral and virucidal potential of thyme oil was studied. Thyme oil reduced viral replication by 2 Log_{10} at 27 μg/ml concentration and it showed virucidal activity by more than 3 Log_{10} at 270 μg/ml concentration in 1 h in solution (Catella et al., 2021). In comparison, in our study, thyme oil showed virucidal activity against SARS-CoV-2 by more than 4 Log_{10} at approximately 800–900 μg/ml concentration (1/1000 vol/volume) in 1 h in solution. Chemical components of thyme oil have been studied for their binding potential of key proteins of SARS-CoV-2. Carvacrol, the main component of thyme oil in our study, was shown to strongly bind to main protease (Mpro) of SARS-CoV-2 by using integrated molecular modeling approaches including molecular docking and molecular simulation. The binding of carvacrol to Mpro was stable (Kumar et al., 2021). In another molecular docking study, carvacrol was found to have a good binding
affinity to the receptor binding domain of the S1 glycoprotein of SARS-CoV-2 (Yadalam et al., 2021). There are in vitro and clinical studies focusing on the antiviral impact of thyme oil against SARS-CoV-2 and COVID-19 disease. In a study, a mixture of three oils including thyme oil has been shown to have antiviral effect against SARS-CoV-2 by 80% in a cell culture study with VERO cells (Lionis et al., 2021). In the same study, authors also indicated that the use of this mixture by SARS-CoV-2-positive patients (1 ml at 15 ml/L concentration daily, for two weeks) exhibiting mild COVID-19 symptoms resulted in a significant amelioration of symptoms of the disease. In another clinical study, 83 patients were included and 40 patients received thyme oil in addition to standard therapy. Thyme oil has been shown to reduce the severity of symptoms of COVID-19 patients such as fever, dizziness, cough, and chest wall pain. In addition, blood urea nitrogen, neutrophil count decreased and lymphocyte count increased significantly in patients receiving thyme oil. These findings indicate a clinical improvement for COVID-19 patients (Sardari et al., 2021). Based on these studies, we focused on virucidal properties of thyme oil against SARS-CoV-2.

Thyme oil in solution demonstrated a virucidal action against SARS-CoV-2 at 1/1000 dilution (v/v) in our study. The activity was more than 99.99% (R=4.75 LOG) in 1 h and this result was comparable with the result of the study with feline coronavirus, although feline coronavirus seemed more sensitive to thyme oil (Catella et al., 2021). However, virucidal impact of thyme oil at 1/4000 and 1/16000 dilutions was substantially reduced and the reduction was not linear (Fig. 1).

Airborne transmission is the dominant route for SARS-CoV-2 infection (Zhang et al., 2020). SARS-CoV-2 virus has a half life of approximately 1 h in aerosol form and more than 10% of the virus is still active after 3 h in the air (van Doremalen et al., 2020). We have also observed a reduction of 0.5–0.8 LOG TCID\textsubscript{50} in titers of virus obtained from the room air in 60 min in 40% relative humidity (unpublished data). There are multiple ways to disinfect room air to prevent airborne transmission of the virus. These methods include filtering of air through HEPA filters by air ventilation, and UV-C disinfection of air by air ventilation devices (Nardell and Nathavitharan, 2020). In a previous study performed in our facilities, we have tested the efficacy of an air heater to eliminate SARS-CoV-2 in air, and we have observed that SARS-CoV-2 was inactivated in seconds in 220 °C (Canpolat et al., 2022). In this study, the temperature of air inside the air heater was 220 °C and SARS-CoV-2 inactivation passing through the heater was measured. However, it may not be always possible to install such a devices in small indoor environments such as houses and small rooms. Hence, other measures such as use of volatile oils may provide protection against airborne SARS-CoV-2 in small indoor environments. There are limited number of studies on the safety of volatile oils or their vapor phase in room air. Volatile oils or their vapor phase are well tolerated up to 450 mg/m\textsuperscript{3} (Tisserand and Young, 2019).

There have been several studies focusing on virucidal efficacy of aerosols or vapor phase of volatile oils. These studies can be compared to our study in 30 m\textsuperscript{3} test room. A blend of tea tree oil, eucalyptus oil and lemon myrtle oils was aerosolized and released in a 0.7 m\textsuperscript{3} chamber with a flow rate of 1 ml/h. These aerosols have been shown to eliminate more than 95% of B. subtilis bacteria and MS2 bacteriophages in 60 min (Mirskaia and Agranovski, 2021). In another similar study performed using tea tree oil and eucalyptus oil aerosols against influenza virus, aerosols of these oils at 125 and 250 mg/m\textsuperscript{3} concentration were able to eliminate more than 99% of airborne influenza virus in 15 min (Usachev et al., 2013). However, there are several differences of these studies compared to our study. First of all, SARS-CoV-2 virus was used in our study instead of MS2 bacteriophages or influenza virus. Second, the investigators used aerosols of different kinds of oils, we used vapor phase of thyme oil inside hot water without aerosol formation. Finally, in our study, we used a 30 m\textsuperscript{3} room instead of a <1 m\textsuperscript{3} chamber. In another study, virucidal efficacy of vapor phase of thyme oil was investigated in a 1.5 ml test tube, SARS-CoV-2 virus was dried in the cap of the tube and the impact of vapor phase of thyme oil against SARS-CoV-2 was investigated. Vapor phase of thyme oil has been shown to have inhibitory activity against influenza virus in 30 min in a 1.5 ml test tube containing 0.25 ml volatile oil (Vimalanathan and Hudson, 2014). In contrast to our study, this study was performed in a very small volume, the ratio of thyme oil volume in the tube was much higher compared to the one in a room, and additionally, the impact on influenza virus spread and dried on a surface was studied instead of airborne SARS-CoV-2 virus. Although there are studies regarding essential oils and their impact on airborne viruses, more studies are needed to find out the minimal concentration of volatile oils in aerosol form or vapor phase to inactivate airborne SARS-CoV-2. Our study provides a part of this information by detailing the impact of thyme oil on airborne SARS-CoV-2.

In our study, we have tested virucidal action of thyme oil both in a solution and in the air. A 1/1000 (v/v) dilution of thyme oil in solution eliminated more than 99.99% of SARS-CoV-2 in 60 min. On the other hand, 40 ml of thyme oil inactivated more than 99.99% of the virus in a 30 m\textsuperscript{3} room in 60 min and this corresponds to a ratio of 1/750000 (v/v) if all thyme oil vapor was assumed to spread to the room. When we make a comparison for the ratio of thyme oil required to inactivate SARS-CoV-2 in solution or in the air, we observe that a much lower ratio of thyme oil is enough to inactivate airborne SARS-CoV-2 in our experimental conditions. This phenomenon might be due to a higher activity of thyme oil active chemicals in the air or, SARS-CoV-2 might be more vulnerable to these chemicals in airborne form. In conclusion, we have demonstrated that thyme oil vapor phase inactivates more than 99.99% of airborne SARS-CoV-2 in a room for the first time to the best of our knowledge. This finding may have applications in air disinfection in small residences, houses as well as larger residences. In addition, virucidal potential of thyme oil vapor phase may stimulate in vivo and clinical studies focusing the impact of its vapor phase against SARS-CoV-2.

**CReditT authorship contribution statement**

Çağrı ŞAKALAR: Conceptualization, Methodology, Validation, Investigation, Writing – original draft. Murat ERTÜRÜK: Conceptualization, Methodology, Writing – review & editing, Project administration, Funding acquisition.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
References

Antimikrop AR-GE ve Biyosidal Analiz Merkezi, A. Main Page.
Campoli, M., Brok, M., Šakalar, C., Cobo, A.V., Karacaylı, D., Toker, E., 2022. Rapid thermal inactivation of aerosolized SARS-CoV-2. J. Virol. Methods 301, 114465.
Catella, C., Camero, M., Lucente, M.S., Fracchiolla, G., Slhano, S., Tempesta, M., Martella, V., Buonavoglia, C., Lanave, G., 2021. Virucidal and antiviral effects of Thymus vulgaris essential oil on feline coronavirus. Res. Vet. Sci. 137, 44–47.
del Río, C., Malani, P.N., 2020. COVID-19—new insights on a rapidly changing epidemic. JAMA 323, 1339–1340.
Elliott, P., Bodinier, B., Eales, O., Wang, H., Haw, D., Elliott, J., Whitaker, M., Jonnerby, J., Tang, D., Walters, C.E., Atchison, C., Diggle, P.J., Page, A.J., Trotter, A. J., Ashby, D., Barclay, W., Taylor, G., Ward, H., Darzi, A., Cooke, G.S., Chadeau-Hyam, M., Donnelly, C.A., 2022. Rapid increase in Omicron infections in England during December 2021: REACT-1 study. Science 375, 1406–1411.
European Standards, E. 2019. Chemical disinfectants and antiseptics. Quantitative suspension test for the evaluation of virucidal activity in the medical area. Test method and requirements (Phase 2/Step 1).
Feriotto, G., Marchetti, N., Costa, V., Beninati, S., Tagliati, F., Mischici, C., 2018. Chemical composition of essential oils from thymus vulgaris, cymbopogon citratus, and rosmarinus officinalis, and their effects on the HIV-1 tat protein function. Chem. Biodivers. 15.
Helmy, Y.A., Fawzy, M., Elaswad, A., Sobieh, A., Kenney, S.P., Shehata, A.A., 2020. The COVID-19 pandemic: a comprehensive review of taxonomy, genetics, epidemiology, diagnosis, treatment, and control. J. Clin. Med. 9.
Hubert, J.J., 1984. Bioassay. Kendall/Hunt publ. Co., Dubuque, Iowa.
Jan, J.-T., Cheng, T.-J.R., Juang, Y.-P., Ma, H.-H., Wu, Y.-T., Yang, W.-B., Cheng, C.-W., Chen, X., Chou, T.-H., Shie, J.-J., Cheng, W.-C., Chen, R.-J., Mao, S.-S., Liang, P.-H., Ma, C., Hung, S.-C., Wong, C.-H., 2021. Identification of existing pharmaceuticals and herbal medicines as inhibitors of SARS-CoV-2 infection. Proc. Natl. Acad. Sci. 118, e2015791186.
Kowalczyk, A., Przychodnia, M., Sopata, S., Bozkurt, S., ¨orning, K., Schmidtke, M., 2020. Comparative in vitro analysis of inhibition of rhinovirus and influenza virus replication by mucoactive secretolytic agents and plant extracts. BMC Complement. Med. Ther. 20, 380.
Nagarathnam, T., Sohn, H., Madhavan, T., 2021. Antiviral essential oil components of rhinovirus and influenza virus replication by mucoactive secretolytic agents and plant extracts. BMC Complement. Med. Ther. 20, 380.

Zhang, R., Li, Y., Zhang, A., Wang, Y., Molina, M.J., 2020. Identifying airborne transmission as the dominant route for the spread of COVID-19. Proc. Natl. Acad. Sci. 117, 14857–14863.

Ç. Šakalar and M. Ertürk
Journal of Virological Methods 312 (2023) 114660