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Persistence of SARS-CoV-2 in the environment and COVID-19 transmission risk from environmental matrices and surfaces[☆]

Federica Carraturo[*], Carmela Del Giudice, Michela Morelli, Valeria Cerullo, Giovanni Libralato, Emilia Galdiero, Marco Guida

Department of Biology, University of Naples Federico II, via Cintia 21, 80126, Naples, Italy

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ABSTRACT

The Coronavirus disease 2019 (COVID-19) is spreading around the world, representing a global pandemic, counting, as of June 5th, 2020, over 6,600,000 confirmed cases and more than 390,000 deaths, with exponentially increasing numbers. In the first half of 2020, because of the widespread of the COVID-19, researches were focused on the monitoring of SARS-CoV-2 in water, wastewater, sludge, air, and on surfaces, in order to assess the risk of contracting the viral infection from contaminated environments. So far, the survival of the novel *Coronavirus* out of the human body has been reported for short time periods (from hours to few days, in optimized in vitro conditions), mainly because of the need of an host organism which could consent the viral attack, and due to the weak external membrane of the virus. SARS-CoV-2 viral shedding strategies in the environment, either through animate and unanimate matrices, or exploiting the organic matter in water, wastewater, and waste in general, have been discussed in the present article. We concluded that, besides the high infectuousness of the novel *Coronavirus*, the transmission of the pathogen may be efficiently contained applying the adequate preventive measures (e.g., personal protection equipments, and disinfecting agents), indicated by national and international health authories.

1. Introduction

The *Coronavirus*, from *Betacoronavirus* sub-genus, was first isolated in the city of Wuhan (China), in December 2019, from a patients' cluster presenting a not recognizable acute pneumonia, whose affected had the only common denominator the visit at the Huanan Seafood Wholesale Market (Wuhan, China) (Peeri et al., 2020). Since COVID-19 spread in China, reported cases in the world kept on increasing in the majority of the industrialised countries in the world (JHU, 2020). The *Coronaviridae* family, enveloped RNA single-stranded viruses of positive polarity (e.g., species of human *Coronavirus*, HCoV), are generally responsible of a wide range of common flus and infections of the upper respiratory tract. H—CoV are involved in severe pathologies, such as bronchitis, bronchilotis, pneumoniae, mainly affecting neonates, children, old people and immunocompromised patients (Geller et al., 2012). The transmission of disease connected to SARS-CoV-2 infections is associated to the contact with infected persons through the emission of droplets (Wang et al., 2005a). Although there are no scientific evidences regarding the transmission of the new *Coronavirus* through water, wastewater, food or other matrices, it can be hypothesised that the virus is inactivated more rapidly than non-enveloped (therefore, less virulent) viruses, holding the same route of transmission (e.g., *Adenovirus*, *Norovirus*, *Rotavirus*, Hepatitis A virus). High temperatures, low or high pH values, sunlight, and the most common disinfection agents represent an essential tool able to inactivate the virus. Based on the experimental data available today, it is not clear how long the virus is capable of surviving on inanimate surfaces, neither in the environment.

2. Analysis

The analysis of the potential transmission of the SARS-CoV-2 in the environment, enhancing the spreading of COVID-19 outbreaks, is necessary, because of the virus extreme contagiousness showed in the first months of the emergence.

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[*] Corresponding author.
E-mail address: federica.carraturo@unina.it (F. Carraturo).

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2.1. Persistance of SARS-CoV-2 on surfaces, food and environmental matrices

The majority of available studies concerning the presistance of *Coronavirus* species in animated environments and surfaces were conducted on a surrogate human *Coronavirus* strain, HCoV-229E (Kampf et al., 2020; World Health Organization, 2020a): on different surfaces of various materials, such as plastic, metal, or glass, the virus is able to survive from 2 h to 9 days. Temperatures ranging from 30 °C to 40 °C are able to substantially reduce the persistance of highly pathogenic viruses, such as the Middle East Respiratory Syndrome *Coronavirus* (MERS-CoV), the Transmissible Gastroenteritis Virus (TGEV) and the Mouse Hepatitis Virus (MHV). A higher viral load of SARS-CoV is capable to survive for longer time. The same study demonstrated, using carrier tests, that the HCoV-229E is effectively inactivated in 1 min on stainless steel, employing the most common biocides, such as ethanol 70% w/v or 0.1% sodium hypochlorite (Kampf et al., 2020; World Health Organization, 2020a). Studies aimed to verify the survival of SARS-CoV, sharing high phylogenetic similarities with SARS-CoV-2 (Forster et al., 2020), showed the survival of a 10^5 viral titre of the pathogen on aluminium, plastic, metal, wood, and paper, of 4–5 days at room temperature (Kampf et al., 2020). The main results of the researches conducted on SARS-CoV-2 surrogate strains (SARS-CoV, and H–CoV-229) are showed in Table 3. The COVID-19 is caused by SARS-CoV-2: recent researches supposed that the probable ecological reservoirs could be the bats, which allegedly transmitted the virus to humans through an intermediate host. Based on previous epidemics from the past 20 years, caused by species from *Coronavirus* genus, such as the Severe Acute Respiratory Syndrome (SARS) and the Middle East respiratory Syndrome (MERS), cases of viral infection transmission through food were never registered, and, until now, no SARS-CoV-2 infections transmitted via food were reported: studies in progress aim to evaluate the mode and time of survival of the virus in food matrices. For examples, it has been demonstrated that, at 4 °C, MERS-CoV is able to survive up to 72 h in food (World Health Organization, 2020b). A study conducted in 2013 regarding the survival of human *Coronavirus* 229E (H–CoV 229E) in different food matrices (fruit and vegetables) describes the lower persistance of the virus on lettuce stored at 4 °C, compared to *Poliovirus* 1 (PV-1). In particular, H–CoV 229E on lettuce registered a $\log_{10}$ reduction >1.31 after 8 days, with respects to the 0.36 $\log_{10}$ reduction of *Poliovirus* 1. H–CoV 229E was not detectable on lettuce samples after 4 days of storage and no viral loads were detected after spiking H–CoV 229E on strawberries samples (Yepiz-Gomez et al., 2013). It is needed to specify that the starting viral loads from the 3 pathogens were different: in fact the overall recovery of H–CoV 229E on lettuce, at the time of virus spiking, resulted lower ($3.99 \pm 0.25 \log_{10}$), compared to *Poliovirus* 1 ($7.14 \pm 0.10 \log_{10}$) and *Adenovirus* 2 ($9.15 \pm 0.19 \log_{10}$) (Yepiz-Gomez et al., 2013). It may be therefore possible that the faster die-off of H–CoV 229E could be linked to the lower viral load, in spite of *Poliovirus* 1 *Adenovirus* 2, whose loads were respectively 3 and 5 $\log_{10}$ higher. The recent evidences regarding monitorings conducted on further *Coronavirus* strains demonstrate that, although these pathogens result stable at low temperatures for a defined period of time, the application of the proper measures to ensure food hygiene and safety are able to prevent the virus shedding. In particular, species from *Coronavirus* genus are thermolabile, thus susceptible to traditional heat treatments (e.g., 70 °C cooking): it would be indeed sufficient avoiding to consume uncooked food of animal origin. It is furthermore important to underline that SARS-CoV and MERS-CoV in general are extremely susceptible to detergency and disinfecting treatments, and there are not evidences showing higher resistance of SARS-CoV-2 (World Health Organzation, 2020b), allowing to consider appropriate the periodic cleaning of surfaces, and the sanitation of food, employing food-contact approved disinfecting agents (e.g., sodium hypochlorite, and hydrogen peroxide).

2.2. Airborne transmission and contribution of atmospheric particulate

COVID-19 airborne spread has recently been reported by on-field studies conducted at Wuhan Hospitals: RNA of SARS-COV-2 RNA was retrieved in air samples collected in the hospitals wards and outside hospital buildings, in lower quantities in the outdoor samples, compared to indoor (Zhi Nang et al., 2020; Setti et al., 2020b). Based on available outcomes, air should be considered a major route of transmission, especially considering certain aerosol-generating procedures performed in health care facilities. The potential airborne diffusion of the virus, enhancing the importance of adopting isolation measures, has been also evaluated by two recent studies conducted at two hospitals in Wuhan (China), in at-risk hospital wards and in public areas (Liu et al., 2020), and at the University of Nebraska Medical Center (Omaha, USA) (Santarpia et al., 2020), during the COVID-19 spread in February 2020. Collected samples were aerosols, and total suspended particles. The persistance of SARS-CoV-2 in the air was evidenced in Wuhan Hospital wards along the COVID-19 outbreak (from 1 to 113 copies/m^3), although the virus was not detected following the reduction of affected patients and the application of more rigorous disinfecting procedures; public spaces outside Wuhan hospitals reported the airborn presence of the virus when high number people were present (Liu et al., 2020). The study conducted at University of Nebraska Medical Center reported the 63.2% positivity from the analyzed samples, ranging from 2 to 9 copies/L (Santarpia et al., 2020).

Based on the studies regarding the viruses spreading in the population, the available literature often linked the incidence of viral infections cases with the concentrations of atmospheric polluting particulate matter (e.g., PM_{10} e $PM_{2.5}$) (Ciencewicki and Jaspers, 2007; Sedlmaier et al., 2009). Indeed, the atmospheric particulate act as a carrier, for the majority of chemical and biological contaminants, viruses included. A preliminary study, describing the possible relation, in Italy, between the COVID-19 diffusion and the exceeding of PM_{10} limit values, has been released in early 2020 (Setti et al., 2020a). The research aimed to evaluate the potential correlation between the atmospheric particulate pollution and the virus shedding. Following the collection of PM_{10} values in several italian cities (data available from Italian Regional Agencies for Health Protection, ARPA), and the identification of events of law limit values exceedings (50 $\mu g/m^3$), data were associated to the numbers of COVID-19 affected population, reported by Italian Civil Protection authority: the hypothesis was confirmed by the registration of the highest number of Italian outbreaks in Po Valley (i.e., Pianura Padana), where the highest levels of pollution are reported yearly. The researchers therefore hypothesised a potential boosting effect of SARS-CoV-2 transmission, thanks to the vehiculation through the PM_{10} (Setti et al., 2020a). The hypothesis was confirmed by a research conducted by the same working group in Northern Italy, reporting the presence of SARS-CoV-2 viral RNA (using RT-PCR, detecting *E*, *N*, and *RdRP* genes) in over the 30% of the 34 PM_{10} specimens of airborne PM_{10} sampled in the industrial area around the city of Bergamo (Italy) (Setti et al., 2020c). The atmospheric persistence of SARS-CoV-2, whose quantity still need to be deeply investigated, would amplify the risk of contracting COVID-19, making necessary periodic air monitoring, to assess the transmission risk of the virus in the most exposed environments.

2.3. Survival of Coronavirus in water, and wastewater effluents

The risk of respiratory syndromes onset and the potential environmental transmission indicates the need to collect more detailed information concerning the survival of species of *Coronavirus* genus in water environments. The survival of surrogate species of *Coronavirus*, Human *Coronavirus* 229E (HCoV), Feline Infectious Peritonitis Virus (FIPV), and *Poliovirus* 1 (PV-1), was analyzed in filtered and unfiltered tap water, and in wastewater. The evaluation on filtered tap water (beyond unfiltered samples) resulted functional to the reduction of the influence coming from the bacteria and the organic matter present in the wastewater effluent, that may inhibit the replication of the viruses under analysis (Gundy et al., 2009).

Results were presented in a study conducted in 2008. The inactivation of *Coronavirus* in water results strongly depending on the temperature, the levels of organic matter, and the presence of antagonists germs, such as *Escherichia coli*, *Enterococcus* spp., *Bacillus* spp., *Clostridium* spp., etc. (generally isolated from wastewater). To reach inactivation rates of 99,9% ($T_{99.9}$) viral load in tap water, at 23 °C, 10 days are needed; at 4 °C, the viral surrogate of SARS-CoV-2 is capable of surviving up to 588 days, considering projected values (Table 1) (Gundy et al., 2009).

The time required to inactivate the virus in wastewater plant effluents at a 99,9% rate ($T_{99.9}$) shows the rapid die off of the *Coronavirus* at 23 °C, from 2.3 to 3.5 days (Table 2), registering a mean reduction > 3 $\log_{10}$ in 3 days. *Poliovirus* 1 is able to survive for longer time, compared to *Coronavirus* (Gundy et al., 2009).

The research performed by Gundy et al., in 2009 indeed reported how the transmission risk of strains from *Coronavirus* genus could be less probable, with respects to Enteroviruses in water environments, because of the faster inactivation process of *Coronavirus* in wastewater at ambient temperatures.

2.4. SARS-CoV-2 in civil, hospital, and industrial wastewater

Wastewater may potentially contain a certain concentration of the *Coronavirus*, beyond enteric viruses; the sludge deriving from wastewater treatment plants, and class B bio-solids, for examples, was demonstrated containing *Coronavirus* genes in more than 80% of the examined samples (Wigginton et al., 2015). However, whether the SARS-CoV-2 is active in the above mentioned environmental, allowing either fecal or oral transmission has not been yet clarified. Studies on the persistance of *Coronavirus* in water (Gundy et al., 2009; Casanova et al., 2009) underlined the strong inhibiting effect on the virus survival, given by the temperature parameter. The composition of the water, included the presence of microorganisms, together with proteins, is able to highly influence virus survival (non sterilized wastewater allowed an lower survival of *Poliovirus* 1 and HAV), although the viral survival is highly reduced with temperatures > 20 °C. It was demonstrated that surrogate viruses in sterilized wastewater (autoclaved at 121 °C for 30 min) are inactivated with different rates, compared to those tested in non-sterilized wastewater (Nasser et al., 1993). Based on the same experimental protocol, the study demonstrated that *Coronavirus* surrogates are able to survive longer in non-filtered primary effluents, compared to filtered samples (Gundy et al., 2009). The increased survival rate in presence of sediments or organic matter may be due to the protection that such components offer towards chemical or biological inactivating agents in the water. The presence of exogenous material is indeed capable of causing a rapid viral inactivation, as demonstrated in a study by Casanova et al., (2009), evaluating the persistance of *Coronavirus* in pasteurized sludge, compared to the viral survival in distilled water. Based on the collected data, the effects of the matrix on the inactivation of the viral load result complex, and highly variable from a viral strain to another, and from sample to sample. SARS-CoV, for example, has been demonstrated to lose infectivity in vitro in culture media earlier than Human *Coronavirus* 229E (H—CoV 229E), considering the same conditions (Rabenau et al., 2005; Wigginton et al., 2015). The available studies on surrogate SARS-COV-2 viruses suggest to suppose that the novel *Coronavirus* may be less persistant in wastewater, mainly due to the presence of either organic matter, or inhibiting matrix autochtonous flora: such factors are indeed able to activate metabolic pathways causing the faster die-off of the viruses. The extreme infectiousness of SARS-CoV-2 led many countries to suggest a monitoring of wastewater in order to evaluate the presence of the virus in the community, mainly to extimate the asymptomatic individuals, and aiming to quantify the potential infection risks for wastewater and solid waste plants' employees (Water & Energy Sustainable Technology Center, 2020). The persistance of SARS-CoV-2 was recently evaluated in wastewater at the Amsterdam Schiphol Airport (Tilburg, Netherlands) and at the wastewater treatment plant in Kaatsheuvel (Netherlands), collecting samples weekly, from February to March 2020. The quantitative monitoring of the virus, brought out the detection of the new *Coronavirus* in the airport wastewater and in the wastewater treatment plant samples collected in March 2020. The monitoring resulted crucial, allowing to associating the presence of the SARS-CoV-2 and the occurrence and registration of the first COVID-19 cases in Netherlands. The genetic material from the virus was indeed detected in wastewater samples taken from the wastewater treatment plants starting from March 2020, while the first official COVID-19 cases in Netherlands were registered on February 27th, 2020 (RIVM Netherlands, 2020; Gale, 2020; Nabi, 2020) the outcomes, considering the mean SARS-COV-2 incubation period between 2 and 11 days, up to a maximum of 14 days (Ministero della Salute, 2020), consent to hypothesize that the first cases of COVID-19 in Netherlands may be actually placed in the

Table 1
Survival, expressed in days, of different viruses in filtered tap water, stored at 23 °C and 4 °C. Tested viral strains: Human *Coronavirus* 229E (HCoV), Feline Infectious Peritonitis Virus (FIPV), Poliovirus 1 (PV-1). The time, in days, of viral load decrease, is expressed based on the decrease rate of 99% (T_{99}) and 99,9% ($T_{99.9}$) (Gundy et al., 2009).

Virus	Tap water filtered 23 °C [days]		Tap water filtered 4 °C [days]	
	T_{99}	$T_{99.9}$	T_{99}	$T_{99.9}$
Human *Coronavirus* 229E (HCov)	6.76	6.76	392	588
Feline Infectious Peritonitis Virus (FIPV)	6.76	6.76	87.0	130
Poliovirus 1 (PV-1)	43.3	43.3	135	203

Table 2
Survival, in days, of different viral strains in wastewater (i.e., wastewater treatment plants effluents, at 23 °C. Tested viral strains: Human *Coronavirus* 229E (HCoV), Feline Infectious Peritonitis Virus (FIPV), Poliovirus 1 (PV-1). The time, in days, of viral load decrease, is expressed based on the decrease rate of 99% (T_{99}) and 99,9% ($T_{99.9}$) (Gundy et al., 2009).

Virus	Primary effluent filtered 23 °C [days]		Primary effluent unfiltered 23 °C [days]		Secondary effluent 23 °C [days]	
	T_{99}	$T_{99.9}$	T_{99}	$T_{99.9}$	T_{99}	$T_{99.9}$
Human *Coronavirus* 229E (HCov)	1.57	2.35	2.36	3.54	1.85	2.77
Feline Infectious Peritonitis Virus (FIPV)	1.60	2.40	1.71	2.56	1.62	2.42
Poliovirus 1 (PV-1)	23.6	35.5	7.27	10.9	3.83	5.74

Table 3
Persistence of the two main SARS-CoV-2 surrogates (HCoV 229E and SARS-CoV) on different types of inanimate surfaces. Reference to the studies are available in the original article (Kampf et al., 2020).

Type of surface	Virus strain	Viral Titre	Temperature	Persistence
Aluminium	HCoV 229E and OC43	10^3-$5x10^3$	21 °C	2–8 h
Metal	SARS-CoV P9	10^5	Room Temperature	5 days
Wood	SARS-CoV P9	10^5	Room Temperature	4 days
Paper	SARS-CoV GVU6109 and P9	10^5–10^6	Room Temperature	3 h to 5 days
Glass	SARS-CoV P9	10^3–10^6	Room Temperature	2–5 days
Plastic	SARS-CoV FFM1, HKU39849, and P9	10^3–10^7	20–25 °C	2–5 days
PVC	HCoV 229E	10^3	21 °C	5 days
Silicon rubber	HCoV 229E	10^3	21 °C	5 days
Surgical glove (latex)	HCoV 229E and OC43	5×10^3	21 °C	≤8 h
Disposable gown	SARS-CoV GVU6109	10^3–10^6	Room Temperature	1 h to 2 days
Ceramic	HCoV 229E	10^3	21 °C	5 days
Teflon	HCoV 229E	10^3	21 °C	5 days

time period reported by Netherland Health authorities.

In 2005, in China, Wang et al. 2020a, 2020b published the results of researches conducted to verify the presence of SARS-CoV in wastewater coming from two hospitals receiving patients affected with SARS. The outcomes reported that, following disinfection protocols (using chlorine), SARS-CoV RNA resulted still detectable from sewages from one of the hospitals involved in the monitoring. The study demonstrated that the virus is able to survive up to 2 days at 20 °C, and the inactivated viral RNA was isolated up to 8 days) (Wang et al., 2005a; Wang et al., 2005b). For this reason, it results essential to apply the adequate disinfection protocols in hospital facilities treating patients with *Coronavirus* syndromes (e.g. COVID-19), aiming to inactivate the virus (presumably persisting for the same time as SARS-CoV), containing the excessive spread in wastewater.

2.5. Sewage and bio-solids sludge viral persistance

SARS-CoV strains are generally able to survive up to 96 h in human biological specimens, such as faeces, sputum, and serum, but result a lot less stable in urine (Duan et al., 2003), probably depending on the inhibiting pH values, and the presence of urea. The faecal excretions of SARS-CoV in the past decade represented a strong concern with respects to the security measures to be applied in order to assess the waste collection in the territory. Nevertheless, as of April 2020, no cases of SARS-CoV or SARS-CoV-2 infections transmitted via sewages or sludge were reported. Some studies performed on similar viruses such as Human Immunodeficiency Virus (HIV), evaluating the persistance of the virus in such waste categories, for the time needed to consider the pathogen as a risk for human health, demonstrated that the risk is to be considered highly improbable. Moreover, it is difficult for the virus to survive to processing treatments to which waste is usually subject (Wolff et al., 2005; Environmental Science and Engineering Magazine, 2003).

2.6. Measures to contain the shedding of the virus in the environment and on surfaces

From the beginning of the global diffusion of COVID-19, following the declaration of the pandemy by World Health Organization (WHO), the health authorities from all over the world issued useful guidelines to handle the emergency. For example, regarding waste treatment, WHO and U.S. Occupational Safety and Health Administration (OSHA), indicated the measures to assess COVID-19 issue, specifying that for this peculiar pathogenic agent no special precautions need to be implemented, beyond the measures already applied to guarantee employees safety (World Health Organisation, 2020a; U.S. Occupational Safety and Health Administration, 2020). *Coronavirus* is indeed susceptible to the same disinfecting conditions employed in the sanitary system to handle the risk connected to the presence of any virus. For this reason, the disinfections protocols for the treatment of water, industrial and civil wastewater, and inanimate surfaces are considered adequate, as well as the personal protective equipment (PPE), if properly employed, that are generally used for the management of non treated waste (U.S. Occupational Safety and Health Administration, 2020). The main disinfection treatments employed in water and wastewater treatment plants consist on oxidants products such as sodium hypochlorite, peracetic acid, and hydrogen peroxide; the UV light is also employed, although less effective towards virus (U.S. Occupational Safety and Health Administration, 2020). The above mentioned disinfecting means should be optimal in SARS-COV-2 reduction and removal.

It can be hypothesised that the treatment plants collecting hospital wastewater are receiving sewage containing high concentration of the SARS-CoV-2 and, whether the virus inactivation treatments result inadequate, the risk of detecting high viral loads in the environment could come up (Casanova et al., 2009). As already premised, *Coronavirus* strains are usually less resistant to disinfection treatments, compared to other organisms which can be found in wastewater, such as *Escherichia coli* phage or human virus, such as *Poliovirus*, which, are commonly employed as surrogates for the evaluation of the efficacy of viruses inactivation (Gundy et al., 2009). Survival of *Coronavirus* strains is generally function of the temperature, showing a higher persistance at low temperatures: it may be therefore supposed that the persistance of SARS-CoV-2 in surface water and wastewater in the warm seasons may be highly reduced. In general, secondary treatments may result crucial for the logarithmic reduction of the virus (more than 90%) (Hewitt et al., 2013; U.S. Environmental Protection Agency, 1986) despite the variability in the collected data supports the need to employ the preventive application of chemical disinfection protocols (e.g., chlorination), and the aid of UV light. The efficacy of chlorination, highly oxidating treatment, additionally depends on the presence, in the matrix that has to be treated, of peculiar substances such as the ammonia, which, reacting with sodium hypochlorite, brings to the formation of chloroammines, active principles less effective virucides than free chlorine. Available researches propose the chlorination of wastewater with a 10 mg/L dosage of sodium hypochlorite, with a 30 min time of contact, and a residual chlorine value > 0.4 mg/L: the suggested disinfection methods resulted efficient to inactivate *Coronavirus* strains up to 5 log (Wang et al., 2005a). As for the disinfection using UV light, the health authorities did not specify viral inactivation protocols yet, considering that the lower inactivation efficacy of UV light, compared to the also cheaper chlorination (U.S. Occupational Safety and Health Administration, 2020). As for the treatment of surfaces in industrial facilities (e.g., food companies, or the water, wastewater, and waste treatment plants), considering the evidences of the pathogenic viruses persistence on such inanimated matrices (Kampf et al., 2020), several researches showed the removal efficacy of the virus, by testing different biocidal products. The virus is successfully eliminated from surfaces using 65–70% ethanol (or isopropanol), 0.5% hydrogen peroxide or 0.1% sodium hypochlorite, with a time of contact of 1 min; further virucidal agents such as benzalkonium chloride (up to 0.2%) or chlorhexidine digluconate based products (0.02%) were demonstrated less active in the virus inactivation (Kampf et al., 2020). European Chemicals Agency (ECHA) published a list of the most effective biocides for SARS-CoV-2 disinfection (European Chemicals Agency, 2020). World Health Organization (WHO) and the U. S. Center for Disease Control and Prevention recommended low environmental impact biocides, such as phenolic compounds, hydrogen peroxide, hydroalcoholic formulates, holding high efficacy towards the new *Coronavirus*, indicating the high susceptibility of the pathogen to the disinfecting agents used to inactivate enveloped viruses (World Health Organization, 2020c; Center for Disease Control and Prevention, 2020). For example, the biocide 2-phenylphenol, at a 0.2% concentration, is capable of breaking the viral membranes and denaturing the virus proteins (Blow et al., 2004). Hydrogen peroxide was demonstrate extremely active in the inactivation of a wide range of viruses, comprised SARS-CoV-2 surrogates (e.g., Human Coronavirus 229E, H–CoV-229E; Trasmissible GatroEnreritis Virus, TGEV), holding a die-off capability > 4 $\log_{10}$ of viral titre, in 1 min time of contact (Kampf et al., 2020; Omidbakhsh and Sattar, 2006; Chen et al., 2004; Wolff et al., 2005), additionally showing a low registered toxicity (Omidbakhsh and Sattar, 2006). Hydrogen Peroxide Vapourized (HPV) was demonstrated inactivating > 4 $\log_{10}$ viral titres of SARS-CoV-2 surrogates (feline *Calicivirus*, FCV; human *Adenovirus*-1, hADV-1; Trasmissible Gatroenreritis Virus, TGEV; etc.), at low percentages of the active principle (1400 ppm), reporting low toxicity on cells (Goyal et al., 2014). Hydrogen peroxide and 2-phenylphenol are generally employed also for food sanitation, and for surfaces disinfection, therefore representing valid alternatives to sodium hypochlorite.

3. Conclusion

COVID-19 airborne transmission has not been yet demonstrated; fecal shedding has been reported from some patients, although the viability of the virus has been evidenced at low levels. Furthermore, based on the studies on surface water, wastewater, sludge and bio-solid waste, the survival of SARS-CoV-2 would result very low with temperatures higher than 20 °C, and the inactivation rate of *Coronavirus* is usually higher than other examined viruses. The same consideration could be made for the risk coming from potentially contaminated food, for which *Coronavirus* persistance was reported for not more than 72 h of storage at 4 °C. On inanimate surfaces, strains of *Coronavirus* genus are capable to surviving up to nine days, but result extremely labile, being inactivated with really low concentrations of disinfectants.

Certainly, a prolonged exposure to contaminated environmental sources, such as the exploitation of air pollutants (e.g., PM_{10}), the extended contact with aerosols produced from wastewater and surface water plants treatment, the inadequate detergency processes of food and surfaces, may potentially lead to an augmented transmission risk, also in non immunocompromised individuals. Therefore, the proper employment, from employees of health system, water, and waste treatment plants, and industries in general, of the appropriate personal protective equipment (PPE), especially masks equipped with filters, along the production chain, the low survival of SARS-CoV-2 in environmental conditions, and the adequate application of disinfection treatments foreseen by national and international guidelines, allow to suppose that the risk linked to the transmission of the virus may result low.

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Declaration of competing interest

We have no conflict of interests for the paper titled “Persistance of SARS-CoV-2 in the environment and COVID-19 transmission from animate and inanimate matrices”.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.envpol.2020.115010.

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