JIVS JOURNAL OF ISTANBUL VETERINARY SCIENCES

Clues for zoonotic potential and transmission of Sars-CoV-2 via food and water

Ahmet Gökhan Coşkun[1], Seran Temelli[2], Ayşegül Eyigör[2]*

1. Bursa Uludag University, Institute of Health Sciences, 16059, Bursa, Turkey; **2.** Bursa Uludag University, Faculty of Veterinary Medicine, Department of Food Hygiene & Technology, 16059, Bursa, Turkey.

Coşkun A. G. ORCID: 0000-0002-5181-7577; Temelli S. ORCID: 0000-0002-8869-4929; Eyigör A. ORCID: 0000-0002-2707-3117

Review Article

Volume: 6, Issue: 2
August 2022
Pages: 52-64

ABSTRACT

As a result of the COVID-19 pandemic caused by SARS-CoV-2 virus, emerged from Wuhan, China in 2020, economic, social, and psychological problems occurred all over the world, mandating implementation of strict curfew, quarantine, travel restriction measures, and vaccinations against the virus. Initially, the source of the virus was not clearly revealed, and case reports from a market in Huanan selling animal products, coupled with sequence analyses of the isolates, revealed close similarity to coronavirus isolated from bats (RatG13) and pangolins, questioning the suspect source of SARS-CoV-2 as zoonotic. Additional epidemiological and experimental studies indicated the presence of SARS-CoV-2, and its specific antibodies in many animals such as cats, dogs, ferrets, calves, and deer. Besides, by the detection of the virus in treated waters of wastewater treatment plants, faecal shedding, and possible faecal-oral transmission of the virus gained importance. Accordingly, vegetables and fruits irrigated with contaminated water, and foods such as shellfish grown in contaminated waters had the risk of carrying the virus. Although one of the most effective ways for protection against SARS-CoV-2 is mass and booster vaccinations, emergence of new variants raises concerns on vaccines' effectiveness. Thus, urgent implementation of one health concept addressing human, animal, and environmental health as a whole is required to overcome this and other possible future pandemics. In this article, emergence, spread, zoonotic potential, faecal-oral transmission risk, and the possible role of food and water in the transmission of the SARS-CoV-2 virus were reviewed based on up-to-date published data.

Keywords: Covid-19, faecal-oral transmission, zoonotic suspicions

Article History

Received: 13.02.2022
Accepted: 27.06.2022
Available online: 08.08.2022

DOI: https://doi.org/10.30704/http-www-jivs-net.1072726

To cite this article: Coşkun, A. G., Temelli, S., & Eyigör, A. (2022). Clues for zoonotic potential and transmission of Sars-CoV-2 via food and water. ***Journal of Istanbul Veterinary Sciences, 6*(2),** 52-64. **Abbreviated Title*:* J. İstanbul vet. sci.**

Introduction

Coronavirus (CoV) is an enveloped, single-stranded (ss) RNA virus belonging to the *Coronaviridae* family. CoVs are divided into four genera: Alphacoronavirus (alpha-CoV), betacoronavirus (beta-CoV), gammacoronavirus (gamma-CoV), and deltacoronavirus (delta-CoV). As of today, there are seven types of coronoviruses that can infect humans. Two of them are CoV-229E and CoV-NL63 belonging to the alpha-CoV genus. Others are in beta-CoV genus, including CoV-OC43, CoV-HKU1, severe acute respiratory syndrome (SARS-CoV), Middle East respiratory syndrome (MERS-CoV), and SARS-CoV-2, which is newly discovered as the causative agent of the current pandemic. CoVs were first discovered in 1968, and named 'corona' meaning 'crown' in Latin, based on their crown-like appearance under electron microscopy (Masters, 2006; Ye et al., 2020).

*Corresponding Author: Ayşegül Eyigör
E-mail: aeyigor@uludag.edu.tr

Until the end of 2002, CoVs were known as viruses that cause mild diseases, such as mild upper respiratory diseases and colds. However, with the outbreaks of SARS-CoV between 2002-2003, and MERS -CoV of 2012, the perspective on the virus changed, due to concerns about the pathogenicity and increased pandemic potential of CoVs (Harypursat and Chen, 2020). CoVs circulate among many species in nature affecting gastrointestinal, respiratory, central nervous system, and liver, thus causing infections in humans, cattle, birds, bats, rodents and wild animals. After SARS-CoV and MERS-CoV epidemics, CoVs gained importance, and wild animals such as bats were indicated as natural hosts of the virus in both epidemics, where various intermediate hosts as camels and civets had roles in transmission to humans. Likewise, in SARS-CoV-2 epidemic of December 2019, initial source and intermediate hosts of infection is thought as bats, and wild animals such as pangolins sold in wild animal market in Wuhan, respectively (Lam et al., 2020; Rodriguez-Morales et al., 2020).

SARS-CoV infection progressed with malaise, headache, myalgia, fever, cough, dyspnea and eventually respiratory failure, causing 8096 cases and 774 deaths (9.5% mortality rate). SARS-CoV was also isolated from bats, which was shown as evidence that the virus is zoonotic and transmitted to humans via intermediate hosts (Kiulia et al., 2015; Wassenaar and Zou, 2020; Ye et al., 2020).

MERS-CoV infection had symptoms as myalgia, diarrhoea, fever, sore throat, cough, respiratory and multi-organ failure, causing 2494 cases and 858 deaths (34.4% mortality rate) to date. In seroepidemiological studies, MERS-CoV antibodies were found in dromedary camels suspected as the zoonotic source of MERS infection by direct contact and processing / consumption of camel meat and milk (Ay, 2020).

SARS-CoV-2 Virus

Origin: COVID-19 emerged in Wuhan, China, towards the end of December 2019, and was declared 'public health emergency' by World Health Organization (WHO) on January 30, 2020. On March 11, 2020, COVID-19 infection caused by SARS-CoV-2 virus was confirmed as a pandemic by WHO. The first case of COVID-19 disease was reported in China on December 31, 2019, and the first death occurred on January 11, 2020. The first case was detected in Turkey on the day the disease was announced as a pandemic by WHO on March 11, 2020, and the first death occurred on March 15, 2020 in our country (Göncüoğlu et al., 2020).

Spread: SARS-CoV-2 infects humans by direct contact with infected or asymptomatic people, such as contact with mouth, nose or eyes, after contact with infected surfaces or inhalation of droplets after coughing or sneezing. Infection through contaminated environmental routes can also occur, as supported by isolation of SARS-CoV-2 from faecal samples. Depending on environmental factors, there is also a risk of nosocomial transmission. In addition, the virus can hang in the air for at least 30 minutes without losing its infectivity in closed and poorly ventilated environments such as buses (Mohan et al., 2021; Ren et al., 2020). Also, SARS-CoV-2 is more stable on plastic and stainless steel surfaces than copper and cardboard, and can maintain its viability on these surfaces for up to 72 hours (van Doremalen et al., 2020). Still, a study from Bangladesh reported 7.29% SARS-CoV-2 RNA carriage by RT-PCR in 425 banknotes collected from the market, emphasizing application of appropriate hygiene measures to the circulating banknotes (Akter et al., 2021).

Course of COVID-19: COVID-19 can progress asymptomatically, as well as with one or more symptoms such as fever, cough, chills, dyspnea, chest pain, pneumonia, myalgia, headache, fatigue, sputum formation, haemoptysis, nausea, vomiting and diarrhea (Huang et al., 2020; Li et al., 2020). In addition, disorders in taste (dysgeusia, hypogeusia, ageusia) and smell (anosmia, hyposmia) are also observed (Giacomelli et al., 2020). A study from China reported these clinical features (number of patients) in decreasing order as fever (82), cough (81), respiratory distress (31), muscle pain (11), confusion (9), headache (8), sore throat (5), rhinorrhoea (4), chest pain (2), diarrhea (2), vomiting (1) in 99 (67 male and 32 female) COVID-19 patients treated at a hospital in Wuhan, with 11 deaths (Chen et al., 2020). Another study from Bangladesh, psychological effects of COVID -19, such as depression, anxiety, insomnia, and suicidal thoughts were investigated on 10,067 participants, and indicated that community psychology was adversely affected by the pandemic (Pakpour et al., 2020).

SARS-CoV-2 and Its Zoonotic Potential: In China, domestic and wild exotic animals (chicken, pheasant, rabbit, snake, civet, pangolin, mouse, salamander, dog, wolf, marmot, beaver, porcupine, crocodile) are frequently consumed for their supposedly health benefits. These animals are kept together in cages alive in close contact to each other, and slaughtered immediately for their meat after purchase. Carrier animals kept under these conditions may well lead to rapid transmission of the virus to other animals or even to humans (Duda-Chodak et al., 2020). In initial emergence of COVID-19, first identified cases were epidemiologically related to a market, where live animals and animal products were sold in Wuhan, Hubei region of China (Lu et al., 2020a). Thus, a systematic review of recent epidemiological, genetic and experimental studies investigating the primary source of the disease, and questioning its zoonotic potential are presented below in detail.

Epidemiological studies: The fact that SARS-CoV-2 emerged from Huanan seafood market, where live animals and animal products are sold, and the first cases appeared in people residing very close to this market or working / shopping in this market show that this location may be the source of the virus, and this situation increased the possibility of the virus being of zoonotic origin. For this reason, this market was temporarily closed by the Chinese government on January 1, 2020 (Duda-Chodak et al., 2020). In an epidemiological study conducted in a hospital in Wuhan, 27 (66%) of 41 COVID-19 patients with symptoms were reported to have direct contact with the Huanan seafood market (Huang et al., 2020), while in another study, 49 (49.5%) of 99 patients reported to have contacts to this market (Chen et al., 2020).

Among studies examining the role of animals, namely cats and dogs in transmission from animal to human in different countries; in Italy, oropharyngeal, nasal and rectal swabs of 603 dogs and 316 cats in regions, where COVID-19 disease was epidemic, were all negative by RT-PCR. In the same study, serum samples taken from 451 dogs and 191 cats within the same group were examined by plaque reduction neutralization test (PRNT), and antibodies were detected in 15 dogs (3.3%) in the titer range of 1/20 – 1/160, and in 11 cats (5.8%) in the titer range of 1/20 – 1/1280, indicating that cats were more susceptible to the disease than dogs, and although the risk of virus transmission from pet animals to humans is not high, this risk should not be ignored in natural environments with highly populated animals (Patterson et al., 2020). Similarly, in a study conducted in China, presence of antibodies against SARS-CoV-2 was investigated in 102 serum samples collected from cats of Wuhan region after COVID-19 pandemic, and antibodies were detected in titers ranging from 1/20 to 1/1080 in 11 samples (10.78%), showing that SARS-CoV-2 could also infect cats (Zhang et al., 2020a). In France, a serological study was carried out on 47 pets (34 cats, 13 dogs), whose owners had COVID-19, and 38 pets (16 cats, 22 dogs) with owners of unknown disease status. Antibodies against SARS-CoV-2 were detected in 8 (23.5%) cats and in 2 (15.4%) dogs with infected owners, and only in one pet of an owner with unknown disease status. Study results showed higher seropositivity in pets of COVID-19 patients, suggesting owners could play a role in the transmission of the virus to animals rather than other animals (Fritz et al., 2020).

Genetic studies: Whole genome sequence results, indicating close similarity between Sars-Cov-2 and viruses isolated from animals such as pangolin and bat; and recent studies showing reverse zoonotic events occurring between humans and animals such as mink, pet animals (cat and dog) and mouse, have led to a conclusion that there is a tight relation between these viruses of different hosts (Wu et al., 2020a). For instance, a study from China, SARS-CoV-2 whole-genome sequences of 9 patients, 8 of whom had visited the Huanan seafood market in Wuhan, had higher (87.99% and 87.23%) similarity to 2 SARS-like bat CoVs (bat-SL-CoVZC45 and bat-SL-CoVZXC21), respectively, than to the SARS-CoV (79%) and MERS-CoV (50%) (Lu et al., 2020b). In another study, whole genome comparisons of SARS-CoV-2-related coronavirus isolates from two Rhinolophus shameli bats in Cambodia in 2010 (RshSTT200 and RshSTT182) were found to share 92.6% genetic similarity to SARS-CoV-2 (Hul et al., 2021). Another recent genome sequence analyses of SARS-CoV-2 virus results revealed 96.2% similarity to the coronavirus isolated from the bat (RaTG13), indicating that SARS-CoV-2 virus originated from bats (Zhou et al., 2020). Similarly, another study, which reported 91.02% and 90.55% similarity between coronavirus isolates from pangolin and bat, respectively to SARS-CoV-2, suggested that pangolins, like bats, could be natural reservoirs of this virus circulating among animals (Lam et al., 2020; Zhang et al., 2020c). A study from Hong Kong investigated genetic similarities of human and animal SARS-CoV-2 isolates from 15 dogs with SARS-CoV-2-infected owners, where 2 dogs were found infected with the virus with no signs of the disease. Based on the results of genetic sequence analysis, similarity was detected between viruses isolated from dogs and viruses in human cases, and it was stated that this could be an indicator of transmission from humans to animals (Sit et al., 2020). In another study carried out in Netherlands, genome sequence analysis of the virus isolated from 16 mink farms, where SARS-CoV-2 virus emerged, showed that the virus was first introduced to animals by humans, then evolved and circulated among minks, and then transmitted back to humans. Results indicated that virus can be transmitted from animal to human in mink farms (Munnik et al., 2021). A parallel study by Wei et al. (2021) suggested that the progenitor of Omicron variant jumped from humans to mice and mutated in the host, then jumped back into humans, and indicated a reverse zoonotic event from humans to mice.

Experimental studies: Palmer et al. (2021) emphasized the importance of detecting the animal species susceptible to SARS-CoV-2 in nature to determine the origin, potential reservoir, and intermediate hosts of the virus. In their study, white-tailed deer (Odocoileus virginianus), a species with high similarity to humans in terms of angiotensin-converting enzyme 2 (ACE2), was intranasally inoculated with SARS-CoV-2, and infectious virus shedding was detected in nasal secretions, and faeces of this animal with subclinical infection. In addition, deer fawns, which did not receive viral inoculation, but were in contact with infected animals were also infected, and virus shedding was detected in their nasal secretions and faeces, as well. Serological examinations from both virus inoculated and from contact animals revealed that antibodies against the virus started to observe at the end of day 7, and that white-tailed deer was a highly susceptible species to this infection. In another study from China, the SARS-CoV-2 virus was inoculated intranasally to a group of animals consisting of cats, dogs, pigs, chickens, ferrets and ducks to determine their susceptibility to the virus. Study results indicated that ferrets and cats were highly susceptible to the virus, and the virus can replicate in these animals. Contrarily, dogs had lower, pigs, chickens, and ducks had no susceptibility to the virus. The same study, which also found that transmission occurs by air in cats, reported that surveillance studies on these animals in the future would be important in terms of providing helpful information in the elimination of COVID-19 in humans (Shi et al., 2020). In South Korea, ferrets, which were experimentally infected with SARS-CoV-2, developed symptoms such as fever, bronchiolitis and cough in two days. Also, viral RNA was detected in nasal fluid, saliva, stool, and urine samples obtained from animals, which spread the virus for 8 days after the onset of infection. Sars-Cov-2 RNA, detected in some ferrets sharing the same environment with the infected animals, indicated that airborne infection could also occur among ferrets. Authors suggested that ferrets can be used as a model for the development of vaccines and drugs against COVID-19 due to the resemblance of the symptoms developed in ferrets and humans (Kim et al., 2020). A study from Germany experimentally infected 6 calves with SARS-CoV-2 through intranasal inoculation, while 3 calves were left uninoculated but in close contact with the inoculated calves. SARS-CoV-2 RNA was detected in nasal swabs of 2 calves in the days of 2 and 3 following inoculation, and antibodies were detected in both calves, while no viral RNA was found in uninoculated calves. Authors concluded that although cattle have lower susceptibility to the disease, anthropo-zoonotic infections can occur in large farms, where infected animal owners or animal keepers work in close contact with cattle (Ulrich et al., 2020). Naturally and experimental occurrence of the disease in many domestic and wild animals, and high sequence similarity between viruses isolated from bats and pangolins, and to SARS-CoV-2 isolates of humans, increase and support the possibility that the source of the disease is zoonotic. Besides bats and pangolins, emergence of the virus in cats, dogs, tigers, lions, and minks increases the concerns of reverse zoonotic transmission (Dhama et al., 2020). However, there are no official declarations either from World Animal Health Organization (OIE) or WHO on the zoonotic transmission of SARS-CoV-2 from pet animals as cats and dogs to humans (Acter et al., 2020). On the other hand, on April 6, 2020, the SARS-CoV-2 s was first detected in a tiger, and later in lions at the Bronx Zoo in New York, USA, where the virus transmission to these animals by an asymptomatic zoo worker was suspected (USDA, 2020).

The role of faecal-oral transmission, food, and water in SARS-CoV-2 infection

Faecal-oral transmission of Sars-Cov-2: In 2020, live detection of SARS-CoV-2 in human excreta, water and sewage suggested the possibility of the virus transmission via faecal-oral route, and food and water. This is a particularly important risk factor in developing countries, which apply agricultural irrigation with contaminated water, with inadequate wastewater treatment systems (Aboubakr et al., 2021). In a study conducted in the same year, SARS-CoV-2 RNA was also detected in urine samples, although not as frequently as in stool samples. Results indicated that the viral load in urine (102-105 gc/ml) and in faeces (102-107 gc/ml) was lower than those in nasopharyngeal fluid samples (105-1011 gc/ml). For this reason, contaminated water with sewage, plants irrigated with this type of contaminated water, or food produced from shellfish grown in these waters can serve for the transmission of the virus (Jones et al., 2020). Since enterocytes are rich in ACE2 receptors, they can easily be infected with the SARS-CoV-2, and replication of the virus in intestinal epithelium supports the possibility of the virus' faecal spread (Lamers et al., 2020). In a data-based analysis study on the transmission of the SARS-CoV-2 to the environment with faeces, average viral concentration, and duration of shedding was 3.4 log virus copies/g, and 20-32 days after the onset of symptoms, respectively (Miura et al., 2021). In another study, 15 (25.4%) of 59 patients treated for COVID-19 in Hong Kong showed gastrointestinal symptoms, and viral RNA was detected in 9 (15.3%) stool samples. When similar studies were examined, 17.6% of a total of 4243 COVID-19 patients showed gastrointestinal symptoms, where 48.1% had SARS-CoV-2 RNA in their stools. Study reports indicated the importance of faecal shedding of the virus even in asymptomatic patients (Cheung et al., 2020). In 8 out of 10 paediatric patients infected with SARS-CoV-2, viral RNA was detected in rectal swabs even after nasopharyngeal swab specimens turned negative, indicating the possibility of both longer duration of faecal shedding, and faecal-oral transmission (Xu et al., 2020). Also, patients with viral RNA detected in stool samples carried SARS-CoV-2 RNA in their stools for at least two weeks after the symptoms of the disease subsided (Pan et al., 2020). In a patient treated for COVID-19, viral RNA was detected in stool on day 33, despite no detection in respiratory tract samples. Another patient with viral RNA in the stool for 47 days after the onset of symptoms indicated the persistence of the virus in stool for longer periods than the respiratory system (Wu et al., 2020b). Similarly, in a study conducted on 3 children, who were treated for COVID-19 in China, virus shedding in stool for 10 days despite negative throat swab samples proved the possibility of faecal-oral transmission of SARS-CoV-2 infection (Zhang et al., 2020b). Another study from China, 93 (36%) of 258 COVID-19 patients' stool samples were found to have SARS-CoV-2 RNA, and although some patients had negative results from oropharyngeal swabs, viral RNA was detected in stool samples. For this reason, authors emphasized that oral swabs, which could not be sufficient for virus detection from infected individuals, should be accompanied by faecal samples (Zhang et al., 2020d).

SARS-CoV-2 virus has been stated to acquire the potential for fecal-oral transmission due to its capacity for multiplication in the human gastrointestinal tract and fecal shedding, and surviving on surfaces for a long time. Based on epidemiological study results showing viral RNA detection in wastewater, occurrence of faecal-oral transmission through the consumption of contaminated drinking water, raw or undercooked saltwater or freshwater products harvested from contaminated sources, and vegetables irrigated with contaminated waters could be expected. There is additional risk for this type of infection in developing countries due to inadequacy of drinking water supplies, improper hygiene applications in food chains, and insufficiencies in health services (Gwenzi, 2021).

Sars-Cov-2 in food and food industry: Today, although there is no clear data on direct food-borne transmission in COVID-19, one cannot assume that contact with food is entirely safe. After determination of high resistance of the virus against environmental conditions, and its detection in the stool in recent studies, Yekta et al. (2021) reported that food should be cooked at 60°C for at least 15 minutes for inactivation of the virus against possible faecal-oral transmission.

Another study from France, conducted to determine the role of shellfish as indicators of SARS-CoV-2, seawater and shellfish (oysters, mussels, clams) were collected between April and August 2020 from the coasts of the touristic beaches. Detection of only human norovirus, but not SARS-CoV-2 RNA in the samples, directed the researchers to conclude that shellfish are good indicators for microbial quality of their environment (Desdouits et al., 2021).

Food facilities, where SARS-CoV-2 virus infected personnel are allowed to work pose a great risk to consumers. In order to reduce this risk, effective food safety control systems together with hygiene applications for personnel, food contact surfaces, and packaging materials must be implemented in the facilities. Utmost care must be taken for: 1 - cleaning and disinfection of the premise, 2 - correct use of protective equipment such as masks and gloves, 3 - social distance between personnel, and 4 - placement of hand disinfectants at easily accessible points within premises (Duda-Chodak et al., 2020). German Federal Institute for Risk Assessment (BfR) report indicated that although there is no definitive proof of transmission of the SARS-CoV-2 virus via food, washing of the textile products as clothes and towels at a temperature of at least 60°C should not be ignored. The same report emphasized contaminated frozen foods as a risk factor, and compliance with hygiene rules in food facilities due to the resistance of viruses in the Coronaviridae family to cold (BfR, 2021). In a study by Shahbaz et al. (2020), washing hands with soap under hot water for at least 20 seconds, sanitation and disinfection of surfaces in contact/non-contact with food, complying with the rule of at least two meters social distance between employees, placing hand disinfectants at the entrances and all accessible places within the enterprise, using appropriate protective clothing for personnel, and taking routine body temperature controls were stated as measures to prevent COVID-19 outbreaks in food facilities. In addition, the importance of reducing contact between personnel by dividing employees into small groups during meal breaks and other breaks, and on-line meetings instead of face-to-face was emphasized. Authors once more pointed out the use hand disinfectants would not replace but only be adopted as an additional preventive measure to hand washing. In a study examining SARS-CoV-2 outbreaks in meat processing facilities in Germany, Günther et al. (2020) stated that environmental conditions such as low ambient temperature and air exchange/refreshing rates, constant air circulation, insufficient social distance between personnel, and overwhelming working load could cause further virus spreading. In the same study, two meters of social distance was reported as insufficient in facilities with these environmental conditions, and implementation of a social distance of at least eight meters between people was advised. Efficient ventilation and air filtering, in addition to the use of high protective masks were also indicated as important factors to reduce infection, particularly in meat and fish processing facilities. Based on United States Centers for Disease Prevention and Control (CDC) report, 4,913 of 130,578 employees from 115 poultry and red meat processing facilities in 19 states had COVID-19 infection with 20 deaths, where physical conditions and working environment were stated as important risk factors in such food businesses (Dyal et al., 2020).

Sars-Cov-2 in water and wastewater: Recent studies from Netherlands (Medema et al., 2020), Spain (Balboa et al., 2021; Randazzo et al., 2020), Italy (La Rosa et al., 2020), Japan (Haramoto et al., 2020; Hata, Hara-Yamamura et al., 2021), United States (Gonzalez et al., 2020; Sherchan et al, 2020), England (Hillary et al., 2021), Serbia (Kolarevic et al., 2021), Hungary (Róka et al., 2021) and Australia (Ahmed et al., 2020) reported the detection of SARS-CoV-2 RNA in wastewater, and indicated the possibility of faecal-oral transmission of the virus should not be overlooked. In this context, focus was given to review the studies below on Wastewater Based Epidemiology (WBE) of municipalities, hospitals, and reports on the detection of viral RNA in various water samples, which were conducted in different continents and countries.

In studies from different continents related to WBE, a study from USA by Weidhaas et al. (2021), detection of SARS-CoV-2 RNA in 61% of 126 wastewater treatment plant samples collected between April and May 2020 was linked to the viral RNA increase in wastewater in parallel to the rise in the cases in the community, emphasizing the importance of WBE studies for public health during the pandemic. Similarly, in a study conducted in Australia, 21 out of 63 (33.3%) wastewater treatment plant water samples collected between February 24 and May 1, 2020, were positive for SARS-CoV-2 RNA. Detection of viral RNA in samples taken up to three weeks before the first clinical case notification in South Brisbane suggested the use of WBE as an early warning system against COVID-19 by the authors (Ahmed et al., 2021b). Parallel to this, findings from wastewater samples collected between June and August 2020 in Canada, where presence of the virus in samples increased 48 hours before new COVID-19 cases, and 96 hours before hospitalizations, implied WBE as more useful than clinical tests in determining the fluctuations of COVID-19 cases in the community (D'Aoust et al., 2021). In South Africa, SARS-CoV-2 presence and load was examined in samples collected from 4 wastewater treatment plants in Central, Isipingo, Darvil, and Howick, suggesting WBE based studies could be used to predict the prevalence of the virus in the population. In the report, viral RNA was detected in all (14/14) Central and Isipingo, and 12 (86%) and 13 (93%) of Darvil and Howick samples. Viral loads of the plants were 3 (x) 104 - 7.32 (x) 105 gc/100 ml, 1.55 (x) 104 - 4.12 (x) 105 gc/100 ml, 0 - 2.73 (x) 105 gc/100 ml, and 0 - 1.52 (x) 105 gc/100 ml, respectively (Pillay et al., 2021).

In one study from Asia, untreated and treated water samples of 11 different wastewater treatment plants in the United Arab Emirates between May and June 2020 were examined, and only 85% of untreated water samples were reported positive for the presence of SARS-CoV-2 (Hasan et al., 2021).

In studies from Europe on WBE, Baldovin et al. (2021) from Italy, presence of viral RNA in 4 of 9 untreated and both of the 2 treated wastewater samples indicated that viral RNA could still be detected in wastewater even after treatment, and the importance of WBE studies was once more emphasized. A second study conducted in Italy in 2020 by Rimoldi et al. (2020), untreated and treated water samples from 3 wastewater treatment plants, and water samples taken from 3 rivers from Milan region were examined for SARS-CoV-2 by RT-PCR. SARS-CoV-2 was present in untreated waters, whereas viral RNA was not detected in treated waters. Sequence analysis of the virus isolates indicated that virus was the most common strain in Europe and was not infective in the cell culture test. Sars-CoV-2 RNA in river samples were suspected as a contamination of sewage or discharge of insufficiently treated waters into the rivers and isolate from this source had no potential infectivity. A study from Sweden, SARS-CoV-2 was detected by RT-PCR method in both treated and untreated samples collected weekly from 5 treatment plants in and around Gothenburg between February and June 2020, where a decrease of 4 log10/l in the viral genome in treated waters, and an increase in viral load in wastewater during peak periods of the epidemic in the community was reported (Saguti et al., 2021). In a study conducted in 9 wastewater treatment plants in Germany, SARS-CoV-2 RNA was detected both in untreated and treated samples, where isolated viral

RNAs' sequences showed significant similarity to human isolates. However, Caco-2 cell culture results indicated that viruses detected in treated wastewater had no infectious potentials to cell culture (Westhaus et al., 2021). A WBE study on hospital related samples from Slovenia, 10 out of 15 SARS-CoV-2 RNA positive hospital wastewater samples (66.7%), where COVID-19 patients were treated, indicated the importance of WBE in determining the social prevalence of COVID-19 disease (Gonçalves et al., 2021).

There are also 'first time' detection reports of SARS-CoV-2 RNA from different water sample types. In one of those reports, Ahmed et al. (2021a) from Australia identified SARS-CoV-2 RNA from cruise and aircraft wastewater tank samples. One other 'first time report' from Mexico examined viral RNA and load in groundwater, dam, and river water samples, which were intentionally collected between October and January 2020 to coincide the SARS-CoV-2 virus peaks, and found viral RNA at the rates of 44%, 12%, and 13% and the viral loads 2.6-38.3 gc/ml, 3.3-3.8 gc/ml, and 2.5-7.0 gc/ml of the samples, respectively (Mahlknecht et al., 2021).

Additionally, the presence of SARS-CoV-2 virus in aquatic environment was investigated in several studies. In 2021, de Oliveira et al. examined the T90 (time required for 1 log reduction) and T99 (time required for 2 log reduction) in viral load over time in two different temperature values (24°C and 4°C) in river water (RW) and wastewater (WW) samples, where from each water type, one sub-group was unfiltered (U, untreated), while another sub-group was filtered (T, treated). At 24°C, T90 and T99 of URW and UWW were 1.9 and 1.2 days, and 6.4 and 4.0 days, respectively. At the same temperature, T90 and T99 of TRW and TWW were 3.3 and 1.5 days, and 8.5 and 4.5 days, respectively. The detection period of the virus increased at 4°C to T90 of 7.7 and 5.5 days for RW and WW, while T99 was reported as 18.7 and 17.5 days. Similarly, in another study by Sala-Comorera et al. (2021), T90 of SARS-CoV-2 virus was measured in river (R) and seawater (S) at 4°C and 20°C. The T90 of the virus in R and S were 3.8 and 2.2 days at 4°C, and 2.3 and 1.1 days at 20°C, respectively, indicating that the virus was more stable in cold conditions and in river water. In a study from Finland, Hokajärvi et al. (2021) collected wastewater plant samples in Helsinki, and stored aliquots at 4°C, -20°C, and -75°C for 84 days to determine the effect of storage temperature on the virus stability. By day 84, viral RNA was detected in all samples, indicating its stability especially in frozen storage conditions. Results suggested that samples from wastewater facilities, which could not be processed immediately should be frozen.

Conclusion

COVID-19 pandemic and similar outbreaks are increasing threats and concerns to humankind mainly as a result of worldwide intentional damage given to forests, thus disturbing natural balance of the ecosystem. Poaching, game meat trade, uncontrolled animal-derived food production and consumption, and increased international trade and travel play vital roles for the occurrence of these problems. Thus, as animal and human health are intermingled, greater concerns for recurrence of zoonotic diseases require strategies to develop and sustain new prevention, diagnosis, and treatment approaches (Contini et al., 2020).

For safe and wholesome food, companies establish quality assurance systems such as Hazard Analysis and Critical Control Points (HACCP), Good Hygiene Practices (GHP), Good Manufacturing Practices (GMP) and standards such as British Retailers Association (BRC), ISO 9000 and ISO 22000. However, these approaches remained inadequate during COVID-19 pandemic, as stated by Jawed et al. (2020), mainly because the agent was then an 'unidentified' hazard, food facilities required a broader system, spanning food fraud and food defense besides HACCP. In the current pandemic, although wild animal trade was thought important in the spread of the SARS-CoV-2, measures taken to prevent the wild animal trade were not sufficient, and that countries should take more effective measures in this regard (Morcatty et al., 2021).

The fact that the origin of SARS-CoV-2 virus is still not clearly revealed, possibility and concerns of faecal-oral transmission have increased consumer interest in food safety and affected consumption habits. A study from Germany indicated an increase in food safety concerns and anxiety during the pandemic, with a negative perception towards game meat consumption in the society (Yang, 2020). Similarly, a Chinese study revealed that the pandemic had a significant positive effect on the food safety knowledge and behavior of the consumers (Min et al., 2020).

There is no specific cure against the SARS-CoV-2 virus, thus strict adherence to up-to-date protection and control measures maintain their importance. Today, vaccination is the most effective approach to keep the pandemic in control, and vaccines produced by various companies are already in use as well as there are vaccine candidates in the approval phase (WHO, 2021). In addition, due to continuous mutations, many new variants such as England, South Africa, Brazil, United States, Japan and India keep emerging (Mahase, 2021; Tao et al., 2021). Also recently, a variant has emerged in South Africa called

Omicron, which is rapidly increasing COVID-19 cases and is likely to be the most contagious variant so far (He et al., 2021). Therefore, in addition to the increase in the contagiousness of the virus, there are also concerns on the effectivity of the currently administered vaccines against new variant viruses.

Apart from vaccination, based on the phylogenetic relatedness, and cross immunity between Bovine coronavirus (BCoV) and SARS-CoV-2 virus, consumption of immune milk containing anti-BCoV antibodies (Bovine coronavirus immune milk-BIM) obtained from cows vaccinated with BCoV was reported to completely or partially inactivate the SARS -CoV-2 virus with a vaccine-like and immunostimulant effect, which could help activate intestinal immune system (Gut-associated lymphoid tissue - GALT) and boost passive immunity (Arenas et al., 2021). Another passive immunity approach reported was immunoglobulin G (IgG) collection from people, who have had the COVID-19, and transferring it to new patients to stimulate the immune system. Similarly, vaccination of cows against SARS-CoV-2 before collecting their milk or colostrum to increase the specificity of IgG in the milk or colostrum against virus, and consumption of this hyperimmune milk was thought to provide short-term protection in individuals (Jawhara, 2020). Another study by Campione et al. (2020), lactoferrin was reported to protect against the coronavirus infection by acting either as natural protector of both respiratory and intestinal mucosa or reverting the iron disorders occurring during viral colonization, suggesting that it could be used to prevent worsening of the course of the disease in mildly symptomatic and asymptomatic patients. A study by Pace et al. (2021), milk produced by SARS-CoV -2 infected mothers, a rich source of specific antibodies as IgA and IgG against the SARS-CoV-2, was suggested for consumption to help neutralize the SARS -CoV-2 activity. In another study by Baird et al. (2021), human milk after vaccination showeding high levels of SARS-CoV-2 specific IgA and IgG antibodies were recommended to protect infants against the virus. Considering the tight link between human, animal and environmental health, one health approach has gained even more importance in COVID-19 pandemic, indicating health programs should keep highlighting this issue in the future (Bonilla-Aldana et al., 2020), in combination with antimicrobial resistance and food safety (Kanamori et al., 2021).

Another huge negative impact of the pandemic is on world's economy, and social psychology. Although there is no official statement about the origin of the virus, zoonotic suspicions are growing after the virus first appeared near the wild animal market in Huanan, and recent studies have shown a great similarity between the SARS-CoV-2 virus and coronaviruses isolated from wild animals such as bats and pangolins. At the same time, the risk of reverse zoonotic infection should not be ignored, as the virus can naturally infect various animals, including pets, and many animals can be experimentally infected. However, the possibility of faecal-oral transmission of the virus is also considered after WBE studies detect the presence of SARS-CoV-2 virus in wastewater, groundwater and rivers, and after detection of the virus being shed in feces and urine, including in asymptomatic patients. In developing countries, the risk of faecal-oral transmission increases further due to inadequate water treatment systems, uncontrolled animal food production and trade. For this reason, precautions should be taken by considering the possibility of faecal-oral contamination in food facilities.

COVID-19 pandemic explicitly indicated how close human, animal and environmental health are, and that a problem in one affects the others as a chain reaction. All measures taken until now and in the future seriously requires immediate action to implement 'one health approach', where veterinary medicine, human medicine and environmental experts work in a harmony to develop control strategies on public health protection to prevent possible future epidemics.

Conflict of interest

The authors declare no conflict of interest for the present study.

References

Aboubakr, H. A., Sharafeldin, T. A., & Goyal, S. M. (2021). Stability of SARS-CoV-2 and other coronaviruses in the environment and on common touch surfaces and the influence of climatic conditions: A review. *Transboundary and emerging diseases, 68*(2), 296–312.

Acter, T., Uddin, N., Das, J., Akhter, A., Choudhury, T. R. & Kim, S. (2020). Evolution of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) as coronavirus disease 2019 (COVID-19) pandemic: A global health emergency. The *Science of the Total Environment, 730*, 138996.

Ahmed, W., Angel, N., Edson, J., Bibby, K., Bivins, A., O'Brien, J. W., Choi, P. M., Kitajima, M., Simpson, S. L., Li, J., Tscharke, B., Verhagen, R., Smith, W., Zaugg, J., Dierens, L., Hugenholtz, P., Thomas, K. V., & Mueller, J. F. (2020). First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: A proof of concept for the wastewater surveillance of COVID-19 in the community. *The Science of the total environment, 728*, 138764.

Ahmed, W., Bertsch, P. M., Angel, N., Bibby, K., Bivins, A., Dierens, L., … & Mueller, J. F. (2021a). Detection of SARS-CoV-2 RNA in commercial passenger aircraft and cruise ship wastewater: A surveillance tool for assessing the presence of COVID-19 infected travellers. *Journal of Travel Medicine, 27*(5), taaa116.

Ahmed, W., Tscharke, B., Bertsch, P. M., Bibby, K., Bivins, A., Choi, P., … & Mueller, J. F. (2021b). SARS-CoV-2 RNA monitoring in wastewater as a potential early warning system for COVID-19 transmission in the community: A temporal case study. The *Science of the Total Environment, 761*, 144216.

Akter, S., Roy, P. C., Ferdaus, A., Ibnat, H., Alam, A., Nigar, S., Jahid, I. K., & Hossain, M. A. (2021). Prevalence and stability of SARS-CoV-2 RNA on Bangladeshi banknotes. The *Science of the total environment, 779*, 146133.

Arenas, A., Borge, C., Carbonero, A., Garcia-Bocanegra, I., Cano-Terriza, D., Caballero, J. & Arenas-Montes, A. (2021). Bovine Coronavirus Immune Milk Against COVID-19. Frontiers in Immunology, 12, 637152.

Ay, A. (2020). Orta Doğu Solunum Sendromu Coronavirüsü Salgınları. ESTÜDAM Halk Sağlığı Dergisi, 5(1), 158–167.

Baird, J. K., Jensen, S. M., Urba, W. J., Fox, B. A. & Baird, J. R. (2021). SARS-CoV-2 Antibodies Detected in Mother's Milk Post-Vaccination. Journal of Human Lactation, 37(3), 492-498.

Balboa, S., Mauricio-Iglesias, M., Rodriguez, S., Martínez-Lamas, L., Vasallo, F. J., Regueiro, B. & Lema, J. M. (2021). The fate of SARS-COV-2 in WWTPS points out the sludge line as a suitable spot for detection of COVID- 19. Science of the Total Environment, 772, 145268.

Baldovin, T., Amoruso, I., Fonzo, M., Buja, A., Baldo, V., Cocchio, S. & Bertoncello, C. (2021). SARS-CoV-2 RNA detection and persistence in wastewater samples: An experimental network for COVID-19 environmental surveillance in Padua, Veneto Region (NE Italy). Science of the Total Environment, 760, 143329.

Bonilla-Aldana, D. K., Holguin-Rivera, Y., Perez-Vargas, S., Trejos-Mendoza, A. E., Balbin-Ramon, G. J., Dhama, K., … & Rodriguez-Morales, A. J. (2020). Importance of the One Health approach to study the SARS-CoV-2 in Latin America. One Health, 10, 100147.

Bundesinstitut für risikobewertung (BfR), (2021, February, 15). Can the new type of coronavirus be transmitted via food and objects? https://www.bfr.bund.de/en/can_the_new_type_of_coronavirus_be_transmitted_via_food_and_objects_-244090.html

Campione, E., Cosio, T., Rosa, L., Lanna, C., Di Girolamo, S., Gaziano, R., … & Bianchi, L. (2020). Lactoferrin as protective natural barrier of respiratory and intestinal mucosa against coronavirus infection and inflammation. International Journal of Molecular Sciences, 21, 4903.

Chen, N., Zhou, M., Dong, X., Qu, J., Gong, F., Han, Y., … & Zhang, L. (2020). Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan , China: a descriptive study. The Lancet, 395(10223), 507–513.

Cheung, K. S., Hung, I. F. N., Chan, P. P. Y., Lung, K. C., Tso, E., Liu, R., … & Leung, W. K. (2020). Gastrointestinal Manifestations of SARS-CoV-2 Infection and Virus Load in Fecal Samples From a Hong Kong Cohort: Systematic Review and Meta-analysis. Gastroenterology, 159(1), 81–95.

Contini, C., Nuzzo, M. Di, Barp, N., Bonazza, A., Giorgio, R. De, Togron, M. & Rubino, S. (2020). The novel zoonotic COVID-19 pandemic : An expected global health concern. The Journal of İnfection in Developing Countries, 14(3), 254–264.

D'Aoust, P. M., Graber, T. E., Mercier**,** E., Montpetit, D., Alexandrov, I., Neault, N., … & Delatolla, R. (2021). Catching a resurgence: Increase in SARS-CoV-2 viral RNA identified in wastewater 48 h before COVID-19 clinical tests and 96 h before hospitalizations. Science of the Total Environment, 770, 145319.

de Oliveira, L. C., Torres-Franco, A. F., Lopes, B. C., Santos, B. S. A. da S., Costa, E. A., Costa, M. S., … & Mota, C. R. (2021). Viability of SARS-CoV-2 in river water and wastewater at different temperatures and solids content. Water Research, 195, 117002.

Desdouits, M., Piquet, J.-C., Wacrenier, C., Le Mennec, C., Parnaudeau, S., Jousse, S., … & Le Guyader, F. S. (2021). Can shellfish be used to monitor SARS-CoV-2 in the coastal environment ? Science of the Total Environment, 778, 146270.

Dhama, K., Patel, K. S., Sharun, K., Pathak, M., Tiwari, R., Yatoo, M. I., … & Rodriguez-Morales, A. J. (2020). SARS-CoV-2 jumping the species barrier: Zoonotic lessons from SARS , MERS and recent advances to combat this pandemic virus. Travel Medicine and Infectious Disease, 37, 101830.

Duda-Chodak, A., Lukasiewicz, M., Ziec, G., Florkiewicz, A. & Filipiak-Florkiewicz, A. (2020). Covid-19 pandemic and food: Present knowledge, risks, consumers fears and safety. Trends in Food Science and Technology, 105, 145–160.

Dyal, J.W., Grant, M.P., Broadwater, K., Bjork, A., Waltenburg, M. A., Gibbins, J. D., … & Honein, M. A. (2020). COVID-19 among workers in meat and poultry processing facilities - 19 States, April 2020. CDC – MMWR, 69, 557–561.

Fritz, M., Rosolen, B., Krafft, E., Becquart, P., Elguero, E., Vratskikh, O., … & Leroy, E. M. (2020). High prevalence of SARS-CoV-2 antibodies in pets from COVID-19 + households. *One Health, 11*, 100192.

Giacomelli, A., Pezzati, La., Conti, F., Bernacchia, D., Siano, M., Oreni, L., … & Galli, M. (2020). Self-reported Olfactory and taste Disorders in Patients With Severe Acute Respiratory Coronavirus 2 Infection: A Cross-sectional Study. *Clinical Infectious Diseases, 71*, 889–890.

Gonçalves, J., Koritnik, T., Mioc, V., Trkov, M., Boljesic, M., Prosenc, K., … & Paragi, M. (2021). Detection of SARS-CoV-2 RNA in hospital wastewater from a low COVID-19 disease prevalence area. Science *of the Total Environment, 755*, 143226.

Gonzalez, R., Curtis, K., Bivins, A., Bibby, K., Weir, M. H., Yetka, K., … & Gonzalez, D. (2020). COVID-19 surveillance in Southeastern Virginia using wastewater-based epidemiology. *Water Research, 186*, 116296.

Göncüoğlu, M., Ayaz, N. D., Cengiz, G., Onaran, B. & Çufaoğlu, G. (2020). Emerging details about COVID-19 and chronology of the pandemic in Turkey. Ankara Üniversitesi Veteriner Fakültesi Dergisi, 67, 323–332.

Günther, T., Czech-Sioli, M., Indenbirken, D., Robitaille, A., Tenhaken, P., Exner, M., … & Brinkmann, M. M. (2020). SARS-CoV- 2 outbreak investigation in a German meat processing plant. *EMBO Molecular Medicine, 12*, e13296.

Gwenzi, W. (2021). Leaving no stone unturned in light of the COVID-19 faecal-oral hypothesis? A water, sanitation and hygiene (WASH) perspective targeting low-income countries. *Science of the Total Environment, 753*, 141751.

Haramoto, E., Malla, B., Thakali, O. & Kitajima, M. (2020). First environmental surveillance for the presence of SARS-CoV-2 RNA in wastewater and river water in Japan. Science *of the Total Environment, 737*, 140405.

Harypursat, V. & Chen, Y.-K. (2020). Six weeks into the 2019 coronavirus disease outbreak: it is time to consider strategies to impede the emergence of new zoonotic infections. *Chinese Medical Journal, 133*(9), 1118–1120.

Hasan, S. W., Ibrahim, Y., Daou, M., Kannout, H., Jan, N., Lopes, A., … & Yousef, A. F. (2021). Detection and quantification of SARS-CoV-2 RNA in wastewater and treated effluents: Surveillance of COVID-19 epidemic in the United Arab Emirates. *Science of the Total Environment, 764*, 142929.

Hata, A., Hara-Yamamura, H., Meuchi, Y., Imai, S. & Honda, R. (2021). Detection of SARS-CoV-2 in wastewater in Japan during a COVID-19 outbreak. *Science of the Total Environment, 758*, 143578.

He, X., Hong, W., Pan, X., Lu, G. & Wei, X. (2021). SARS-CoV-2 Omicron variant : Characteristics and prevention. *Medcomm, 2*(4), 838-845.

Hillary, L. S., Farkas, K., Maher, K. H., Lucaci, A., Thorpe, J., Distaso, M. A., … & Jones, D. L. (2021). Monitoring SARS-CoV-2 in municipal wastewater to evaluate the success of lockdown measures for controlling COVID-19 in the UK. *Water Research, 200*, 117214.

Hokajärvi, A.-M., Rytkönen, A., Tiwari, A., Kauppinen, A., Oikarinen, S., Lehto, K.-M., … & Pitkanen, T. (2021). The detection and stability of the SARS-CoV-2 RNA biomarkers in wastewater influent in Helsinki, Finland. *Science of the Total Environment, 770*, 145274.

Huang, C., Wang, Y., Li, X., Ren, L., Zhao, J., Hu, Y., … & Cao, B. (2020). Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet, 395*, 497–506.

Hul, V., Delaune, D., Karlsson, E. A., Hassanin, A., Tey, P. O., Baidaliuk, A., ... & Duong, V. (2021). A novel SARS -CoV-2 related coronavirus in bats from Cambodia. *BioRxiv*.

Jawed, I., Tareen, F. R., Cauhan, K. & Nayeem, M. (2020). Food safety and COVID-19: Limitations of HACCP and the way forward. *Pharma Innovation Journal, 9*(5), 01–04.

Jawhara, S. (2020). Can drinking microfiltered raw immune milk from cows immunized against SARS-CoV-2 provide short-term protection against COVID-19? *Frontiers in Immunology, 11*, 1888.

Jones, D. L., Baluja, Q. M., Graham, D. W., Corbishley, A., Mcdonald, J. E., Malham, S. K., … & Farkas, K. (2020). Shedding of SARS-CoV-2 in feces and urine and its potential role in person-to-person transmission and the environment-based spread of COVID-19. *Science of the Total Environment, 749*, 141364.

Kanamori, H., Baba, H. & Weber, D. J. (2021). Rethinking One Health approach in the challenging era of COVID-19 pandemic and natural disasters. *Infection Ecology & Epidemiology, 11*(1), 1852681.

Kim, Y. I., Kim, S. G., Kim, S. M., Kim, E.-H., Park, S. J., Yu, K. M., … & Choi, Y. K. (2020). Brief report infection and rapid transmission of SARS-CoV-2 in ferrets. *Cell Host and Microbe, 27*, 704–709.

Kiulia, N. M., Hofstra, N., Vermeulen, L. C., Obara, M. A., Medema, G. & Rose, J. B. (2015). Global occurrence and emission of rotaviruses to surface waters. *Pathogens, 4*, 229–255.

Kolarevic, S., Micsinai, A., Szántó-Egész, R., Lukács, A., Kracun-Kolarevic, M., Lundy, L., … & Paunovic, M. (2021). Detection of SARS-CoV-2 RNA in the Danube River in Serbia associated with the discharge of untreated wastewaters. *Science of the Total Environment, 783*, 146967.

Lam, T. T.-Y., Jia, N., Zhang, Y.-W., Shum, M. H.-H., Jiang, J.-F., Zhu, H.-C., … & Cao, W.-C. (2020). Identifying SARS-CoV-2-related coronaviruses in Malayan pangolins. *Nature, 583*, 282–285.

Lamers, M. M., Beumer, J., van der Vaart, J., Knoops, K., Puschhof, J., Breugem, T. I., … & Clevers, H. (2020). SARS-CoV-2 productively infects human gut enterocytes. *Science, 369*(6499), 50–54.

La Rosa, G., Iaconelli, M., Mancini, P., Bonanno Ferraro, G., Veneri, C., Bonadonna, L., … & Suffredini, E. (2020). First detection of SARS-CoV-2 in untreated wastewaters in Italy. *Science of the Total Environment, 736*, 139652.

Li, Y., Wang, W., Lei, Y., Zhang, B., Yang, J., Hu, J. & Lu, Q. (2020). Comparison of the clinical characteristics between RNA positive and negative patients clinically diagnosed with coronavirus disease 2019. *Zhonghua jie he he hu xi za zhi = Zhonghua jiehe he huxi zazhi = Chinese journal of tuberculosis and respiratory diseases*, 43, 427–430.

Lu, H., Stratton, C. W. & Tang, Y.-W. (2020a). Outbreak of pneumonia of unknown etiology in Wuhan, China: The mystery and the miracle. Journal *of Medical Vİrology, 92*, 401–402.

Lu, R., Zhao, X., Li, J., Niu, P., Yang, B., Wu, H., ... & Tan, W. (2020b). Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. *Lancet, 395*(10224), 565-574.

Mahase, E. (2021). Covid-19 : What new variants are emerging and how are they being investigated ? *BMJ, 372*, n158.

Mahlknecht, J., Reyes, D. A. P., Ramos, E., Reyes, L. M. & Alvarez, M. M. (2021). The presence of SARS-CoV-2 RNA in different freshwater environments in urban settings determined by RT-qPCR: Implications for water safety. *Science of the Total Environment, 784*, 147183.

Masters, P. S. (2006). The Molecular Biology of Coronaviruses. *Advances in Virus Research, 66*, 193–292.

Medema, G., Heijnen, L., Elsinga, G., Italiaander, R. & Brouwer, A. (2020). Presence of SARS-Coronavirus-2 RNA in Sewage and Correlation with Reported COVID -19 Prevalence in the Early Stage of the Epidemic in the Netherlands. *Environmental Science and Technology Letters, 7*(7), 511–516.

Min, S., Xiang, C. & Zhang, X. Heng. (2020). Impacts of the COVID-19 pandemic on consumers' food safety knowledge and behavior in China. *Journal of Integrative Agriculture, 19*(12), 2926–2936.

Miura, F., Kitajima, M. & Omori, R. (2021). Duration of SARS-CoV-2 viral shedding in faeces as a parameter for wastewater-based epidemiology: Re-analysis of patient data using a shedding dynamics model. *Science of the Total Environment, 769*, 144549.

Mohan, S. V., Hemalatha, M., Kopperi, H., Ranjith, I. & Kumar, A. K. (2021). SARS-CoV-2 in environmental perspective : Occurrence , persistence , surveillance , inactivation and challenges. Chemical *Engineering Journal, 405*, 126893.

Morcatty, T. Q., Feddema, K., Nekaris, K. A. I. & Nijman, V. (2021). Online trade in wildlife and the lack of response to COVID-19. *Environmental Research*, *193*, 110439.

Munnik, B. B. O., Sikkema, R. S., Nieuwenhuijse, D. F., Molenaar, R. J., Munger, E., Molenkamp, R., … & Koopmans, M. P. G. (2021). Transmission of SARS-CoV-2 on mink farms between humans and mink and back to humans. *Science, 371*, 172–177.

Pace, R. M., Williams, J. E., Järvinen, K. M., Belfort, M. B., Pace, C. D. W., Lackey, K. A., … & McGuire, M. K. (2021). Characterization of SARS-CoV-2 RNA, Antibodies, and Neutralizing Capacity in Milk produced by Women with COVID-19. *mBio, 12*(1), e03192-20.

Pakpour, A. H., Al Mamun, F., Hosen, I., Griffiths, M. D. & Mamun, M. A. (2020). A population-based nationwide dataset concerning the COVID-19 pandemic and serious psychological consequences in Bangladesh. *Data in Brief, 33*, 106621.

Palmer, M. V., Martins, M., Falkenberg, S., Buckley, A., Caserta, L. C., Mitchell, P. K., … & Diel, D. G. (2021). Susceptibility of White-Tailed Deer (Odocoileus virginianus) to SARS-CoV-2. *Journal of Virology, 95* (11), e00083-21.

Pan, X., Chen, D., Xia, Y., Wu, X., Li, T., Ou, X., … & Liu, J. (2020). Viral load of SARS-CoV-2 in clinical samples. *Lancet Infectious Diseases, 20*(4), 411–412.

Patterson, E. I., Elia, G., Grassi, A., Giordano, A., Desario, C., Medardo, M., … & Decaro, N. (2020). Evidence of exposure to SARS-CoV-2 in cats and dogs from households in Italy. *Nature Communications, 11*, 6231.

Pillay, L., Amoah, I. D., Deepnarain, N., Pillay, K., Awolusi, O. O., Kumari, S. & Bux, F. (2021). Monitoring changes in COVID-19 infection using wastewater-based epidemiology: A South African perspective. *Science of the Total Environment, 786*, 147273.

Randazzo, W., Truchado, P., Cuevas-Ferrando, E., Simón, P., Allende, A. & Sánchez, G. (2020). SARS-CoV-2 RNA in wastewater anticipated COVID-19 occurrence in a low prevalence area. *Water Research, 181*, 115942.

Ren, S.-Y., Wang, W.-B., Hao, Y.-G., Zhang, H.-R., Wang, Z.-C., Chen, Y.-L. & Gao, R.-D. (2020). Stability and infectivity of coronaviruses in inanimate environments. *World Journal of Clinical Cases,* 8(8), 1391–1399.

Rimoldi, G. S., Stefani, F., Gigantiello, A., Polesello, S., Comandatore, F., Mileto, D., … & Salerno, F. (2020). Presence and infectivity of SARS-CoV-2 virus in wastewaters and rivers. *Science of the Total Environment, 744*, 140911.

Rodriguez-Morales, A. J., Bonilla-Aldana, D. K., Balbin-Ramon, G. J., Rabaan, A. A., Sah, R., Paniz-Mondolfi, A., … & Esposito, S. (2020). History is repeating itself : Probable zoonotic spillover as the cause of the 2019 novel Coronavirus Epidemic. *Le Infezioni in Medicina, 28*(1), 3–5.

Róka, E., Khayer, B., Kis, Z., Kovacs, L. B., Schuler, E., Magyar, N., … & Vargha, M. (2021). Ahead of the second wave: Early warning for COVID-19 by wastewater surveillance in Hungary. Science *of the Total Environment, 786*, 147398.

Saguti, F., Magnil, E., Enache, L., Churqui, M. P., Johansson, A., Lumley, D., … & Norder, H. (2021). Surveillance of wastewater revealed peaks of SARS-CoV-2 preceding those of hospitalized patients with COVID-19. *Water Research, 1*89, 116620.

Sala-Comorera, L., Reynolds, L. J., Martin, N. A., O'Sullivan, J. J., Meijer, W. G. & Fletcher, N. F. (2021). Decay of infectious SARS-CoV-2 and surrogates in aquatic environments. *Water Research, 201*, 117090.

Shahbaz, M., Bilal, M., Moiz, A., Zubair, S. & Iqbal, H. M. N. (2020). Food Safety and COVID-19 : Precautionary Measures to Limit the Spread of Coronavirus at Food Service and Retail Sector. *Journal of Pure and Applied Microbiology, 14*, 749-756.

Sherchan, S. P., Shahin, S., Ward, L. M., Tandukar, S., Aw, T. G., Schmitz, B., … & Kitajima, M. (2020). First detection of SARS-CoV-2 RNA in wastewater in North America: A study in Louisiana, USA. *Science of the Total Environment, 743*, 140621.

Shi, J., Wen, Z., Zhong, G., Yang, H., Wang, C., Huang, B., … & Bu, Z. (2020). Susceptibility of ferrets, cats, dogs, and other domesticated animals to SARS – coronavirus 2. *Science, 368*(6494), 1016–1020.

Sit, T. H. C., Brackman, C. J., Ip, S. M., Tam, K. W. S., Law, P. Y. T., To, E. M. W., … & Peiris, M. (2020). Infection of dogs with SARS-CoV-2. *Nature, 586* (7831), 776–778.

Tao, K., Tzou, P. L., Nouhin, J., Gupta, R. K., de Oliveira, T., Pond, S. L. K., … & Shafer, R. W. (2021). The biological and clinical significance of emerging SARS-CoV-2 variants. *Nature Reviews Genetics, 22*, 757–773.

Ulrich, L., Wernike, K., Hoffmann, D., Mettenleiter, T. C. & Beer, M. (2020). Experimental infection of cattle with SARS-CoV-2. *Emerging Infectious Diseases, 26* (12), 2979–2981.

USDA Animal and Planet Health Inspection Service (2020, April, 5). Statement on the confirmation of COVID-19 in a tiger in New York. https://www.aphis.usda.gov/aphis/newsroom/news/sa_by_date/sa-2020/ny-zoo-covid-19

van Doremalen, N., Bushmaker, T., Holbrook, M. G., Gamble, A., Williamson, B. N., Tamin, A., … & Munster, V. J. (2020). Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. *New England Journal of Medicine, 382*(16), 1564–1567.

Wassenaar, T. M. & Zou, Y. (2020). 2019_nCoV/SARS-CoV-2: rapid classification of betacoronaviruses and identification of Traditional Chinese Medicine as potential origin of zoonotic coronaviruses. *Letters in Applied Microbiology, 70*(5), 342–348.

Wei, C., Shan, K. J., Wang, W., Zhang, S., Huan, Q., & Qian, W. (2021). Evidence for a mouse origin of the SARS-CoV-2 Omicron variant. Journal *of genetics and genomics, 48*(12), 1111-1121.

Weidhaas, J., Aanderud, Z. T., Roper, D. K., VanDerslice, J., Gaddis, E. B., Ostermiller, J., … & Lacross, N. (2021). Correlation of SARS-CoV-2 RNA in wastewater with COVID-19 disease burden in sewersheds. *Science of the Total Environment, 775*, 145790.

Westhaus, S., Weber, F.-A., Schiwy, S., Linnemann, V., Brinkmann, M., Widera, M., … & Ciesek, S. (2021). Detection of SARS-CoV-2 in raw and treated wastewater in Germany – Suitability for COVID-19 surveillance and potential transmission risks. *Science of the Total Environment, 751*, 141750.

World Health Organization (2021, December, 23). Status of COVID-19 *Vaccines within WHO EUL/PQ evaluation process.* https://extranet.who.int/pqweb/sites/default/files/documents

Wu, A., Peng, Y., Huang, B., Ding, X., Wang, X., Niu, P., ... & Jiang, T. (2020a). Genome composition and divergence of the novel coronavirus (2019-nCoV) originating in China. *Cell Host & Microbe, 27*(3), 325-328.

Wu, Y., Guo, C., Tang, L., Hong, Z., Zhou, J., Dong, X., Yin, H., Xiao, Q., Tang, Y., Qu, X., Kuang, L., Fang, X., Mishra, N., Lu, J., Shan, H., Jiang, G., & Huang, X. (2020b). Prolonged presence of SARS-CoV-2 viral RNA in faecal samples. *Lancet. Gastroenterology & hepatology, 5*(5), 434–435.

Xu, Y., Li, X., Zhu, B., Liang, H., Fang, C., Gong, Y., Guo, Q., Sun, X., Zhao, D., Shen, J., Zhang, H., Liu, H., Xia, H., Tang, J., Zhang, K., & Gong, S. (2020). Characteristics of pediatric SARS-CoV-2 infection and potential evidence for persistent fecal viral shedding. *Nature medicine, 26*(4), 502–505.

Yang, X. (2020). Potential consequences of COVID-19 for sustainable meat consumption: the role of food safety concerns and responsibility attributions. *British Food Journal, 123*(2), 455-474.

Ye, Z. W., Yuan, S., Yuen, K. S., Fung, S. Y., Chan, C. P., & Jin, D. Y. (2020). Zoonotic origins of human coronaviruses. *International journal of biological sciences, 16*(10), 1686–1697.

Yekta, R., Vahid-Dastjerdi, L., Norouzbeigi, S., & Mortazavian, A. M. (2021). Food products as potential carriers of SARS-CoV-2. *Food control, 123*, 107754.

Zhang, Q., Zhang, H., Gao, J., Huang, K., Yang, Y., Hui, X., He, X., Li, C., Gong, W., Zhang, Y., Zhao, Y., Peng, C., Gao, X., Chen, H., Zou, Z., Shi, Z. L., & Jin, M. (2020a). A serological survey of SARS-CoV-2 in cat in Wuhan. *Emerging microbes & infections, 9*(1), 2013–2019.

Zhang, T., Cui, X., Zhao, X., Wang, J., Zheng, J., Zheng, G., Guo, W., Cai, C., He, S., & Xu, Y. (2020b). Detectable SARS-CoV-2 viral RNA in feces of three children during recovery period of COVID-19 pneumonia. *Journal of medical virology, 92*(7), 909–914.

Zhang, T., Wu, Q., & Zhang, Z. (2020c). Probable pangolin origin of SARS-CoV-2 associated with the COVID-19 outbreak. *Current biology : CB, 30*(7), 1346–1351.e2.

Zhang, Y., Chen, C., Song, Y., Zhu, S., Wang, D., Zhang, H., Han, G., Weng, Y., Xu, J., Xu, J., Yu, P., Jiang, W., Yang, X., Lang, Z., Yan, D., Wang, Y., Song, J., Gao, G. F., Wu, G., & Xu, W. (2020d). Excretion of SARS-CoV-2 through faecal specimens. *Emerging microbes & infections, 9*(1), 2501–2508.

Zhou, P., Yang, X. L., Wang, X. G., Hu, B., Zhang, L., Zhang, W., Si, H. R., Zhu, Y., Li, B., Huang, C. L., Chen, H. D., Chen, J., Luo, Y., Guo, H., Jiang, R. D., Liu, M. Q., Chen, Y., Shen, X. R., Wang, X., Zheng, X. S., … & Shi, Z. L. (2020). Addendum: A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature, 588*(7836), E6.