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# SARS-CoV-2 transmission via aquatic food animal species or their products: A review

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ABSTRACT

Outbreaks of COVID-19 (coronavirus disease 2019) have been reported in workers in fish farms and fish processing plants arising from person-to-person transmission, raising concerns about aquatic animal food products' safety. A better understanding of such incidents is important for the aquaculture industry's sustainability, particularly with the global trade in fresh and frozen aquatic animal food products where contaminating virus could survive for some time. Despite a plethora of COVID-19-related scientific publications, there is a lack of reports on the risk of contact with aquatic food animal species or their products. This review aimed to examine the potential for Severe Acute Respiratory Syndrome-Coronavirus-2 (SARS-CoV-2) contamination and the potential transmission via aquatic food animals or their products and wastewater effluents. The extracellular viability of SARS-CoV-2 and how the virus is spread are reviewed, supporting the understanding that contaminated cold-chain food sources may introduce SAR-CoV-2 via food imports although the virus is unlikely to infect humans through consumption of aquatic food animals or their products or drinking water; i.e., SARS-CoV-2 is not a foodborne virus and should not be managed as such but instead through strong, multifaceted public health interventions including physical distancing, rapid contact tracing, and testing, enhanced hand and respiratory hygiene, frequent disinfection of high-touch surfaces, isolation of infected workers and their contacts, as well as enhanced screening protocols for international seafood trade.

## 1. Description of foodborne viruses

The early reports suggested that the seafood market's exceptionally wide contamination, such as seafood tanks, air contamination by live animals from various sources for sale, or rodent infestation, might explain the initiation of the SARS-CoV-2 outbreak (Jalava, 2020; Ceylan et al., 2020), but this virus is characteristically not foodborne (Li et al., 2020a). Most recently, the transmission of SARS-CoV-2 via contaminated cold-chain food sources has been linked to two re-emergent outbreaks of COVID-19 in Beijing, China (Han et al., 2020; Pang et al., 2020), but the route of infection was not established. This nuance can be categorized as a "non-traditional" transmission mechanism (Fisher et al., 2020). In this review, foodborne viruses refer to human and animal viruses infecting humans via food consumption and drinking water. These viruses normally infect humans upon ingestion of food contaminated in one of three main ways: (1) by infected food handlers, (2) by food that has been in contact with animal body fluids (zoonotic transmission), human feces or vomit, or aerosols from an infected person or contaminated materials, and (3) by food products (e.g., pork and liver) originating from infected animals (zoonotic transmission) (Meng et al., 1997; Acha and Szyfres, 2003; Tei et al., 2003; Koopmans and Duizer, 2004; FAO/WHO Food and Agriculture Organization of the United Nations/World Health Organization, 2008; Vasickova et al., 2005; Lewis et al., 2010; EFSA European Food Safety AuthorityHAZ, 2011; Velebit et al., 2019; Desdouits et al., 2020; Carraturo et al., 2020). Infections with these viruses are common causes of human disease (Havelaar et al., 2015; Petrović and D'Agostino, 2016; Desdouits et al., 2020).

The viruses, sometimes referred to as enteric viruses (Fabiszewski de Aceituno et al., 2013; Miranda and Schaffner, 2019), are shed in feces (Koopmans and Duizer, 2004), resulting in fecal-oral transmission (Li

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coronavirus-associated receptors and factors (SCARFs).

In contrast, although a positive fecal test is as accurate as a pharyngeal swab test for laboratory diagnosis of COVID-19, patients with a positive fecal test did not have gastrointestinal symptoms (Zhang et al., 2020c). Moreover, while the virus is readily isolated from throat and lung samples, there is only one report on the isolation of SARS-CoV-2 from a single fecal sample (Holshue et al., 2020) – despite high concentrations of viral RNA (Wölfel et al., 2020). Besides, viral RNA detection does not equate to the infectious virus (Cevik and Bamford, 2020) - "The viral RNA is the equivalent of the corpse of the virus," (Emanuel Goldman quoted by Lewis (2021)); while RT-PCR could detect SARS-CoV RNA in untreated wastewater from two hospitals, the virus could not be isolated using Vero E6 cell culture (Wang et al., 2005a). The stability of SARS-CoV in feces, urine, and water and chemical inactivation of the virus in wastewater were studied by Wang et al. (2005b). The intact virus was reported to persist for two days (viral RNA for seven days) in hospital or domestic sewage or tap water; three days in feces; 14 days in PBS; and 17 days in urine at 20 °C (Silverman and Boehm, 2020). The virus persisted longer at 4 °C: 14 days in wastewater and 17 days in feces or urine (Wang et al., 2005b). It is also unknown if SARS-CoV-2 could survive passage through the stomach (Ng and Tilg, 2020), and how long it remains infective in wastewater remains to be determined (Wartecki and Rzymski, 2020).

In experimental studies of SARS-CoV-2 infection in cats published to date (Shi et al., 2020; Halfmann et al., 2020; Bosco-Lauth et al., 2020), and where fecal samples were tested, viral RNA was either not detected in the feces of virus-inoculated cats or was detected. However, the virus was not recovered from the viral RNA-positive small intestines. Experimental studies using ferrets showed them to be highly susceptible to SARS-CoV-2 infection and transmitted the virus through direct and indirect contact similar to humans (Kim et al., 2020; Richard et al., 2020; Schlottau et al., 2020). However, the infectious virus could not be recovered from the trachea, kidney, and intestine tissues (Kim et al., 2020) or was isolated from the throat and nasal swabs but not from rectal swabs (Richard et al., 2020). In the experimental study with minks, which developed the more severe disease, infectious virus was detected in the nasal washes of all three animals on days 2 and 4 post-inoculation (p.i) but not from the concha swabs or rectal swabs of any animals at any time points (Shuai et al., 2020). White-tailed deer experimentally inoculated intranasally with SARS-CoV-2 developed a subclinical infection, and infected animals shed infectious virus in their nasal secretions (Palmer et al., 2021). Although viral RNA was detected in nasal secretions of all inoculated and indirect contact animals between 2 and 21 days p.i, viral RNA from feces was detected only intermittently and transiently through days 6–7 p.i; infectious SARS-CoV-2 shedding was detected by virus isolation in nasal secretions of all inoculated and indirect contact animals between days 2 and 7 p.i, whereas shedding in feces was only detected in inoculated animals and only on day 1 p.i (Palmer et al., 2021). Thus, the SARS-CoV-2 material detected in wastewater may not be infectious, and wastewater may not move the viable virus to an aquatic environment (Wartecki and Rzymski, 2020). However, it is still possible for the ingested virus to migrate to the respiratory tract (Li et al., 2020a).

Wartecki and Rzymski (2020) reviewed the potential survival of coronaviruses in aquatic environments and wastewater and observed that coronavirus survival likely depends on four key conditions:

1. Water temperature – higher temperature decreases survivability.
2. Light availability – UV-B light decreased SARS-CoV titer.
3. Level of organic matter – adsorption of virus particles to the suspended organic matter may be protective, whereas the presence of antagonistic microorganisms may inactivate the virus.
4. Predation – certain protozoa graze on viruses (Feichtmayer et al., 2017).

In organic matter, for example, transmissible gastroenteritis virus (TGEV), a diarrheal pathogen of swine and surrogate for SARS-CoV-2, at 25 °C, survived for 22 days in reagent-grade water. In contrast, in wastewater (lake water), it survived for only nine days (Casanova et al., 2009). Thus, coronavirus survival in treated wastewater (Carducci et al., 2020) is significantly different from survival in untreated wastewater that is known to contain microorganisms (protozoa, ciliates, flagellates, bacteria), which decrease the presence of viable viruses (Feichtmayer et al., 2017; Wartecki and Rzymski, 2020).

## 4. Consideration for the aquaculture industry

The impacts of the COVID-19 pandemic on the fisheries and aquaculture sector are wide-ranging (FAO/WHO Food and Agriculture Organization of the United Nations/World Health Organization, 2008). The concerns about the safety of aquatic animal food products have directly impacted the aquaculture industry. This review aims to better understand the potential for SARS-CoV-2 contamination and its potential transmission via aquatic food animals or their products to curtail these direct impacts. The industry also faces global economic impacts by changing consumer demands, access to international markets, and problems with transport and border restrictions (FAO/WHO Food and Agriculture Organization of the United Nations/World Health Organization, 2008) that may be longer-lasting, making the COVID-19 pandemic one of the most economically devastating diseases to affect the whole aquaculture value chain. This review supports the understanding that contaminated cold-chain food sources may introduce SAR-CoV-2 via food imports (Dai et al., 2020; Fisher et al., 2020), although the virus is unlikely to infect humans through consumption of aquatic food animals or their products or drinking water, i.e., SAR-CoV-2 is not a foodborne virus (Li et al., 2020a) and should not be managed as such but instead through the implementation of strong, multifaceted public health interventions such as physical distancing, rapid contact tracing, and testing, enhanced hand and respiratory hygiene, frequent disinfection of high-touch surfaces, and isolation of infected workers and their contacts, as advocated by the GAA (GAA [Global Aquaculture Alliance], 2020). The "non-traditional" transmission of SAR-CoV-2 via cold-chain food contamination calls for enhanced screening protocols used in international seafood trade to prevent re-introducing SAR-CoV-2 in importing countries and regions.

## 5. Conclusions

We provide critical information about how aquatic food does not present the big danger to the human population as was initially feared due to the association of early outbreaks to seafood markets and indicate areas needing more research. SARS-CoV-2 is not a foodborne virus and should not be managed as such. This virus can contaminate surfaces, including food handled by an infected person or coming in contact with contaminated material. Although SARS-CoV-2 has low stability on fomites at 21-23 °C (room temperature), it has been demonstrated that the virus can survive the time and temperatures associated with transportation and storage conditions associated with international food trade, thereby presenting a "non-traditional" transmission mechanism requiring enhanced screening protocols for the international seafood trade. While mostly viral RNA has been found on aquatic animals' products or surfaces in contact with aquatic animal products, a recent COVID-19 resurgence in Beijing, China, was linked to contaminated cold-chain food sources. However, a direct link between SARS-CoV-2 infection and food consumption remains to be documented.

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