Received: 22 December 2020 | Revised: 10 February 2021 | Accepted: 27 February 2021

DOI: 10.1111/jfs.12898

INVITED REVIEW

Journal of Food Safety WILEY

# In the landscape of SARS-CoV-2 and fresh fruits and vegetables: The fake and hidden transmission risks

Noureddine Benkeblia

Department of Life Sciences, The University of the West Indies, Kingston, Jamaica

**Correspondence**
Noureddine Benkeblia, Department of Life Sciences, The University of the West Indies, Mona Campus, Kingston 7, Jamaica.
Email: noureddine.benkeblia@uwimona.edu.jm

## Abstract

From the first notification reporting to the WHO a cluster of coronavirus in Wuhan City (China), over 114 million cases of SARS-CoV-2 have been confirmed, with more than 2,530,000 deaths, and over 400,000 new cases and 10,000 deaths daily. Numerous viruses are susceptible to contaminate crops during growth, harvesting, handling, marketing and minimally processing, and these steps share one common factor which is human. Different studies showed that viruses might persist on different crops for periods of 2 to 14 days under different conditions such as refrigeration, household and freezing. Little is known on SARS-CoV-2, but preliminary studies showed that this virus might survive 24 hr on cardboard and 72 hr on plastic, materials used in fruits and vegetables packaging. Based on preliminary data, there is no evidence of food or food packaging being associated with transmission of SARS-CoV-2. Certainly, to date there is no scientific evidence that SARS-CoV-2 might be transmitted by a contact with, or the ingestion of contaminated fresh or minimally processed fruits and vegetables. However, this risk even though being considered improbable, it cannot be "*completely and definitely*" discarded or ignored, particularly where the virus is spreading in the word. Some agencies indicated that in case some commodities and handlers are contaminated among the multiple people involved from the farm to the table, a cross-contamination may occur, and the risk of the contamination of food, food contact materials, and packaging from infected but asymptomatic workers should not be discarded even though considered "*Very Low = meaning very rare but cannot be excluded*."

## 1 | INTRODUCTION

From the first notification (December 2019) reporting to the World Health Organization (WHO) a cluster of cases of pneumonia caused by a novel coronavirus in Wuhan City (China), and as of this day (March 4, 2020), the SARS-CoV-2 outbreak has now been confirmed in 223 countries on the six continents. Globally, over 114 million cases of SARS-CoV-2 have been confirmed, including more than 2,530,000 deaths, and an average of more than 400,000 new cases and 10,000 deaths reported daily. The most affected regions are the Americas (44.5%) and Europe (34.1%), while Eastern Mediterranean (5.7%), South-East Asia (11.9%), Africa (2.5%), and Western Pacific (1.4%) are less.

Contrary to the hundreds of pathogenic microorganisms known, human pathogens account for much less than 1% and only few viruses are associated with foodborne outbreaks. Unfortunately, the last few decades have been characterized by many environmental, urbanistic, and socioeconomic changes causing severe disorders to the natural ecosystems. Consequently, the causality viruses and outbreaks associated with foodborne illness became obvious as reported by many studies, and therefore becoming an emerging problem representing a significant threat to global public health requiring a surveillance

  

platform for the early recognition of food related threats (FAO, 2004; Koopmans & Duizer, 2004; Lipkin, 2013; Tetro, 2014).

Indeed, the history of viruses as food contaminant and foodborne illness causing agents is recent and juvenile compared to bacterial foodborne illness known from decades ago. To date, more than a hundred of enteric viruses have been recognized pathogenic causing foodborne illness and most of them are Hepatitis A and Noroviruses (Bintis, 2017). In an interesting review, Appleton (2000) described two main foodborne virus infections. The first is the viral gastroenteritis caused by small round structured viruses (SRSV) and the second hepatitis A. These two infections are in most cases transmitted from person-to-person; however, they might also occasionally be foodborne (Butt, Aldridge, & Sanders, 2004) or water-borne (Carter, 2005; Gerba & Rose, 1990). Unfortunately, consequently to the social development of the humanity and its interaction with the macro- and the micro- ecosystems, the list of emerging viral pathogens that could threaten the food supply is growing and other foodborne related viruses are identified.

During the last few decades, consumption of fruits and vegetables showed a significant increase, and this trend is expected to continue through the next decades. According to the FAO (2020), fruit consumption increased by c.a. 25% while vegetable consumption increased by c.a. 22%, with some discrepancies observed between different regions of the word.

## 2 | MODE OF TRANSMISSION OF VIRUSES BY FRUITS AND VEGETABLES

Indeed, there are different mode of transmission of viruses. Person-to-person (touch, blood and bodily fluids, saliva, air) is the most predominant mode of transmission, but food, water, insects and fomites might also be a mode of transmission. Specifically talking, faecally contaminated foods have been shown to be a route of a direct or indirect transmission of viruses to humans. Although seafood and mollusks are the major vehicle of viruses' transmission to humans, other foods might be contaminated by persons or contaminated water, and therefore be a mode of transmission (Cliver, 1997). Disregarding the different categories of foods and food products, we will focus on fresh fruits and vegetables. First, it is important to discuss briefly the persistence and the potential transmission of some viruses by fruits and vegetables and the threats they might cause. In the 1990s, c.a. 12% of foodborne illnesses were linked to the consumption of fresh fruits and vegetables which is increasing due to the health benefits of these commodities. With the increase of fresh crop commodities trade, particularly between USA, Canada, and Mexico, and between the European countries more particularly, food safety concerns are being created, and the major issue among wholesalers, retailers and consumers is ensuring fresh crops safety. Indeed, safety of fresh fruits and vegetables have known a real advance over the past two decades. In this regard, numerous governmental and public food safety standards have been developed and implemented, and incommensurate efforts were put in place aiming to address the consumers' concerns related to food safety, especially in the developed countries. However, these advances are still not enough to ensure a desired and total fresh produce safety and still few foodborne outbreaks have been associated with the consumption of fresh snow peas, raspberries, basil, mesclun lettuce and a variety of other fresh fruits and vegetables (Matthews, 2006).

Overall, enteric viruses contribute to large extent to foodborne diseases. Major viruses found in food are adenovirus, astrovirus, rotavirus, sapovirus, hepatitis A and E viruses, and norovirus (Todd & Greig, 2015; Velebit et al., 2019). Most of the studies show that the foodborne viruses are generally transmitted by contaminated raw or processed foods including handlers, however, person-to-person contact or through environmental contamination might also be other modes of transmission (Bidawid, Farber, & Sattar, 2000a; Richards, 2001; Todd & Greig, 2015). In 2001, an interesting review was published by Seymour and Appleton (2001) listing numerous viruses susceptible to contaminate fresh produce. Indeed, either fresh or minimally processed fruits and vegetables might be contaminated by different viruses, and these contaminations occur either in the field or during handling, marketing or minimally processing.

Basically, it is important to distinguish between the pre-harvest and the post-harvest viruses contamination of fresh produce. Indeed, both pre- and postharvest steps have their specific constraints, however, they share one common factor which is human (handlers) and either during cropping and cultivation or during harvesting, handling, transportation, storage, marketing and retail, human is the pivot factor of these successive operations.

During cultivation, the origin and these viruses transmission modes have been highlighted by many reports. The sources and routes of contamination in the field and during cultivation are variables. Fresh crops are likely to be contaminated by the introduced viruses into soils by manure or green fertilizers, faecally contaminated irrigation water, animals and insects, or workers themselves (Alegbeleye, Singleton, & Sant'An, 2018; Bosch, Pintó, & Guix, 2016; Lynch, Tauxe, & Hedberg, 2009). In contrary, the post-harvest contamination results from poor or inadequate hygiene practices during handling, transportation, minimally processing, storage, and marketing (Ruggeri et al., 2013; Van der Poel, 2014). The risk of contamination is likely to be increased by the number of intermediaries such as wholesale houses, packing houses, storage facilities, involved in fresh crops handling from the farm to the table, and post-harvest handling is considered the darkest step of the fresh crop supply chain.

## 3 | POSTHARVEST PERSISTENCE OF FOODBORNE VIRUSES ON FRUITS AND VEGETABLES

It is obvious that fresh and minimally processed fruits and vegetables crops require intensive handling during the multiple steps of the supply chain. Although rarely observed, few viruses might be a cause of foodborne outbreaks, and some outbreaks of viral infection are attributed to consumption of contaminated fresh fruits and vegetables. Thus, improper cultivation conditions or gaps in the best agricultural

practices from one hand, and poor handling and lack in hygienic conditions or gaps in best post-harvest practices from another hand, make the fresh crops of risks even though of low level. Indeed, the persistence of the viruses depends on the inanimate surface or the medium (Goli, 2020b; Thippareddi, Balamurugan, Patel, Singh, & Brassard, 2020), and greatly on their two major structures. First are enveloped viruses possessing an external layer made of proteins and lipids and this layer is easily destructured by soaps or alcohols inactivating the viruses (Klein, 2004). In contrary, the second category of viruses are non-enveloped ones and have an external protein shell which is resistant to environmental stressors and many disinfectants (Maillard & Russell, 1997; Sattar, Springthorpe, Karim, & Loro, 1989). Unfortunately, in the context of foodborne diseases caused by viruses only avian influenza, SARS, and Nipah diseases are caused by enveloped ones, while other non-enveloped ones are major contributors to many infections for example, astroviruses, Aichi virus, caliciviruses, HAV, and HEV which are small and more difficult to control (Maillard & Russell, 1997). In matter of persistence, the different studies show that rotavirus (non-enveloped) were found on strawberry irrigated with contaminated water (Brassard, Gagné, Généreux, & Côté, 2012), and these non-enveloped viruses are more persistent, therefore, surviving and spreading from fresh produce production (Baert et al., 2011; Van Boxstael, Habib, Jacxsens, & de Vocht, 2013) to their storage (Butot, Putallaz, & Sanchez, 2008) even though their concertation declines because of their inability to multiply. An interesting research investigated the persistence of poliovirus on different fruits and vegetables. In this study, the decimal reduction times (*D*-value = days after which the initial virus number declines by 90%) was 14.2 days for white cabbage, 11.6 days for lettuce and 8.4 days for frozen strawberries, while no decline was observed for green onion and fresh raspberries (Kurdziel, Wilkinson, Langton, & Cook, 2001). Other examples reported the persistence of hepatitis A virus in spinach during refrigerated storage (Shieh, Stewart, & Laird, 2009) and onion (Sun, Laird, & Shieh, 2012), and norovirus and adenovirus were found to be persistent on soft berries (Verhaelen, Bouwknegt, Lodder-Verschoor, & Rutjes, 2012). These results show well that viruses could persist under the retail and household storage conditions several days and represent a real risk for the consumers if fresh crops are contaminated prior to their consumption.

Beside the fresh produce, minimally processed fruits and vegetables are typically sold to the consumer in a ready-to-use or ready-to-eat form, and are well appreciated by the consumers, especially in the developed countries. Unfortunately, during their processing and packaging, produce might be subjected to some viruses' contamination. For example, enteric viruses were detected on the packaging material of minimally processed leafy greens (Mattison et al., 2010), and many viruses survive well on hands and are spread by workers (Greig, Todd, Bartleson, & Michaels, 2007; Todd, Greig, Bartleson, & Michaels, 2009). Another case was reported by Bidawid, Farber, and Sattar (2000b), who demonstrated that approximately 10% of the HAV virus particles are transferred from faecally contaminated fingers to foods and surfaces, thus increasing the potential for contamination (Mokhtari & Jaykus, 2009).

Nevertheless, links between foodborne viruses and their persistence in fresh produce and minimally processed fruits and vegetables seem more complex and not a simple passive transfer as concluded by several studies carried out by phytopathologists and food microbiologists (Tyler & Triplett, 2008). For example, if plastic packaging material used in minimally processed fruits and vegetables is contaminated by worker's fingers, adenoviruses may survive c.a. 35 days in a low relative humidity (RH) environment (Nauheim et al., 1990). However, the viruses survival under different RH is questionable, since enteroviruses were found to survive better under high RH, whereas low RH favors survival of HAV and human rotavirus (HRV) (Mbithi, Springthorpe, & Sattar, 1991; Sattar, Dimock, Ansari, & Springthorpe, 1988).

## 4 | TRANSMISSION OF SARS-COV-2 BY FRESH FRUITS AND VEGETABLES

The 2019 novel coronavirus disease (2019-nCoV or COVID-19) recently reported from Wuhan (China), which has cases in Thailand, Japan, South Korea, and the United States, has been confirmed as a new coronavirus (WHO, 2020). The SARS-CoV-2 has infected millions of humans and has caused more than two and half-million deaths. Current evidence suggests that person-to-person is the main mode of contamination, and the main way the virus spreads is by respiratory droplets or aerosol transmission, and when persons are in contact with contaminated surfaces or objects, for example tables, doorknobs and handrails.

Although numerous research and review papers reported the spread of viruses through the food chain supply in general and fruits and vegetables in particular, data on the persistence and transmission of SARS-CoV-2 through fresh crops is still not well established and numerous questions remain to be answered. Thus, SARS-CoV-2 pandemic raised numerous concerns and questions among them air and water borne transmission and survival of coronavirus (Bilal, Nazir, Rasheed, Parra-Saldivar, & Iqbal, 2020; Goli, 2020a; Wathore, Gupta, Bherwani, & Labhasetwar, 2020) and whether SARS-CoVs-2 can potentially be transmitted *via* "*surface-contaminated*" foods products (Ceylan, Meral, & Cetinkaya, 2020) including fresh fruits and vegetables and food packaging materials bearing in mind the possibility of no foodborne transmission can be excluded for any virus.

At the beginning of the pandemic, according to the FDA (2019) and based on the preliminary data on the disease (van Doremalen et al., 2020), SARS-CoV-2 is an enveloped virus and can survive 24 hr on cardboard, 48 hr on stainless steel, and 72 h on plastic. However, two interesting reviews reported variable survival times (24 hr to 5 days) on the same materials depending on the initial inoculum concentration and SARS-CoV-2 strains (Carraturo et al., 2020; Kampf, Todt, Pfaender, & Steinmann, 2020). These packaging materials are used extensively in the fresh and minimally processed crops sectors, therefore, a customer can get infected by SARS-CoV-2 after his hand has been in contact with a surface or object that has the virus on it and then touching his mouth, nose, or possibly his eyes, even though, this mode of transmission is not thought to be the main way the virus spreads. On the other hand, CDC (2019) (Centre for Disease Control

and Prevention) and FDA (2019) (Food and Drug Administration) stated that "*currently there is no evidence of food or food packaging being associated with transmission of* SARS-CoV-2," and this statement corroborates the statement that there is no tangible or strong evidence that the virus can be spread by fresh produce and other non-packaged foods purchased at the grocery store. However, with the development of the situation, the increasing number of infected persons and a better understanding of the virus based on the few scientific published work, the CDC (2020a) released on the 22 of May 2020 an update on SARS-CoV-2 transmission to clarify information about types of spread. In this update the CDC states that "*Based on data from laboratory studies on* SARS-CoV-2 *and what we know about similar respiratory diseases, it may be possible that persons can get* SARS-CoV-2 *by touching a surface or object that has the virus on it and then touching their own mouth, nose, or possibly their eyes, but this isn't thought to be the main way the virus spreads*."

To corroborate this recommendation, it is pertinent to refer to one study published in 2013, and reporting on the survival of two respiratory viruses (adenovirus 2-Ad2 and coronavirus 229E – CoV229E) on fresh lettuce, strawberries, and raspberries produce. Interestingly, the results show that CoV229E survives and declines after 2 days, but it was not detected after 4 days on lettuce stored at 4°C, while Ad2 survived 10 days on the three produce. Considering the studies on the persistence of many foodborne viruses, these results show well that respiratory viruses can also survive for few days on fresh crops under the domestic storage conditions, therefore, the potential for transfer to the handlers' hand and subsequently a risk of contamination and a route of transmission of the virus (Yépiz-Gómez, Gerba, & Bright, 2013). In a more recent review of Mitchie, Zhao, and Tan (2021) comparing coronaviruses and human noroviruses, it seems that the possibility of CoVs foodborne transmission is low compared to other routes of transmission. However, the authors in their conclusion stated that the possibility of CoV infection through food ingestion should be monitored because many facts of these viruses still remain not well known and the viruses may evolve rapidly.

Certainly, there is no scientific evidence that SARS-CoV-2 might be transmitted by fresh or minimally processed fruits and vegetables, however the risk cannot be discarded or ignored, particularly in the actual context where the virus is spreading in many countries and regions of the word. However, in a recent study on food contamination by SARS-CoV it was reported that the virus was detected on some frozen foods, packaging materials and storage environments with 9 incidents reported by health authorities across China between early July and mid-August 2020. These findings should change our view and reconsider the possible risks of food contaminations from the farm-to-table chain including harvesting and postharvest handling of fresh crops (Han, Zhang, He, & Jia, 2020).

In a recent assessment report authored by Oakenfull and Wilson (2020) and published by the Food Standards Agency (UK), the authors indicated that for some commodities, in case some handlers are contaminated among the multiple people involved from the farm to the table, a cross-contamination may occur. Interestingly, the authors do not discard the risk of the contamination of food, food contact materials, and packaging from infected but asymptomatic workers and consider the risk "*Very Low = meaning very rare but cannot be excluded*," in case of course the food hygiene and HACCP processes are followed. Nevertheless, from the beginning of SARS-CoV-2 pandemic, hygiene measures have

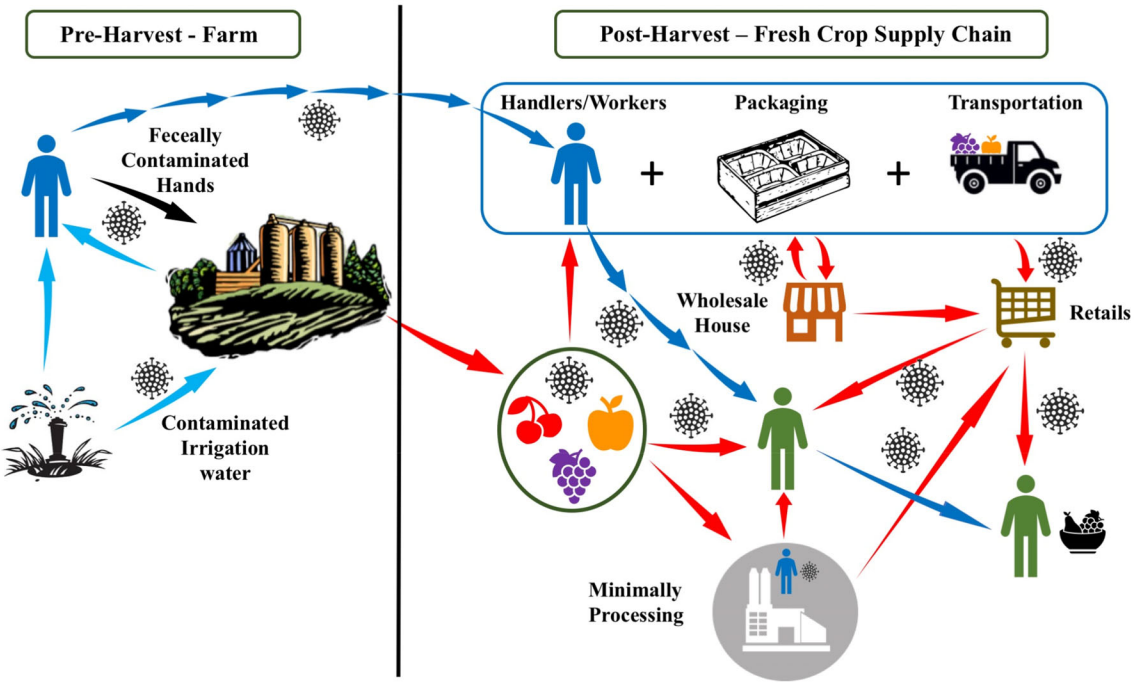


**FIGURE 1** Potential routes of transmission of COVID-19 by fruits and vegetables. *Sapphire blue arrow*: Transmission though persons, *Azur blue*: Transmission through water; *Red arrow*: Transmission by fruits and vegetables

been drastically reinforced in particular by recommending regular hand washing which should considerably reduce the risk of contamination by handlers because keeping hands clean is especially important to help prevent the virus from spreading (CDC, 2020b).

## 5 | TRANSMISSION RISKS PERSPECTIVES AND RECOMMENDATIONS

The potential transmission risks of SARS-CoV-2 by fresh fruits and vegetables and recommendations to reduce these risks should be based on the answer to one essential question. Can a person be contaminated by SARS-CoV-2 from being in contact with contaminated fresh fruits and vegetables? Before answering this question, it is important to know (a) fresh fruits and vegetables might be contaminated by SARS-CoV-2 and the virus may persist and survive at least 2 days on the contaminated commodity, (b) 50% of the viral outbreaks have been caused by leafy vegetables and fruits including nuts (Hall et al., 2012), (c) a SARS-CoV-2 infected person can contaminate a fresh produce or its packaging by handling it with contaminated hands or via infectious droplets produced when coughing or sneezing (Shukla, Cho, Kwon, Chung, & Kim, 2018), and last but not least, (d) no foodborne contamination can be excluded. Consequently, it appears regarding the numerous opinions and conclusions of the different research and awareness that fruits and vegetables including minimally processed ones might play a non-negligible role in spreading SARS-CoV-2 infection. Of course, this role is relatively much less than the classic mode of transmission of person-to-person. However, this mode of transmission should not be completely ignored and taken to some extent into consideration, and we should learn from the previous outbreaks rather than to minimize a risk that can lead to what we do not know. Indeed, what is scaring about SARS-CoV-2 is not "*what we know about it, but what we do not know*." As depicted by Figure 1, we obviously see the potential risk of being directly or indirectly contaminated by SARS-CoV-2 caused by the handling of contaminated fruits and vegetables and where human plays a major role in this scenario. At this stage and before a vaccine is developed, our main goal and unique confrontation is at least to slow down the spread of the virus and save lives. Therefore, beside the good hygiene practices at the farm, wholesale and retail levels, small actions should be taken. First, it is recommended to simply thoroughly wash the fresh produce before consuming. It is recommended to wash thoroughly the fresh fruits and vegetables consumed raw (for an enhanced safety and because the enveloped viruses are the easiest to kill, dip fresh fruits and raw eaten vegetables 30 s in water containing 0.1% sodium hypochlorite or domestic bleach c.a. 10 drops per liter), and this wash is more efficient to inactivate SARS-CoV-2 if present or any other enveloped virus as confirmed by numerous studies. Because diet is necessary to our life and well-being, we should perpetually have in mind the safety of what we are eating. In the context of SARS-CoV-2, each avoided contamination which might lead to death is likely a saved life and therefore a small step to our victory against this disease, and often small action can make a big difference.

## 6 | CONCLUSIONS

In conclusion, to date SARS-CoV-2 has caused the death of more than 2.5 million persons and this number is increasing daily and no one is in the position to predict reliably when this number will decrease or stop. Among these deaths, no data are available on how much exactly have been caused by person-to-person contact and contact with other materials including fruits and vegetables in the grocery or the wholesale markets. Even though the number of infected persons from fruits and vegetables might be extremely low in comparison, it is a life that could have been saved by breaking the transmission chain of the virus in the fresh crops supply chain.

### CONFLICT OF INTEREST

The author declares no conflicts of interest.

### DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

### ORCID

*Noureddine Benkeblia* https://orcid.org/0000-0002-7477-2092

### REFERENCES

Alegbeleye, O. O., Singleton, I., & Sant'Ana, A. S. (2018). Sources and contamination routes of microbial pathogens to fresh produce during field cultivation: A review. *Food Microbiology*, *73*, 177–208. https://doi.org/10.1016/j.fm.2018.01.003

Appleton, H. (2000). Control of food-borne viruses. *British Medical Bulletin*, *56*, 172–183. https://doi.org/10.1258/0007142001902879

Baert, L., Mattison, K., Loisy-Hamon, F., Harlow, J., Martyres, A., Lebeau, B., … Uyttendaele, M. (2011). Review: Norovirus prevalence in Belgian, Canadian and French fresh produce: A threat to human health? *International Journal of Food Microbiology*, *151*, 261–269. https://doi.org/10.1016/j.ijfoodmicro.2011.09.013

Bidawid, S., Farber, J., & Sattar, S. (2000a). Contamination of foods by food handlers: Experiments on hepatitis A virus transfer to food and its interruption. *Applied Environmental Microbiology*, *66*, 2759–2763. https://doi.org/10.1128/AEM.66.7.2759-2763.2000

Bidawid, S., Farber, J., & Sattar, S. (2000b). Inactivation of hepatitis A virus (HAV) in fruits and vegetables by gamma irradiation. *International Journal of Food Microbiology*, *57*, 91–97. https://doi.org/10.1016/S0168-1605(00)00235-X

Bilal, M., Nazir, M. S., Rasheed, T., Parra-Saldivar, R., & Iqbal, H. M. N. (2020). Water matrices as potential source of SARS-CoV-2 transmission – An overview from environmental perspective. *Case Studies in Chemical and Environmental Engineering*, (in press, *2*, 100023. https://doi.org/10.1016/j.cscee.2020.100023

Bintis, T. (2017). Foodborne pathogens. *AIMS Microbiology*, *3*, 529–563. https://doi.org/10.3934/microbiol.2017.3.529

Bosch, A., Pintó, R. M., & Guix, S. (2016). Foodborne viruses. *Current Opinion in Food Science*, *8*, 110–119. https://doi.org/10.1016/j.cofs.2016.04.002

Brassard, J., Gagné, M. J., Généreux, M., & Côté, C. (2012). Detection of human food-borne and zoonotic viruses on irrigated, field-grown strawberries. *Applied Environmental Microbiology*, *78*, 3763–3766. https://doi.org/10.1128/AEM.00251-12

Butot, S., Putallaz, T., & Sanchez, G. (2008). Effects of sanitation, freezing and frozen storage on enteric viruses in berries and herbs. *International*

*Journal of Food Microbiology*, *126*, 30–35. https://doi.org/10.1016/j.ijfoodmicro.2008.04.033

Butt, A. A., Aldridge, K. E., & Sanders, C. V. (2004). Infections related to the ingestion of seafood part I: Viral and bacterial infections. *The Lancet*, *4*, 201–212. https://doi.org/10.1016/S1473-3099(04)00969-7

Carraturo, F., Del Giudice, C., Morelli, M., Cerullo, V., Libralato, G., Galdiero, E., & Guida, M. (2020). Persistence of SARS-CoV-2 in the environment and COVID-19 transmission risk from environmental matrices and surfaces. *Environmental Pollution*, *265*, 115010. https://doi.org/10.1016/j.envpol.2020.115010

Carter, M. J. (2005). Enterically infecting viruses: Pathogenicity, transmission and significance for food and waterborne infection. *Journal of Applied Microbiology*, *98*, 1354–1380. https://doi.org/10.1111/j.1365-2672.2005.02635.x

CDC (Centers for Disease Prevention and Control). (2019). *Coronavirus Disease 2019 (COVID-19)*. Retrieved from https://www.cdc.gov/coronavirus/2019-ncov/index.html.

CDC (Centers for Disease Prevention and Control). (2020a). *CDC updates COVID-19 transmission webpage to clarify information about types of spread*. Media Statement. Retrieved from https://www.cdc.gov/media/releases/2020/s0522-cdc-updates-covid-transmission.html.

CDC (Centers for Disease Prevention and Control). (2020b). *When and how to wash your hands*. Retrieved from https://www.cdc.gov/handwashing/when-how-handwashing.html.

Ceylan, Z., Meral, R., & Cetinkaya, T. (2020). Relevance of SARS-CoV-2 in food safety and food hygiene: Potential preventive measures, suggestions and nanotechnological approaches. *VirusDisease*, *31*, 154–160. https://doi.org/10.1007/s13337-020-00611-0

Cliver, D. O. (1997). Virus transmission via food. *World Health Statistics Quarterly. Rapport Trimestriel de Statistiques Sanitaires Mondiales*, *50* (1–2), 90–101.

FAO (Food and Agriculture Organization). (2020). *FAOSTAT*. Retrieved from http://www.fao.org/faostat/en/#data/FBS.

FAO/WHO (Food and Agriculture Organization/World Health Organization). (2004). *Fruit and Vegetables for Health. Report of a Joint FAO/-WHO Workshop*. Retrieved from https://apps.who.int/iris/bitstream/handle/10665/43143/9241592818_eng.pdf?sequence=1&isAllowed=y.

FDA (Food and Drug Administration). (2019). *Food Safety and the Coronavirus Disease 2019 (COVID-19)*. Retrieved from https://www.fda.gov/food/food-safety-during-emergencies/food-safety-and-coronavirus-disease-2019-covid-19.

Gerba, C. P., & Rose, J. B. (1990). Viruses in source and drinking water. In G. A. McFeters (Ed.), *Drinking water microbiology* (pp. 380–396). New York: Springer.

Goli, M. (2020a). Review of novel human β-coronavirus (2019-nCoV or SARS-CoV-2) from the food industry perspective—Appropriate approaches to food production technology. *Food Science and Nutrition*, *8*, 5228–5237. https://doi.org/10.1002/fsn3.1892

Goli, M. (2020b). Review of novel human β-coronavirus (2019-nCoV or SARS-CoV-2) from the food industry perspective—Food plant health principles. *Journal of Food Safety*, *40*, e12853. https://doi.org/10.1111/jfs.12853

Greig, J. D., Todd, E. C. D., Bartleson, C. A., & Michaels, B. S. (2007). Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 1. Description of the problem, methods, and agents involved. *Journal of Food Protection*, *70*, 1752–1761. https://doi.org/10.4315/0362-028x-70.7.1752

Hall, A. J., Eisenbart, V. G., Etingue, A. L., Gould, L. H., Lopman, B. A., & Parashar, U. D. (2012). Epidemiology of foodborne norovirus outbreaks, United States, 2001–2008. *Emerging Infectious Diseases*, *18*, 1566–1573. https://doi.org/10.3201/eid1810.120833

Han, J., Zhang, X., He, S., & Jia, P. (2020). Can the coronavirus disease be transmitted from food? A review of evidence, risks, policies and knowledge gaps. *Environmental Chemistry Letters*, *19*, 5–16. https://doi.org/10.1007/s10311-020-01101-x

Kampf, G., Todt, G., Pfaender, S., & Steinmann, S. (2020). Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. *Journal of Hospital Infection*, *104*, 246–251. https://doi.org/10.1016/j.jhin.2020.01.022

Klein, G. (2004). Verbreitung von viren uber die lebensmittelkette. *Deutsche Tierärztliche Wochenschrift*, *111*, 312–314.

Koopmans, M., & Duizer, E. (2004). Foodborne viruses: An emerging problem. *International Journal of Food Microbiology*, *90*, 23–41. https://doi.org/10.1016/s0168-1605(03)00169-7

Kurdziel, A. S., Wilkinson, N., Langton, S., & Cook, N. (2001). Survival of poliovirus on soft fruit and salad vegetables. *Journal of Food Protection*, *64*, 706–709. https://doi.org/10.4315/0362-028x-64.5.706

Lipkin, W. I. (2013). The changing face of pathogen discovery and surveillance. *Nature Reviews Microbiology*, *11*, 133–141. https://doi.org/10.1038/nrmicro2949

Lynch, M. F., Tauxe, R. V., & Hedberg, C. W. (2009). The growing burden of foodborne outbreaks due to contaminated fresh produce: Risks and opportunities. *Epidemiology and Infection*, *137*, 307–315. https://doi.org/10.1017/S0950268808001969

Maillard, J. Y., & Russell, A. D. (1997). Viricidal activity and mechanisms of action of biocides. *Science Progress*, *80*, 287–315.

Matthews, K. (2006). Microorganisms associated with fruits and vegetables. In K. Matthews & M. Doyle (Eds.), *Microbiology of fresh produce* (pp. 1–19). Washington, DC: ASM Press.

Mattison, K., Harlow, J., Morton, V., Cook, A., Pollari, F., Bidawid, S., & Farber, J. M. (2010). Enteric viruses in ready-to-eat packaged leafy greens. *Emerging Infectious Disease*, *16*, 1815–1817. https://doi.org/10.3201/eid1611.100877

Mbithi, J. N., Springthorpe, V. S., & Sattar, S. A. (1991). Effect of relative humidity and air temperature on survival of hepatitis A virus on environmental surfaces. *Applied Environmental Microbiology*, *57*, 1394–1399.

Mitchie, D. E., Zhao, Y., & Tan, T. H. M. (2021). What makes a foodborne virus: Comparing coronaviruses with human noroviruses. *Current Opinion in Food Science*, *42*, 1–7. https://doi.org/10.1016/j.cofs.2020.04.011

Mokhtari, A., & Jaykus, L. A. (2009). Quantitative exposure model for the transmission of norovirus in retail food preparation. *International Journal of Food Microbiology*, *133*, 38–47. https://doi.org/10.1016/j.ijfoodmicro.2009.04.021

Nauheim, R. C., Romanowski, E. G., Araullo-Cruz, T., Kowalski, R. P., Turgeon, P. W., Stopak, S. S., & Gordon, Y. J. (1990). Prolonged recoverability of desiccated adenovirus type 19 from various surfaces. *Ophthalmology*, *97*, 1450–1453. https://doi.org/10.1016/s0161-6420(90)32389-8

Oakenfull, R. J., & Wilson, A. J. (2020). *Qualitative risk assessment: What is the risk of food or food contact materials being a source or transmission route of SARS-CoV-2 for UK consumers? Risk Assessment Report*. Retrieved from https://www.food.gov.uk/sites/default/files/media/document/web-version-qualitative-risk-assessment-risk-of-food-or-food-contact-materials-as-transmission-route-of-sars-cov-2-002.pdf.

Richards, G. P. (2001). Food-borne pathogens enteric virus contamination of foods through industrial practices: A primer on intervention strategies. *Journal of Industrial Microbiology and Biotechnology*, *27*, 117–125. https://doi.org/10.1038/sj.jim.7000095

Ruggeri, F. M., Di Bartolo, I., Ponterio, E., Angeloni, G., Trevisani, M., & Ostanello, F. (2013). Zoonotic transmission of hepatitis E virus in industrialized countries. *New Microbiologica*, *36*, 331–344.

Sattar, S. A., Dimock, K. D., Ansari, S. A., & Springthorpe, V. S. (1988). Spread of acute hemorrhagic conjunctivitis due to enterovirus-70: Effect of air temperature and relative humidity on virus survival on fomites. *Journal of Medical Virology*, *25*, 289–296. https://doi.org/10.1002/jmv.1890250306

Sattar, S. A., Springthorpe, V. S., Karim, Y., & Loro, P. (1989). Chemical disinfection of non-porous inanimate surfaces experimentally contaminated with four human pathogenic viruses. *Epidemiology and Infection*, *102*, 493–505. https://doi.org/10.1017/s0950268800030211

Seymour, I. J., & Appleton, H. (2001). A review. Foodborne viruses and fresh produce. *Journal of Applied Microbiology*, *91*, 759–773. https://doi.org/10.1046/j.1365-2672.2001.01427.x

Shieh, Y. C., Stewart, D. S., & Laird, D. T. (2009). Survival of hepatitis A virus in spinach during low temperature storage. *Journal of Food Protection*, *72*, 2390–2393. https://doi.org/10.4315/0362-028x-72.11.2390

Shukla, S., Cho, H., Kwon, O. J., Chung, S. H., & Kim, M. (2018). Prevalence and evaluation strategies for viral contamination in food products: Risk to human health—A review. *Critical Reviews in Food Science and Nutrition*, *58*, 405–419. https://doi.org/10.1080/10408398.2016.1182891

Sun, Y., Laird, D. T., & Shieh, Y. C. (2012). Temperature-dependent survival of hepatitis A virus during storage of contaminated onions. *Applied and Environmental Microbiology*, *78*, 4976–4983. https://doi.org/10.1128/AEM.00402-12

Tetro, J. (2014). Control of foodborne viruses at retail. In J. Farber, J. Crichton, & O. P. Snyder (Eds.), *Retail food safety* (pp. 59–79). New York: Springer-Verlag.

Thippareddi, H., Balamurugan, S., Patel, J., Singh, M., & Brassard, J. (2020). Coronaviruses – Potential human threat from foodborne transmission? *LWT – Food Science and Technology*, *134*, 110147. https://doi.org/10.1016/j.lwt.2020.110147

Todd, E. C., Greig, J. D., Bartleson, C. A., & Michaels, B. S. (2009). Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 6. Transmission and survival of pathogens in the food processing and preparation environment. *Journal of Food Protection*, *72*, 202–219. https://doi.org/10.4315/0362-028x-72.1.202

Todd, E. C. D., & Greig, J. D. (2015). Viruses of foodborne origin: A review. *Virus Adaptation and Treatment*, *7*, 25–45. https://doi.org/10.2147/VAAT.S50108

Tyler, H. L., & Triplett, E. W. (2008). Plants as a habitat for beneficial and/or human pathogenic bacteria. *Annual Review of Phytopathology*, *46*, 53–73. https://doi.org/10.1146/annurev.phyto.011708.103102

Van Boxstael, S., Habib, I., Jacxsens, L., & de Vocht, M. (2013). Food safety issues in fresh produce: Bacterial pathogens, viruses and pesticide residues indicated as major concerns by stakeholders in the fresh produce chain. *Food Control*, *32*, 190–197. https://doi.org/10.1016/J.FOODCONT.2012.11.038

Van der Poel, W. H. M. (2014). Food and environmental routes of hepatitis E virus transmission. *Current Opinion in Virology*, *4*, 91–96. https://doi.org/10.1016/j.coviro.2014.01.006

van Doremalen, N., Bushmaker, T., Morris, D. H., Holbrook, M. G., Gamble, A., Williamson, B. N., … Munster, V. J. (2020). Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *New England Journal of Medicine*, *382*, 1564–1567. https://doi.org/10.1056/NEJMc2004973

Velebit, B., Djordjevic, V., Milojevic, L., Babic, M., Grkovic, N., Jankovic, V., & Yushina, Y. (2019). The common foodborne viruses: A review. *IOP Conference Series: Earth and Environmental Science*, *333*, 012110. https://doi.org/10.1088/1755-1315/333/1/012110

Verhaelen, K., Bouwknegt, M., Lodder-Verschoor, F., & Rutjes, S. A. (2012). Persistence of human norovirus GII.4 and GI.4, murine norovirus, and human adenovirus on soft berries as compared with PBS at commonly applied storage conditions. *International Journal of Food Microbiology*, *160*, 137–144. https://doi.org/10.1016/j.ijfoodmicro.2012.10.008

Wathore, R., Gupta, A., Bherwani, H., & Labhasetwar, N. (2020). Understanding air and water borne transmission and survival of coronavirus: Insights and way forward for SARS-CoV-2. *Science of the Total Environment*, *749*, 141486. https://doi.org/10.1016/j.scitotenv.2020.141486

WHO. (2020). *Novel coronavirus. Situation report—4 (2019-nCoV)*. Retrieved from https://www.who.int/emergencies/diseases/novel-coronavirus-2019?gclid=EAIaIQobChMI64SyyNLZ6gIVy5-zCh3hAg3iEAAYASAAEgLDaPD_BwE.

Yépiz-Gómez, M. S., Gerba, C. P., & Bright, K. R. (2013). Survival of respiratory viruses on fresh produce. *Food and Environmental Virology*, *5*, 150–156. https://doi.org/10.1007/s12560-013-9114-4

**How to cite this article:** Benkeblia N. In the landscape of SARS-CoV-2 and fresh fruits and vegetables: The fake and hidden transmission risks. *J Food Saf*. 2021;e12898. https://doi.org/10.1111/jfs.12898