Review article

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Assessment of Food Safety During Covid-19 Pandemic

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ABSTRACT

SARS-CoV-2, a novel Coronavirus that causes COVID-19 disease and the World Health Organization (WHO) declared COVID-19 as a pandemic on March 11, 2020. Until now, foodborne or waterborne exposure to this virus has not been reported as the transmission route. However, the infected individual in the food production and service facility and, contaminated surfaces, may serve as the source of transmission route since Coronavirus can survive on the inanimate surfaces. Based on the available data, we reviewed the persistence of Coronaviruses on inanimate surfaces in the context of the food contact materials. Coronavirus persists on stainless steel, plastic and glass surfaces for a few days which are commonly used in food production and processing facilities. Therefore, appropriate food contact materials having fewer risk levels can be preferred. Additionally, using biocidal surfaces could help reduce the incidence of infections spread due to touching contaminated surfaces. In other parts of this review, appropriate inactivation procedures and ongoing food handling practices were explained. For prevention of virus transfer due to the contamination of food packaging material and also, food-handling by an infected person through food processing and serving, ongoing hygiene practices in food facilities should continue and inactivation procedures should be widened by taking into consideration the human Coronavirus and also, other foodborne viruses which have distinct properties compared to bacteria. Last of all, pandemics have impacts on the food supply chains, especially during harvest and logistics. Therefore, it is important to continue production and processing by raising awareness about food safety to ensure people in the food supply chain are not at risk of transmission.

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Introduction

Food and water are essential requirements for the survival of living beings. However, due to both natural and human-based processes, an array of contaminants find their way into food and water through multiple routes and contamination of drinking water and foods consumed by people is a global food safety issue [1, 2]. Food products undergo various stages during production, processing, packaging and transportation and each stage could be a potential source of contaminants of biological, chemical and physical origins [3]. If food is contaminated with pathogenic microorganisms or their toxins or

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chemical contaminants, it is a significant problem due to causing transmission or onset of diseases [4].

Chemical contaminants in food and water are substances that can lead to disease or injury when consumed at high concentrations. Natural toxic compounds produced by plants or marine organisms, mycotoxins, food additives, environmental contaminants, pesticides and veterinary drug residues, thermal process contaminants such as acrylamide, furan, 3-monochloropropanediol (3-MCPD) and migrants from packaging materials can be categorized in that group [2, 5, 6].

Biological hazards are the microorganisms such as bacteria, yeasts, molds, viruses and parasites. Some microorganisms including many bacteria, yeast and mold species are considered safe and used in the production of fermented foods and food ingredients due to their beneficial and functional effects [7]. On the other hand, some microbial species can cause foodborne diseases or food spoilage [8]. Microbial foodborne diseases can result in either infection by a pathogen itself or intoxications by toxins or toxic metabolites of microorganisms [4]. Most foodborne illnesses are infections caused by a variety of bacteria, viruses and parasites [9]. Pathogens cause a great number of foodborne and waterborne illness outbreaks with significant impacts on human health and also, economy [10]. Therefore, they have a noteworthy concern in the food industry.

Viruses are very different than other foodborne bacterial pathogens since they have distinct properties. Viruses are not free-living organisms and need an appropriate host for multiplication. Therefore, they only reproduce in the living cells of humans, other animals, plants and bacteria [11]. Viruses cannot replicate in foods, but they can be present; hence, they do not require food, water or air for their survival [4]. Unlike bacteria, viruses can not multiply or produce toxins in food. Therefore, foods only act as vehicles for their transfer [12]. Viruses could persist a long time as infectious particles in the environment or foods [13]. Food and water contamination can occur during different stages of the food production chain. Food may be intrinsically contaminated at any stage of pre-harvest, harvest and post-harvest production or contaminated if handled by infected food handlers under a food handling environment with poor sanitation conditions [14]. On the other hand, the transmission of zoonotic viruses could occur through the consumption of animal-origin products contaminated with viruses [15].

Viruses with a lipid envelope could be easily inactivated [16]. But viruses that do not contain a lipid envelope are more resistant and stable to even extreme conditions for a long time in foods or the environment. In food processing, a virus could resist some of the food processing techniques which destroy bacterial pathogens. Therefore, if food or water is contaminated with viruses, they could survive in foods, on food contact surfaces and on hands for extended periods [11].

Enteric viruses are an important food safety concern [11]. European Food Safety Authority (EFSA) reported that viruses accounted for 9.2% of total foodborne and waterborne outbreaks in 2015 [17]. In foodborne infections, the most frequently involved viruses human Norovirus (NoV) and Hepatitis A virus (HAV), but the other viruses such as Human Rotavirus (HRV), Hepatitis E virus (HEV), Astrovirus (AstV), Enterovirus(EV), Sapovirus, Aichivirus (AiV), Parvovirus, Coronavirus and Human Adenovirus (HAdV) could also transmit by food [12, 18-20]. Among them, NoV has been recognized as one of the most common causes of foodborne gastroenteritis worldwide [21]. NoV and Hepatitis A virus are very infectious viruses and human-to-human spread is the most common transmission route and the secondary transmission route of these viruses is through foodborne contamination [13]. Food handling is an important route of transmission. In addition, foods consumed raw or undercooked are considered at greatest risk of causing enteric viral diseases since viral foodborne outbreaks have been associated mainly with contaminated foods served and eaten raw or uncooked such as shellfish [22], fruits and vegetables [23]. Contaminated water, fruits and vegetables, shellfish, and food-handling are transmission routes of NoV. Foods commonly involved in Hepatitis A outbreaks were contaminated shellfish, fruits, vegetables, salads, dairy products, reconstituted frozen orange juice and raw or not fully cooked foods [24]. Hepatitis E outbreaks were associated with the consumption of contaminated meat and shellfish. The consumption of contaminated meat from infected animals, contaminated shellfish and vegetables has been associated with Rotavirus [25, 26]. Different from foodborne gastrointestinal viruses that cause illness through contaminated food, highly pathogenic human Coronaviruses caused important outbreaks in the world [27].

The novel Coronavirus has recently emerged as the third highly pathogenic human Coronavirus and named as the severe acute respiratory syndrome Coronavirus-2

(SARS-CoV-2) causing COVID-19 disease [28]. This review aims to discuss effects of COVID-19 disease on food safety in the light of current knowledge.

SARS-COV-2 Virus

Coronaviruses are members of *Coronavirinae* subfamily in the *Coronaviridae* family [29]. Coronaviruses are enveloped, pleomorphic or spherical particles, including single-stranded (positive-sense) RNA associated with a nucleoprotein within a capsid comprised of matrix protein [30]. Coronaviruses are important pathogens that cause human and vertebrate diseases [31]. Highly pathogenic Coronavirus outbreaks, SARS-CoV in 2002-2003 and MERS-CoV in 2012, have occurred in the last two decades and these CoVs caused illnesses from cold to more severe diseases such as severe acute respiratory syndrome (SARS) and Middle East Respiratory syndrome (MERS). Currently, a novel Coronavirus, SARS-CoV-2 causing COVID-19 disease has recently emerged from China and then, quickly spread globally. The WHO declared COVID-19 as a pandemic on March 11, 2020 [32]. According to current evidence, WHO reported person-to-person transmission of SARS-CoV-2 causing COVID-19 disease through direct contact to the respiratory droplets of the infected person by sneezing or coughing. Another route could be indirect contact with contaminated surfaces or objects [33]. Currently, foodborne exposure to this virus has not been known yet as the route of transmission and there is no evidence of food and food packaging being associated with transmission of the COVID-19 disease [34]. However, food handling by an infected person or contamination of food packaging material should be evaluated. Because it is known that Coronaviruses can persist on inanimate surfaces [35]. Therefore, it is important to assess the possible impacts on the current knowledge.

Food and Water Safety during COVID-19 Pandemic

COVID-19 pandemic has affected the food systems [36] from many routes including food safety, food security, contamination of foods and food contact materials, hygiene and sanitation procedures, resilience and sustainability, lockdowns of the food facilities, changes in food consumption patterns and consumer behaviors as shown in Figure 1.

Food safety is one of the four pillars of the food systems that were affected during COVID-19 pandemic and is a very important matter for preventing the spread of the SARS-CoV-2 virus, which causes COVID-19 pandemic, among consumers, producers and retailers [37]. In the light of current knowledge, foodborne or drinking water exposure to this virus has not been reported as the transmission route. However, surfaces and fomites may serve as a source of transmission respiratory droplets of the infected individual or contaminated hands [38]. Surface contamination could occur by the direct landing of droplets expelled during infected person sneezing or coughing or due to the indirect transfer from contaminated hands. Therefore, viruses retained on surfaces could cause a risk of infection to anyone who contacts the contaminated surface.

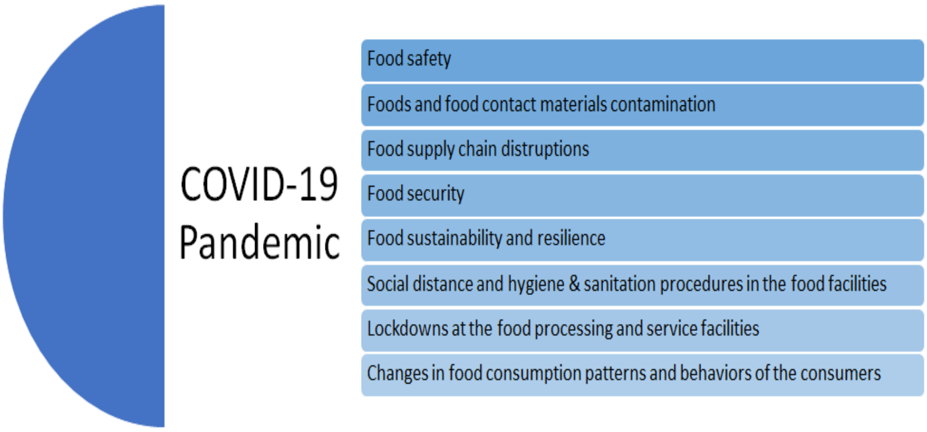

Fig 1 Effects of COVID-19 on food systems

Ensuring the safety of food reaching consumers' plates is very important for the food sector [39]. Therefore, the possibility of virus transfers due to the contamination of food packaging material and also, food handling by an infected person through food processing and serving should be assessed for food safety and precaution measures should be implemented. First of all, four key steps of food safety, cleaning, separation, cooking and chilling, should be followed as normally done to prevent any foodborne illness [34]. Secondly, it is known that Coronaviruses can persist on inanimate surfaces [35]. While there is limited data about the survival of the enveloped COVID-19 virus, however, it is likely to be inactivated significantly more rapidly than non-enveloped human enteric viruses [38]. Therefore, food production, processing and service facilities should take appropriate infection-control measures by optimal inactivation of the virus to prevent the possible transfer from one person to another person, to the surface or food or food packaging material.

Moreover, the number of foodborne illnesses were decreased in 2020 compared to the previous year [40]. Foodborne illnesses have significant impacts from a public health and also, economical point of view [41]. Widespread public health interventions together with increased precautions and hygiene procedures in the food facilities to prevent transmission of SARS-CoV-2 for reducing the risk of COVID-19 disease might affect the number of foodborne illnesses. Besides, public health and hygiene procedures, closures of restaurants, or fewer food businesses trading could have contributed to declines. Centers for Disease Control and Prevention (CDC) reported a 26% reduction compared with 2017–2019 in the incidence of infections caused by pathogens transmitted commonly through food in the US during 2020 which is an important ratio from a food safety point of view [42].

Contamination of Coronaviruses through food contact materials

Surface contamination and transmission of pathogens from contaminated surfaces have recently been found that they could be more important than originally thought for the spread of illnesses [43, 44]. Food contact surfaces are typically made of stainless steel and different kinds of plastic material and also, could contain other materials like wood, ceramics, rubber or glass [45]. Among them, stainless steel surfaces and utensils are the most preferred in kitchen areas and other food production and processing facilities [46]. Glass is used as the food packaging material for making bottles and jars and also commonly used in kitchens as food serving materials. Therefore, some food contact materials could be a source of transmission in the food and drink service and preparation facilities. Also, plastics are used as food contact equipment. Viruses can persist for days and even weeks on inanimate surfaces under ambient conditions of temperature and humidity. Persistence of viruses on different surfaces, survival temperature and durations and also, some inactivation procedures are given in Table 1.

In food technology, many food packaging materials with different features are used to protect the food from physical, chemical and biological damage from the external environment, to extend shelf life, to retard deterioration and to maintain the food product's quality and safety until the food reaches to the consumer and also, provide ingredient and nutritional information to the consumers. Due to the low cost and functional advantages, multiple types of plastic polymers are used for food packaging. In the current knowledge, virus could persist on stainless steel and plastic and food packaging material could be the source of the transmission, maybe not to food but the hands or other surfaces.

Enveloped viruses remain infectious on surfaces for several days [47, 48]. However, many of them are less stable in the environment and are more susceptible to oxidants [49]. Howie, Alfa [50], investigated the survival of two laboratory enveloped and non-enveloped viruses after dried on the surface of polyvinyl chloride test carriers in the absence or presence of an organic matrix and reported the survival of the non-enveloped reovirus during 30 days despite drying in a commercial artificial test soil (ATS; US Patent 6447990) containing worst-case levels of carbohydrate, protein, endotoxin and hemoglobin to represent the low-level nutrient surface. On the other hand, enveloped virus survived 2 days and died. They confirmed that the non-enveloped viruses could persist in the environment, especially in the presence of organic material. Recently, Kampf, Todt [35] reviewed the analysis of 22 studies of human and veterinary Coronaviruses and reported that human Coronaviruses could survive on inanimate surfaces like plastic, metal or glass for up to 9 days, but they could be inactivated by various surface disinfection procedures efficiently.

In a recent study conducted by [46], survival rates of infectious SARS-CoV-2 was investigated at 20 °C, 30 °C and 40 °C with 50% relative humidity on several common surface types and results showed that viable virus was isolated for up to 28 days at 20 °C from glass, stainless steel and paper surfaces and with increased temperature, survival rate was decreased. In the study of Duan, Zhao [51], the survival abilities of a SARS-CoV (strain P9) on the eight different surfaces and also, in water and soil, were investigated and strong persistence of Coronaviruses on the surfaces were reported since viral infectivity of the viruses persisted for 60 hours, however, after 72 to 96 h of exposure it started to drop and then became almost undetectable after 120 h. After 48 h, determined infected cells were less than 50 % except for glass surface since 51-75 % infected cells were detected on it. After 120 h, any cells were not detected on the surfaces, except filter paper, metal and cloth which still contained a few infected cells at the end of 5 days. van Doremalen, Bushmaker [52] investigated the stability of MERS-CoV on plastic and steel surfaces by comparing MERS-CoV (HCoV-EMC/2012) and A/Mexico/4108/2009 (H1N1) viruses. H1N1 virus was only stable until four hours on both surfaces. On the other hand, MERS-CoV could be recovered from both surfaces after 48 hours at 20°C (40% relative humidity) as shown in Table 1. At 30°C, MERS-CoV virus remained viable for 8 and 24 hours with 80% and 30% relative humidity on both surfaces, respectively. These surfaces are commonly used surfaces in the food industry and also, food preparation facilities. In addition, they are used as food contact materials.

Temperature and relative humidity affect the stability of the viruses. A study conducted on an airborne enveloped human Coronavirus (HCoV-229E) reported that besides temperature, relative humidity is also important for the survival of the virus since recovery was higher at low relative humidity than at high relative humidity [53]. It was reported that at 20 °C, HCV/229E recovery was better at 30% RH and 50% RH (87% and 91%, respectively), but, at 80% RH, only 55% of the original input HCV/229E was detected. However, at 6°C, at all three relative humidity levels, the survival of aerosolized virus was significantly enhanced. But this study was conducted with a human Coronavirus and, it was reported that SARS-CoV on surfaces could be more persistent compared to human Coronavirus 229E [54, 55]. Rabenau, Cinatl [54] reported that in a dried state, HCoV-229E human Coronavirus loses its infectivity within 24 h while SARS-CoV retains its infectivity even after 6 days and it loses completely after 9 days at the dried state. Casanova, Jeon [56] investigated the effects of air temperature and relative humidity on survival of two potential surrogates on the surfaces and reported that survival was greater at low relative humidity. This study was conducted using two potential surrogate viruses, mouse hepatitis virus (MHV) and transmissible gastroenteritis virus (TGEV) due to the challenges of working with SARS-CoV and concluded that the relationship between inactivation and relative humidity was not monotonic and at low relative humidity, the survival rate was higher. It was concluded that based on the survival data for surrogate viruses, enveloped viruses could remain infectious long enough on the surfaces for people contacting them, posing a risk for exposure that causes to possible illness transmission. The same study reported the persistence on the stainless steel at 4°C for as long as 28 days. The inactivation was reported to be faster at 20°C than at 4°C at all humidity levels. Both viruses were inactivated more rapidly at 40°C than at 20°C [56]. As reported, storing in food at refrigerating conditions did not stop the survival of the foodborne [57] or human viruses [56]. Viruses can remain stable under refrigerated and frozen storage conditions [58].

Chan, Peiris [59] showed that dried SARS-CoV (HKU39849) virus on plastic maintained its viability for up to 5 days at 22–25°C and of 40–50% relative humidity and high temperature (38°C) at high relative humidity (>95%) have a synergistic effect on inactivation of SARS-CoV viability while low temperature and low humidity levels caused prolonged persistence of virus on the contaminated surfaces.

A recent study was conducted on the stability of SARS-CoV-2 (HCoV-19 nCoV-WA1-2020) and SARS-CoV-1 (Tor2) in aerosols and on various surfaces including plastic (polypropylene), stainless steel (AISI 304 alloy), copper and cardboard at 21 - 23°C and 40% relative humidity for over 7 days and reported that the stabilities of SARS-CoV-2 and SARS-CoV-1 were similar under the experimental conditions [43]. The study reported that fomite and aerosol transmission of SARS-CoV-2 is probable because the virus could stay viable and infectious in aerosol for hours and on surfaces for days. It was observed that SARS-CoV-2 remained viable in aerosols for 3 hours, with a reduction in infectious titer [43]. A similar reduction was determined SARS-CoV-1. It was reported that SARS-CoV-2 was more stable on stainless steel and plastic compared to copper and cardboard. After application on stainless steel and plastic surfaces, the viable virus was detected for up to 72 hours. SARS-CoV-1 survived 72 hours on plastic and 48 hours on stainless steel. Plastics including polypropylene form and stainless steel are commonly used in food production and processing facilities. Stainless steel (Type 304) is among the used food contact materials in the food industry. An exponential decay was observed in virus titer for both viruses during all experimental conditions, but the viable virus was still detected up to 72 hours after application to stainless steel and plastic surfaces. On the other hand, on copper, no viable SARS-CoV-2 and SARS-CoV-1 were measured after 4 and 8 hours, respectively. On cardboard, no viable SARS-CoV-2 and SARS-CoV-1 were detected after 24 and 8 hours, respectively. Therefore, the longest viability of both of the viruses was reported on stainless steel and plastic surfaces; the estimated median half-life of SARS-CoV-2 was approximately 5.6 and 6.8 hours on stainless steel and plastic, respectively. According to the determined results, inanimate surfaces, but especially plastic and stainless steel could be the source of transmission of SARS-CoV-2, since the virus can remain viable on surfaces up to days depending on the inoculum. It is very important to perform precautionary preventive measures for pandemic mitigation efforts.

Table 1 Persistence of viruses on different surfaces

Virus	Surface	Inoculum[2]	Survival Temperature	Survival Time[1]	Inactivation	Reference
SARS-CoV-2	stainless steel plastic cardboard copper	$10^{5.25}$	21-23 °C	72 h 72 h 24 h 4 h		[43]
SARS-CoV-1	stainless steel plastic cardboard copper	$10^{6.75-7.00}$		48 h 72 h 8 h 8 h		
SARS-CoV-2	stainless steel glass vinyl paper cotton	4.97×10^7	20 °C	28 d 28 d 28 d 28 d 7 d		[46]
	stainless steel glass vinyl cotton paper		30 °C	7 d 7 d 3 d 3 d 21 d		
	stainless steel glass vinyl cotton paper		40 °C	<1 d <1 d <1 d <1 d <1 d		
Reovirus (non-enveloped)	ATS[4]	$\tilde{}10^8$	Room temperature	30 d	*2.6% glutaraldehyde 7%, %0.5 AHP[3]*	[50]
Sindbis virus (enveloped)				˜2 d	*2.6% glutaraldehyde 7%, %0.5, %0.05 AHP[3]*	
SARS-CoV	wood glass mosaic metal cloth Press paper Filter paper plastic water soil	10^6	Room temperature	4 d 4 d 3 d 5 d 5 d 4 d 5 d 4 d 4 d 4 d	*Heat treatment* *-56°C for 90 min* *-67°C for 60 min* *-75°C for 30 min* *UV irradiation for 60 min*	[51]
TGEV	Stainless steel	10^6	4°C 20°C 40°C	≥28 d 3-28 d <6-120 h		[56]
MHV			4°C 20°C 40°C	≥28 d 3-28 d <6-120 h		
SARS-CoV H-CoV	plastic	10^7	21–25°C	6-9 d 72 h	*Thermal inactivation -56°C-60°C 30 min*	[54]
SARS-COV	plastic	10^5	21-25 °C	5 d		[59]
MERS-CoV	steel plastic	10^5	20°C 30°C 20°C 30°C	48 h 8-24 h 48 h 8-24 h		[52]
H-CoV	polyfluorotetraethylene (Teflon; PTFE) polyvinyl chloride (PVC) ceramic tiles stainless steel glass silicon rubber copper	10^3	21 °C	5 d 5 d 5 d 5 d 5 d 3 d <0.5h-2h		[44]
H-CoV	Aluminum	$5 *10^3$	21 °C	2-8 h		[60]

[1]h: hours; d:days, [2]Inoculum: 50% tissue-culture infectious dose ($TCID_{50}$)/ml; pfu: plaque-forming units; viral titer, [3]AHP: accelerated hydrogen peroxide, [4] ATS: artificial test soil (US Patent 6447990)

Warnes, Little reported that SARS and MERS human Coronaviruses caused increasing concern of contact transmission during outbreaks and determined that human Coronavirus (HuCoV-229E) could survive for at least 5 days on the polyfluorotetraethylene (Teflon; PTFE), polyvinyl chloride (PVC), ceramic tiles, glass and stainless steel surfaces and for 3 days on the silicon rubber at 21°C and relative humidity of 30- 40% [44]. The initial inoculum in that study was lower compared to other studies, but although low-level initial inoculum concentration, the virus maintained infectivity for 5 days on all of the surfaces, with the exception of silicon rubber. It was reported that contamination of surface material with very few Coronavirus particles can cause a considerable risk of infection spread after being touched and then transferred to facial mucosa. As the food contact material, stainless steel is preferred in the food industry due to its corrosion resistance and also, durability based on the percentage of chromium and nickel. The same study showed that nickel and stainless steel did not show any antiviral activity. However, the inactivation of human Coronavirus was reported on brass and copper-nickel surfaces at room temperature. In this study, brasses containing at least 70% copper were very effective to inactivate the studied human Coronavirus and the rate of inactivation was proportional to the copper percentage. Coronavirus was inactivated on copper nickels containing less than 70% copper in 120 min and if alloy contains >90% copper inactivation of Coronavirus in <30 min. The study concluded that incorporation of copper alloys to commonly used areas can help to decrease infection spread from touching surfaces contaminated with Coronaviruses [44]. Antimicrobial properties mainly on pathogenic bacteria of copper previously reported [61-63]. Also, viral inactivation of murine norovirus (MNV) on copper and copper alloy surfaces was reported [64]. Parra, Toro [62] suggested the potential usage of copper surfaces to control the microbiological hazards in the poultry industry based on the antimicrobial effect over pathogenic and non-pathogenic microorganisms. Geng, Zhang [63] reported that compared to stainless steel, copper could have a potential application in the field of food packaging, disinfection and piping of drinking water due to the antibacterial activity. Delgado, Quijada [65] reported that ion copper delivery plastic materials based on polypropylene with embedded copper nanoparticles could have great potential as antimicrobial agents. However, copper and copper alloys such as brass have limited usage in the food industry due to the corrosion problem especially when it is contacted with low acidity food products. Stainless steel is a cheaper alternative compared to copper and has excellent properties to be used as a food contact material. But, using biocidal surfaces could help to decrease the incidence of infections spread by touching contaminated surfaces and more studies should be conducted for possible usage.

Coronavirus inactivation techniques

Viruses can persist for days and even weeks on inanimate surfaces and enveloped viruses remain infectious on surfaces during several days [47, 48]. However, many of them are more susceptible to oxidants [49]. Therefore, disinfection practices are important and should continue to be applied. Bosch, Gkogka [58] reviewed the various control procedures and different antiviral food components for the inactivation of foodborne viruses and reported that incorporating additional preservation steps to an existing process should assist in eliminating or destroying viruses in many foods.

In the current COVID-19 pandemic, foods, hands or contaminated surfaces could serve as vehicles. Therefore, disinfection should be applied. WHO [66] reported that many disinfectants are active against enveloped viruses and currently, recommended effective ones include 70% ethyl alcohol and sodium hypochlorite at 0.1%.

Recently, Ong, Tan [67] analyzed SARS-CoV-2 causing COVID-19 in the environmental samples and reported extensive environmental contamination with the virus, but post-cleaning samples were negative showing current decontamination practices are sufficient. It is already known that the virus could be easily inactivated by commonly used disinfectants [68]. Howie, Alfa [50] investigated the efficacy of glutaraldehyde and hydrogen peroxide: accelerated hydrogen peroxide (AHP) formulations on the destroying two enveloped and non-enveloped viruses during 1-20 min and reported the elimination of the enveloped test virus by diluted disinfectants. In their study, glutaraldehyde 2.6%, 7% and 0.5% AHP killed both of the test viruses within 20 min (Table 1). Kampf, Todt [35] reviewed in details all of the persistence of veterinary and human Coronaviruses on the inanimate surfaces and also, their inactivation procedures with biocidal agents applied for chemical disinfection and reported that surface disinfection procedures with various concentrations of ethanol, propanol, hydrogen peroxide or sodium hypochlorite were efficient for inactivation compared to biocidal agents such as chlorhexidine digluconate or benzalkonium chloride which are less effective. The review evaluated the results of the biocidal agents in suspension or carrier tests to inactivate human and veterinary Coronaviruses. Among them, the biocidal agents in suspension tests inactivating infectivity of SARS and MERS Coronaviruses more than 4 log_{10} include ethanol (78-95%), 2-propanol (75%), the combination of 2-propanol (45%) with 1-propanol (30%), 0.5% hydrogen peroxide, glutardialdehyde (0.5-2.5%) and povidone iodine (0.23-7.5%).

Food facilities are required to use EPA-registered sanitizer products for cleaning and sanitizing practices [34]. United States Environmental Protection Agency (US EPA) listed all the commercial products that meet EPA's criteria for using against SARS-CoV-2 on surfaces [69]. According to the update (22.04.2020), active ingredients for human Coronavirus include quaternary ammonium, hydrogen peroxide, peroxyacetic acid, octanoic acid, sodium hypochlorite, isopropanol, sodium carbonate, ethanol, triethylene glycol, l-lactic acid, glycolic acid, silver ion, citric acid, phenolic, hypochlorous acid, ammonium carbonate, ammonium bicarbonate. Different brands were listed including reported active ingredients alone or in combination. For the efficient use of disinfectants, it is very important to prepare according to the manufacturer instructions at appropriate concentration during enough time.

Chemical sanitizing is more frequently used in food production facilities. However, sanitization may be achieved through thermal or radioactive processes besides chemical disinfectants. Thermal processing is an effective strategy in inactivating viruses and different viruses could be inactivated depending on the applied temperature degree and duration [58, 70]. Irradiation is effective to preserve foods. However, most viruses could be far more resistant to irradiation and the effectiveness of the irradiation against viruses is dependent on the virus, food product characteristics and application conditions [58, 71].

Rabenau, Cinatl [54] reported that thermal inactivation at 56°C was very effective in the absence of protein; but, the addition of 20% protein exerted a protective effect in the residual infectivity. Heat treatment at 60°C for at least 30 min should be used for the inactivation of protein-containing solutions (Table 1). Duan, Zhao [51] reported that when SARS-CoV cells were exposed to higher temperatures, the infectivity was virtually eliminated at 56°C for 90 min, 67°C for 60 min and 75°C for 30 min. Exposure to UV irradiation on the virus in culture medium for 60 min destroyed viral infectivity at an undetectable level. Leclercq, Batéjat [72] investigated the survival of MERS-CoV at 25, 56 and 65°C and reported that 56°C, the common temperature used for inactivation of enveloped viruses, for almost 25 minutes were required to decrease initial titer by 4 $\log_{10}$. Raising the temperature to 65°C showed a negative effect on the viral infectivity since virucidy decreased significantly in 1 min and 15 min at 65°C was more sufficient for complete inactivation. Kampf, Voss [73] reported that a thermal disinfection at 60°C - 30 min, 65°C - 15 min and 80°C - 1 min was efficient to significantly reduce Coronavirus infectivity by at least 4 $\log_{10}$. The effect of heat could be related to the thermal aggregation of SARS-CoV membrane protein [74]. It was reported that the nucleocapsid protein of SARS-CoV is completely denatured at 55°C in 10 min [75]. The survival ability of the viruses could depend on the type of surface, temperature, relative humidity and the strain of the virus. Therefore, the development of new procedures to assess the activity of new antiseptic disinfectants on the viruses should be further investigated.

Mitigation of biological risks

Food supply chains have paramount importance during the pandemic and every step to prevent contamination should be implemented. There is no evidence of the transmission of this virus through foods or food packaging materials but the asymptomatic food handlers that might carry the virus could be the potential transmission route to the food chain [76]. Four key steps of food safety, cleaning, separation, cooking and chilling, should be followed as normally done to prevent any foodborne illness [34]. There are already ongoing practices for food safety to prevent any foodborne illnesses such as frequent hand-washing, cleaning of the surfaces and utensils, and cooking food to the right temperature and these steps could also reduce the potential transmission of any virus particles through food.

In a food facility, ongoing applied procedures related to personal hygiene, sanitation and also, recognized food safety practices will decrease the possibility of pathogens that will threaten the safety of food supply chain [77]. As reported by French Agency for Food, Environmental and Occupational Health & Safety [78], two theoretical routes of food contamination by the SARS-CoV-2 virus could be associated with infected livestock animals and the transfer of the virus to food products of animal origin, or the handling of foods by people infected with this virus. However, there is not any evidence that the

SARS-CoV-2 virus causing COVID-19 disease is carried by the domestic food-producing animals, the consumption of foods of animal origin from infected animals was not thought as a source of infection based on the current knowledge [77, 78]. The other route, contamination of food via the infected person with the SARS-CoV-2 virus could be prevented in the food facilities through ongoing good hygiene practices. Moreover, it is evident that Coronavirus persist on inanimate surfaces, it is very important to often apply heat or sanitizers such as chlorine and hydrogen peroxide for the disinfection. Individuals could contaminate the environment and surroundings by sneezing or coughing due to the transmission of the virus through respiratory droplets. Therefore, in food-processing environments, to prevent contamination of any equipment, food contact material or food directly or through cross-contamination from surfaces or workers' hands to food and to protect other healthy workers (Figure 2), food workers experiencing clinical gastrointestinal or respiratory disease symptoms should not participate in food preparation and processing [77].

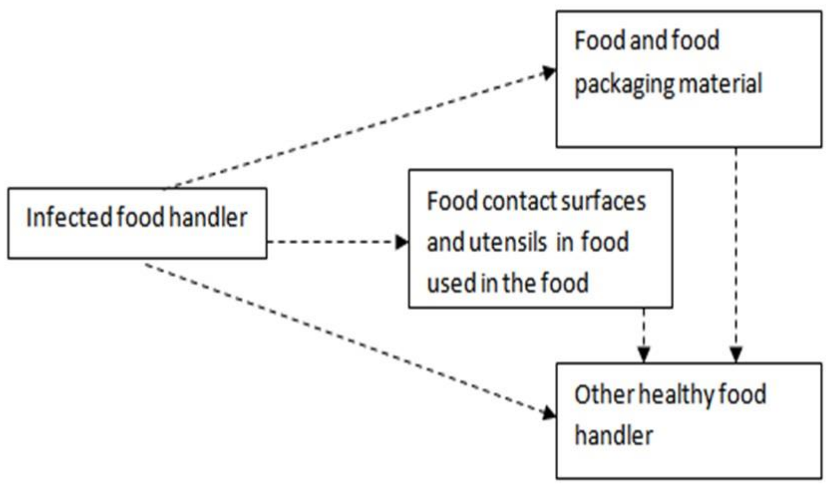

Fig 2 Possible modes of transmission from inanimate surfaces in the food production environments based on the available data from [33, 34, 77]

Possible reduction techniques of SARS-CoV-2 contamination for some specific food types and water

In the food industry, it is important for food or water not to be contaminated at any point during its journey along the supply chain. Foodborne exposure to SARS-CoV-2 virus has not been known to be a route of transmission [79]. However, it is very important to be aware of the possible roles of water and fresh foods. Because viruses could be stable at many conditions and surfaces. Despite not being grown in foods, they could be stable on the surfaces and cause to contaminate other surfaces and hands. In addition, person-to-person transfer in a food facility should be taken into consideration [80].

Fresh fruits and vegetables

Viruses cannot replicate in foods, but they can be present [4]. Microbial control strategies used to keep foods safe microbiologically could not be directly applicable to viruses because for viruses ‘growth’ is not a concern whereas ‘survival’ or maintaining infectivity is key [58]. Although viruses will not grow in or on foods, raw vegetables and fruits might serve as vehicles for infection [81]. Mullis, Saif [82] investigated if the contaminated vegetables may serve as a vehicle for Coronavirus transmission to humans by using bovine Coronavirus as a surrogate on lettuce surface at refrigeration conditions and determined that on lettuce bovine Coronavirus retained infectivity for at least 14 days.

During COVID-19, food consumption patterns were changed compared to previous years due to increased awareness of consumers and fruits and vegetables have significantly higher consumption scores compared to the period before the pandemic [83]. Good personal and food hygiene practices are very important during the handling of ready-to-use foods, fresh fruits and vegetables that may be consumed raw and/or without any further processing. Effective thermal treatment is very important for pathogen inactivation. Therefore, fresh food that will be consumed without heat treatment could be particularly susceptible to contamination from the environment and food handlers. It is critically important to keep food contact environments, equipment and tools clean, conduct good hand washing practices, and separate raw and cooked foods and use clean water for minimizing the risk of exposure to any foodborne bacteria and viruses [77]. Moreover, surface decontamination using sanitizers could be applied. Fresh products usually undergo a sanitization step after harvesting from the field, but commonly used sanitizers could be unsuccessful for viruses [11]. Therefore, it is important to apply formulations appropriate for the target virus inactivation and, toxicologically safe. For consumers, as normally done, it is very important to continue to wash fruits and vegetables using potable running water effectively.

Meat and poultry

There is no evidence that meat and poultry play a role in the spread of the SARS-CoV-2 virus causing this disease [78]. However, separating raw meats and poultry from other foods and cooking to the right temperature should be followed as normally done to prevent any foodborne illness [34]. It is important to avoid the consumption of raw or undercooked foods of animal origin including meat, milk products, eggs to reduce exposure to all viruses and also, other foodborne pathogens. Therefore, foods of animal origin should be heat-treated sufficiently before consumption [77].

On the other hand, high numbers of COVID-19 cases in meat processing facilities were reported worldwide and compared to other food sectors, outbreaks were so severe in meat companies causing some plants to shut down in the United States. However, exposure to SARS-CoV-2 was not through the meat products the workers handle in meat processing facilities. Centers for Disease Control and Prevention (CDC) reported that the reason SARS-CoV-2 spread rapidly in meat processing facilities is due to the work environments where employees have prolonged close workplace contact with each other at processing lines and other areas in busy plants for long periods. This may contribute significantly to their potential exposures [84].

Water

As reported by WHO [38], although the persistence of the virus in drinking water, there is no evidence about the waterborne transmission of the virus causing COVID-19. Updated report of WHO (23 April 2020) claimed that the virus could be in untreated drinking water, however, it has not been detected in drinking-water supplies yet. Based on the available virus on other Coronaviruses, the risk of Coronavirus transmission through water supplies is low [66]. CDC [85] reported that the virus was found in untreated wastewater. However, there is no evidence to date that this virus can cause disease through exposure to untreated wastewater or sewerage systems. Enveloped Coronavirus becomes inactivated considerably more rapidly than non-enveloped human enteric viruses since enveloped viruses are less stable in the environment and are more susceptible to oxidants. Standard filtration and disinfection procedures for water treatment can inactivate COVID-19 [66]. Determination of gene fragments of the SARS-CoV-2 virus in incoming sewage water and screening of the virus at municipal waste water plants should be possible to follow the evolution of the pandemic [84, 86, 87].

Conclusion

In the light of current knowledge and cases, the foodborne transmission of SARS-CoV-2 was not reported as the route. However, the infected individual in the food production and service facility and, contaminated surfaces, may serve as the source of transmission route since Coronavirus can survive on the inanimate surfaces. Therefore, it is important to evaluate food contact surfaces since the survival of the virus is changed depending on the surface type. In the food industry, it is important for food or water not to be contaminated at any point during its journey along the supply chain. Food supply chains have paramount importance during the pandemic and every step to prevent contamination should be implemented. Standard practices for food safety to prevent any foodborne illnesses especially hand-washing frequently, cleaning of surfaces and utensils, and cooking food to the right temperature should continue to decrease the possible transmission of any virus particles through food. It is important to efficiently apply chemical sanitation, thermal or UV treatment applications. Moreover, food facilities could plan a more frequent cleaning and sanitation schedule to prevent cross-contamination. The COVID-19 pandemic has already affected food systems. Some food chains, especially high-value commodities requiring a large amount of labor for their production, were affected more than others due to the health problems of the employees, lockdowns resulting in unable to travel of local and migrant laborers or social distancing requirements in the food processing facilities. Therefore, sustainable and also, resilient food systems to shocks, crisis and pandemics should be developed for continuity of the food production. In addition, food safety should be the high priority. It has been observed that public health interventions to prevent SARS-CoV-2 transmission influenced exposures associated with other foodborne illnesses. It is critically important to continue production and processing by raising awareness about food safety to ensure people along the food supply chain are not at risk of COVID-19 disease transmission. Prevention strategies should be well defined and applied through farm to processing plant to restaurants and homes to reduce the occurrence of infections.

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