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Coronaviruses – Potential human threat from foodborne transmission?

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ABSTRACT

The COVID-19 pandemic has worldwide impact in terms of number of illnesses, deaths and long-term sequelae. While the main route for the spread of the SARS-CoV-2 virus is person to person from respiratory droplets, survival of the virus in the air and its ability to infect subsequently have raised concerns. COVID-19 outbreaks in meat and other food processing plants raise concern for potential foodborne spread. We focus on the survival of the virus in the food subjected to various unit operations during processing, storage and distribution and the risk to consumers. While the risk of contamination of food products is possibly due to survival of the virus in the air in food processing operations if preventive measures are not followed, survival of the virus on fresh foods is dependent on the intrinsic and extrinsic properties of the specific foods and antimicrobial interventions used during production. Even if the virus remains infective on contaminated foods, maintenance of infectivity after ingestion of food and subsequent invasion of tissue has not been reported. An alternate route of infection from contaminated foods can be during handling of foods and subsequent spread of the virus to other surfaces such as face, nose, leading to infection. However, due to the extensive treatments foods receive during processing, often inhospitable environs of the food products and further food preparation prior to consumption significantly reduce the risk of transmission of the SARS-CoV-2 virus.

1. Introduction

The COVID-19 pandemic has significant global impact with ~13.4 million cases and 581,000 deaths as of July 15, 2020 (Johns Hopkins Coronavirus Resource Center, 2020). CDC and the World Health Organization stress that the main route of transmission of SARS-CoV-2 is person to person via respiratory droplets generated when coughing, sneezing or speaking (Tang et al., 2020). Currently no evidence suggesting food as a vehicle of transmission (Kingsbury & Lake, 2020). Asymptomatic transmission of SARS-CoV-2 remains controversial (Bai et al., 2020). Other potential routes of transmission include droplet-contaminated surfaces or aerosols (Van Doremalen et al., 2020) or the fecal-oral route (Gu et al., 2020). The CDC emphasizes that the major risks continue to be from being around people, and to a lesser extent touching surfaces and/or not washing and/or sanitizing hands. As of June 24, 2020, at least 250 meat packing and 86 food processing plants as well as 46 farms and production facilities have confirmed cases of COVID-19 (FERN, 2020). This pandemic has caused significant disruption of the economy and challenged the food sector with managing risks for employees, concerns regarding SARS-CoV-2 contamination of foods, and changes in inspection and recall management.

1.1. Coronaviruses – characteristics, pathogenesis and animal origins

The name coronavirus is derived from Greek word κορώνα (corona; crown) referring to the virions' round shape surrounded by spikes when observed under the microscope. Protruding spike proteins are used by the virus for receptor binding and entry into host cells. Receptors for previously known human CoVs have been identified, including the angiotensin I-converting enzyme 2 (ACE2) for SARS-CoV, the likely receptor for SARS-CoV-2 based on spike proteins sequence similarity (Tang et al., 2020). ACE2 receptors expression patterns in the lung, heart, kidney and intestine dictate the virus tissue tropism and correlated with manifestations of illness in humans (Jin et al., 2020; Su et al., 2016).

Most human emerging infectious diseases are of animal origin and result from interspecies transmission. Coronaviruses have a wide range

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Acronyms

ASFV   African swine fever virus
BoCoV   Bovine Coronavirus
CDC   Centers for Disease Control and Prevention
CoV   Coronavirus
COVID-19   Coronavirus disease – 19
MERS-CoV   Middle East Respiratory Syndrome - Coronavirus
MHV   Mouse Hepatitis Virus
PEDV   Porcine Epidemic Diarrheal Virus
SARS-CoV   Severe Acute Respiratory Syndrome – Coronavirus
SARS-CoV-2 Severe Acute Respiratory Syndrome – Coronavirus 2
TGEV   Transmissible Gastroenteritis Virus

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Table 1
Phylogeny, pathogenesis and clinical manifestations of human coronaviruses.

Human CoVs	Genus clusters	Natural host	Intermediate host	Receptor	Human disease
HCoV-229E	*Alpha-CoV*	Bat	Alpaca	ANPEP	Mild respiratory tract infections
HCoV-NL63	*Alpha-CoV*	Bat	Unknown	ACE2	Mild respiratory tract infections
HCoV-HKU1	*Beta-CoV*, Lin. A	Rodent	Unknown	9-O-Ac-Sia	Mild respiratory tract infections
HCoV-OC43	*Beta-CoV*, Lin. A	Rodent	Cow	9-O-Ac-Sia	Mild respiratory tract infections
SARS-CoV	*Beta-CoV*, Lin. B	Bat	Palm civet	ACE2	SARS, mild or severe respiratory tract infections
SARS-CoV-2	*Beta-CoV*, Lin. B	Bat	Unknown	ACE2	COVID-19, mild or severe respiratory tract infections
MERS-CoV	*Beta-CoV*, Lin. C	Bat	Camel	DPP4	MERS, mild or severe respiratory tract infections

ANPEP: human aminopeptidase N.
9-O-Ac-Sia: 9-O-acetylsialic acids.
DPP4: Dipeptidyl peptidase-4.
ACE2: Angiotensin converting enzyme 2.

of animal hosts (Cui et al., 2019). Prior to the emergence of SARS-CoV, MERS-CoV and SARS-CoV-2, information on human CoVs was scarce and those circulating in the population were associated with mild respiratory infections whereas animal CoVs were widely studied in veterinary medicine as they represented important animal health and economic issues in animal husbandry (Decaro & Lorusso, 2020). Genomic epidemiology and phylogenetic analyses of sequence databases revealed that all human CoVs are of animal origin (Su et al., 2016).

Since many species of CoVs circulate among different animal species interacting with each other, some wildlife and domestic animals may be intermediate hosts allowing virus transmission to humans. Civets and camels have been identified as intermediate hosts for SARS-CoV and MERS-CoV (Kan et al., 2005; Paden et al., 2018). Pangolin was suggested as a potential intermediate host for SARS-CoV-2 (Zhang et al., 2020). Additional research is needed to explore the pathogenicity and diversity of CoVs in these animals. Phylogenic classifications, natural and intermediate hosts, target cell receptors, and clinical manifestations of human CoVs are described in Table 1.

2. Coronaviruses in foods

2.1. Routes of contamination

Human-to-human transmission of SARS-CoV-2 occurs primarily through respiratory droplets generated by infected individuals. The presence of SARS-CoV and SARS-CoV-2 viral RNA in the air, on fomites and high-touch surfaces, mainly in hospitals with multiple infected patients has been substantiated (Booth et al., 2005; Chia et al., 2020). Individuals may contract COVID-19 indirectly by touching a contaminated surface before touching their mouth, nose or their eyes (Cai et al., 2020). Concerns regarding the potential for transmission through foods have been raised considering that pre-symptomatic or asymptomatic workers in the agri-food sector may become a source of contamination for foods or food contact surfaces if adequate mitigation measures are not implemented. Food production and processing involves handling by several people that may cross-contaminate foods along the farm-to-fork continuum (Fig. 1). While transmission of SARS-CoV-2 has not been linked to the consumption of contaminated food, it cannot be totally excluded and fecal-oral transmission remains a possibility. Recent studies have detected SARS-CoV-2 RNA in untreated wastewater (Randazzo et al., 2020), anal swabs and stool samples collected from patients with COVID-19 (Wu et al., 2020). Although water treatment appears to inactivate CoVs (Randazzo et al., 2020), a large proportion of the world's wastewater is discharged into surface waters due to the lack of appropriate infrastructure (Arslan et al., 2020). The presence of CoVs in water raises the possibility of food contamination through irrigation of fresh produce with surface water, bioaccumulation of viral particles in shellfish due to the contamination of harvest water and exposure of production animals to untreated wastewater (Fig. 1 and Table 2). To date, there has been no evidence to suggest that livestock play a role in transmission of the SARS-CoV-2 despite the fact that several animal species express ACE2 receptors in some tissues (Li et al., 2020). However, wildlife hunted for food may be asymptomatic carrier of pathogenic viruses and butchering and consumption of their raw or undercooked meat and organs may present a potential route of transmission (Fig. 1).

2.2. Behavior in foods and food-related surfaces

2.2.1. Impact of food properties (pH, a_w, ingredients, antimicrobials, etc.)

Viruses do not propagate on foods and can lose infectivity during storage. Some food properties and storage conditions that can affect the rate of loss of infectivity are briefly discussed here.

Yépiz-Gómez et al. (2013) compared the stability of CoV and an enteric poliovirus artificially inoculated on lettuce, strawberries and raspberries stored at 4 °C and observed that enteric poliovirus survived better than CoV on lettuce, with only ≤1 log reduction after 10 days of storage at 4 °C compared to CoV not being recovered after 4 days, while Mullis et al. (2012) was able to detect infectious CoV until day 14 on lettuce stored at 4 °C using an enhanced virus elution method. The loss of infectivity of CoVs in a variety of matrices at relatively high temperatures achieved during food processing is presented in (Fig. 2). Persistence of CoVs in food, water and food industry-related surfaces at different temperatures and relative humidities are summarized in Table 2.

Acidification of foods to a pH < 4.6 is used to control growth of pathogenic and spoilage bacteria and enhance safety and shelf-life of foods. The nucleocapsid protein of SARS-CoV begins to unfold at a pH near 5.0 and is fully denatured at a pH near 2.7, suggesting that SARS-CoV is sensitive to pH changes (Wang et al., 2004). Darnell et al. (2004) reported that exposure of SARS-CoV in a buffer to moderate acidification from pH 9 to 5 did not affect the infectivity, regardless of the exposure temperature. These data indicate that infectivity of SARS-CoV is retained at moderate pH values normally encountered in foods.
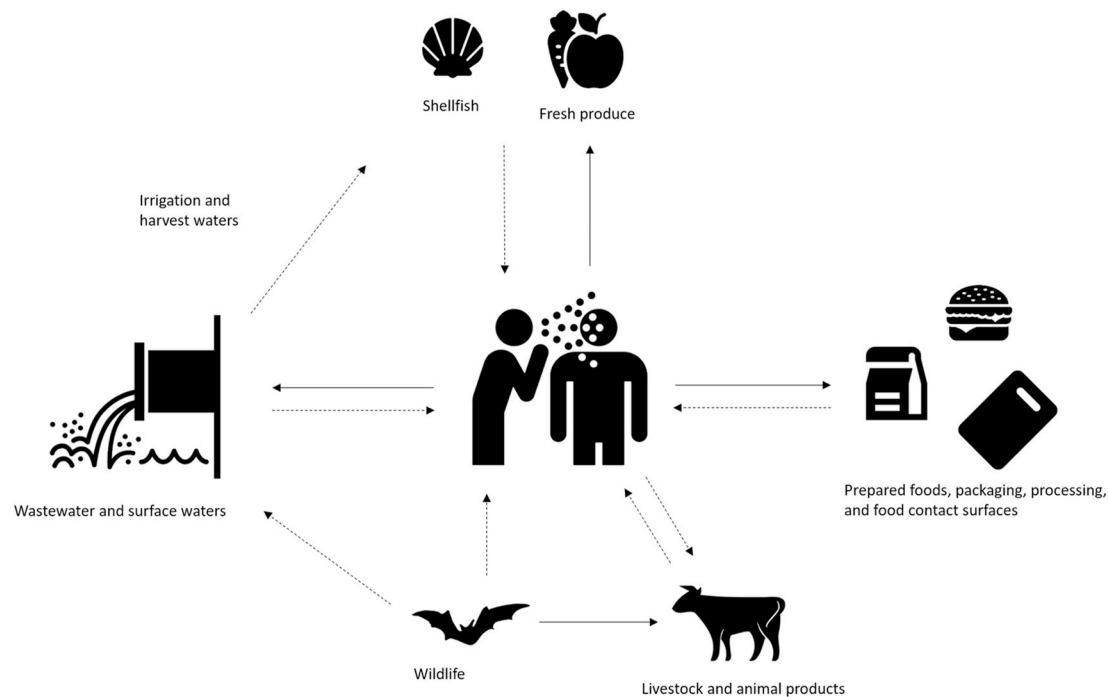
Fig. 1. Schematic representation of the potential routes of food contamination by human coronaviruses. Solid lines represent putative contamination routes whereas dashed lines represent suspected but not conclusively demonstrated routes of contamination. Center: Human-to-human transmission via respiratory droplets. Left: Contamination of wastewaters or surface waters by human or wildlife fecal excreta (solid line) and possible transmission via exposure to contaminated waters as well as potential contamination of agriculture and aquaculture sites (dashed lines). Top: Putative contamination of fresh produce or shellfish via respiratory droplets or hand contaminated with fecal matter (solid line) and potential transmission via the consumption or handling of raw or undercooked foods contaminated by irrigation or harvest waters or sick food handlers (dashed lines). Right: putative contamination of prepared (ready-to-eat) foods, packaging, processing equipment and food contact surfaces by respiratory droplets (solid line) and potential transmission via the consumption of prepared foods or indirect transfer of virus from contaminated packaging or food surfaces. Bottom: Putative spillover of coronavirus from wildlife to domestic animals and potential transmission to humans via handling or consumption raw or undercooked virus-contaminated bush meat or livestock products. Survival and stability of CoVs on food, surfaces and in the environment depend on a multitude of factors such as temperature, relative humidity, intrinsic and extrinsic properties of the matrix, applied treatments, time, starting viral load. Although the main mode of transmission of SARS-CoV-2 appears to be the person-to-person respiratory route, it is important to better understand the behavior of CoVs in the food sector in order to better characterize the risk that their potential presence represents.

Water activity (a_w) of food products can affect the viability of the virus in low moisture foods and also can affect thermal destruction, with longer D values. Mebus et al. (1997) examined the survival of several porcine viruses in different Spanish dry-cured meat products and reported that these viruses were inactivated during the commercial curing process, although swine vesicular disease virus was viable (infective) in Serrano ham manufacturing process. Similarly, Petrini et al. reported survival of ASFV in various Italian dry-cured meat products while the ASFV was inactivated within the curing period of Italian salami (fermented) (Petrini et al., 2019). Addition of sugar and presence of a rich and varied bacterial flora in minced salami could have induced acidification and proteolysis resulting in the inactivation of the virus.

2.2.2. Animal based foods

Recent SARS-CoV-2 outbreaks in meat processing operations highlight the potential for employees being source of contamination to other employees as well as the product itself, either directly or indirectly via contamination of the equipment and through the contaminated air.

Meat and poultry processors apply a variety of antimicrobial interventions during slaughter and fresh meat processing. The processes include physical or chemical treatments (Table 3) and can achieve virus inactivation on fresh meat products. Thermal (Table 4) or chemical treatments (Table 3) are validated to reduce bacterial pathogens and also can cause destruction of viruses, specifically enveloped virus such as SARS-CoV-2 and other CoVs.

Processed meat and poultry products are produced by heating ($\geq 70\,^{\circ}$C), fermentation (pH ≤ 4.6), and/or drying either in low humidity environment or in the presence of secondary inhibitors such as salt

($a_w \leq 0.86$), curing agents (nitrates/nitrates) and spices or a combination of these factors, which can inactivate the CoVs.

The D values of CoVs are similar to *Salmonella* and *E. coli* O157:H7 (Fig. 2), except for the SARS-CoV-2 reported by Chin et al. (2020). However, sampling interval (5 min) used by Chin et al. (2020) was longer; the inoculated SARS-CoV-2 could have been inactivated prior to first sampling time (5 min).

Thermal processing of meat products relies on heating to temperatures $\geq 70\,^{\circ}$C or a combination of temperature-time combinations to achieve at least 6.5 or 7.0 log-reduction in *Salmonella*. Similar to processing of meat and poultry products, PEDV was eliminated during manufacturing of swine feed (low a_w product) at pelleting temperatures $\geq 54.4\,^{\circ}$C for 30 s (Cochrane et al., 2017). These processes will inactivate SARS-CoV-2 and other CoVs, resulting in safe processed meat and poultry products. Fermentation of meat products relies on gradual reduction in product pH to ≤ 4.6 at 35 $^{\circ}$C, and subsequent drying to reduce a_w (≤ 0.86), which can inactivate the CoVs.

As in production of low moisture (or low a_w) meat and poultry products, spray drying of bovine plasma with chamber temperature of 200 $^{\circ}$C, with the outlet dried product temperature of 70–80 $^{\circ}$C resulted in inactivation (4.2 $\log_{10}$ TCID$_{50}$/mL reduction) of the PEDV (Pujols & Segalés, 2014). These results suggest potential inactivation of SARS-CoV-2 during gradual drying of meat and poultry products such as jerky and biltong.

2.2.3. Produce and related products

Contamination of produce with pathogens can occur on the farm or during processing. Certain agricultural practices such as irrigation could

Table 2

Persistence of human and animal coronaviruses on inanimate surfaces, food matrices and in water.

Virus	Surface	Time	Inoculum[b] (viral titer)	Conditions[a]	References
SARS-CoV-2	Copper	4 h	10^5	21–23 °C, 40%	Van Doremalen et al. (2020)
	Cardboard	24 h			
	Stainless steel	48 h			
	Plastic	72 h			
	Nitrile glove	7 d	7.5×10^5	Room temperature	Kasloff et al. (2020)
	Chemical resistant glove	4 d			
	N95 mask	21 d			
	N100 mask	21 d			
	Tyvek coverall	14 d			
	Plastic face shield	21 d			
	Cotton	24 h			
	Stainless steel	14 d			
SARS-CoV	Plastic plate	5–13 d	10^5	22–25 °C, 40–50%	Chan et al. (2011)
	Polystyrene plate	9 d	10^7	21–25 °C	Rabenau et al. (2005)
	Metal	5 d	10^5	Room temperature	Duan et al. (2003)
	Wood	4 d			
	Paper	4–5 d			
	Glass	4 d			
	Paper	24 h	10^6	Room temperature	Lai et al. (2005)
		3 h	10^5		
		‹ 5 min	10^4		
	Disposable gown	2 d			
		24 h			
		1 h			
	Cotton gown	24 h			
		1 h			
		5 min			
MERS-CoV	Stainless steel	48 h	10^5	20 °C, 40%	Van Doremalen et al. (2013)
		24 h		30 °C, 30%	
		8 h		30 °C, 80%	
	Plastic	48 h			
		24 h			
		8 h			
HCoV 229 E	Aluminium	12 h	5×10^3	21 °C	Sizun et al. (2000)
	Latex glove	12 h			
	Stainless steel	5 d	10^3	21 °C, 30–40%	Warnes et al. (2015)
	Glass	5 d			
	PCV	5 d			
	Teflon	5 d			
	Ceramic	5 d			
	Silicon	3 d			
	Nickel	120 min			
	Brass	40 min			
	Polystyrene plate	72 h	10^7	21–25 °C	Rabenau et al. (2005)
	Lettuce	4 d	1.2×10^6	4 °C	Yépiz-Gomez et al. (2013)
HCoV OC43	Aluminium	3 h	5×10^3	21 °C	Sizun et al. (2000)
	Latex glove	1 h			
BoCoV	Lettuce	14 d	1.2×10^4	4 °C	Mullis et al. (2012)
MHV	Reagent-grade water	>49 d	NM	4 °C	Casanova et al. (2009)
		17 d		25 °C	
	Lake water	>14 d			
		10 d			
	Stainless steel	>28 d	10^4–10^5	4 °C, 20%	Casanova et al. (2010)
		28 d		20 °C, 20%	
		120 h		40 °C, 20%	
		>28 d		4 °C, 50%	
		5 d		20 °C, 50%	
		24 h		40 °C, 50%	
		>28 d		4 °C, 80%	
		10 d		20 °C, 80%	
		6 h		40 °C, 80%	
TGEV	Reagent-grade water	>49 d	NM	4 °C	Casanova et al. (2009)
		22 d		25 °C	
	Lake water	>14 d			
		13 d			
	Stainless steel	>28 d	10^4–10^5	4 °C, 20%	Casanova et al. (2010)
		28 d		20 °C, 20%	
		120 h		40 °C, 20%	
		>28 d		4 °C, 50%	
		3 d		20 °C, 50%	
		12 h		40 °C, 50%	
		>28 d		4 °C, 80%	
		14 d		20 °C, 80%	
		6 h		40 °C, 80%	

NM: not mentioned.
  [a] Temperature (°C) followed by relative humidity (%).
  [b] PFU or TCID-50 depending of the study.
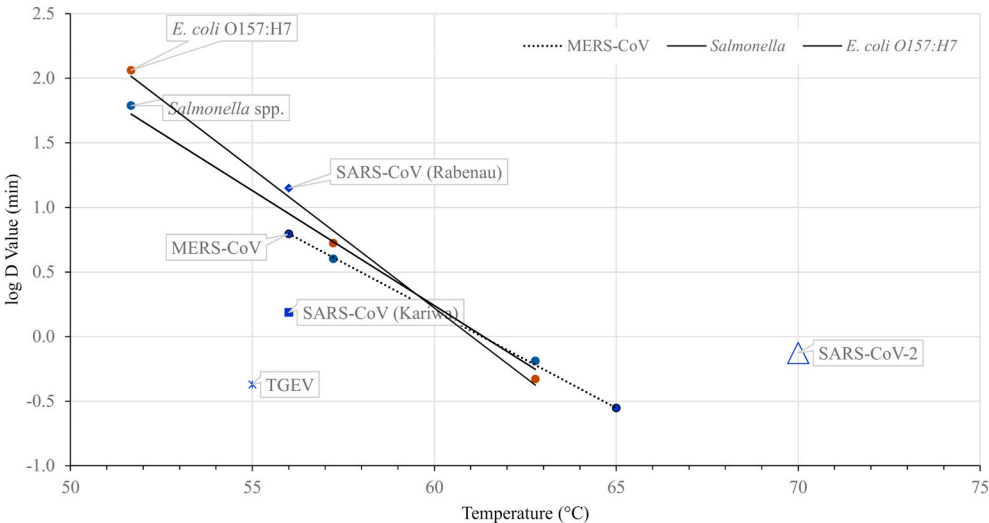
Fig. 2. Thermal destruction curve of bacterial foodborne pathogens of regulatory importance and coronaviruses. The symbols represent the log D_{10} values of the various CoVs {SARS-CoV: Kariwa et al. (2006), Rabenau et al. (2005); TGEV: Laude (1981); MERS-CoV: Leclercq et al. (2014); SARS-CoV-2: Chin et al. (2020)} and foodborne pathogens {*Escherichia coli* O157:H7: Line et al. (1991); *Salmonella* spp: Goodfellow and Brown (1978)}; the solid and dotted lines represent the thermal destruction time (*z* value) curves for the MERS-CoV, *E. coli* O157:H7 and *Salmonella*.

Table 3
Antimicrobial interventions applied to meat animal/poultry carcasses during processing (slaughter and further processing).

Process	Antimicrobial Intervention
Slaughter (beef, swine, poultry [broiler and turkey])	**Physical:** hot water sprays, steam pasteurization, steam-vacuuming **Chemical:** Organic acid sprays (lactic, acetic, citric and combinations), mineral acids (HCl, H_2SO_4, H_3PO_4 and others, primarily in combination with organic acids), oxidants (halogen based – hypochlorous and/or hypobromous acids; other oxidants - Ozone, peracetic acid [PAA], H_2O_2, etc.), quaternary ammonium based antimicrobial (Cecure [cetyl pyridinium chloride]).
Fabrication and/or Cut-up	Organic acid sprays alone or in combination with mineral acids, oxidants (primarily PAA)
Further processed products	**Physical methods:** thermal treatments (immersion in hot water after vacuum packaging, steam pasteurization or other treatments such as radiant wall oven, etc. to increase surface product temperature), high pressure processing (HHP) **Chemical methods:** Organic acid sprays (as above) alone or in combination with mineral acids, oxidants (PAA) and others such as lauric arginate, epsilon-poly lysine.

be vectors of pre-harvest contamination. Fecal shedding of SARS-CoV-2 by infected individuals (Wu et al., 2020) and survival of CoVs in the environment and untreated wastewater (Randazzo et al., 2020) was reported and highlight the potential concern for fecal-oral transmission of the virus from infected farm workers or by contaminated agricultural water, especially in underprivileged societies that are not equipped with the technology to effectively eliminate viruses (Arslan et al., 2020). At the post-harvest, contamination could occur at the processing plant or during handling of produce by infected personnel from respiratory droplets, aerosols or from contaminated equipment. Whereas CoVs can persist on fresh produce at 4 °C (Table 2), survival of SARS-CoV-2 on different produce types should be evaluated as they are often consumed raw. While there is a risk of contamination of produce and subsequent infections from their handling, risk of infection from ingestion of contaminated produce has not been established.

2.3. Impact of food processing unit operations (Pasteurization, freezing, drying)

Pasteurization refers to processes that eliminate vegetative pathogens in the product to render it safe for consumption. Heat treatment is the most common method of achieving pasteurization although other methods such as ultraviolet radiation (UVC), Gamma or electron beam irradiation, high-pressure processing are also used. Thermal pasteurization treatments that achieve destruction of foodborne bacterial pathogens should also inactivate a wide variety of viral species, including CoVs in human milk as well as in other matrices (Pitino et al., 2020). Irradiation is commonly used for assuring the safety of spices and in some cases for ground beef. Trudeau et al. (2017) reported a Delta value of 17.25 kGy for PEDV in swine feed, indicating that CoVs can be inactivated using irradiation. Food products often are frozen to extend their shelf life by preventing the growth of spoilage bacteria. However, many foodborne viruses are resistant to the freezing process and several outbreaks of foodborne illness have been linked to frozen products. Although there is little data on the effect of freezing on CoVs, Lamarre and Talbot (1989) reported that HCoV 229E suspensions did not lose infectivity following 25 repeated freeze (−70 °C) – thaw cycles, suggesting survival of virus in frozen foods.

3. Risk reduction

3.1. Cleaning and sanitation procedures (end of processing)

Cleaning of food processing operations can be divided into several steps – dry pick-up, pre-rinse with water, application of cleaning agents and soaking, scrubbing and other physical actions to loosen the soil, and final water rinse. While majority of the cleaning steps may not affect virus survival, the application of cleaning agents can result in significant inactivation of the virus. Typical cleaning agents employed in food processing facilities using "wet cleaning" process include alkaline based cleaners (to remove protein and fat deposits), acid based cleaners (to remove mineral deposits), and detergents to assist removal of the dirt and soil from equipment surfaces. All of these were shown to be effective in reducing virus populations, with high pH (alkaline cleaners), low pH (acid cleaners) or through detergent action and reduction in surface tension of the solution.

Table 4
Characteristics of the studies that explored thermal inactivation of infectivity of coronaviruses.

Virus (Genus)	Sub-genus	Strain	Measurement	Temperature (°C)	Conditions associated with treatment	Reference
MERS-CoV (β)	*Sarbecovirus*	FRA2	Cellular infectivity in Vero cells (TCID-50)	$D_{56°C}$ – 6.25 min; $D_{65°C}$ – 0.28 min; z = 6.67 °C	Cell culture supernatant	Leclercq et al. (2014)
PEDV (α)	*Pedacovirus*	V215/78	PFU on Vero cells	$D_{50°C}$ – 60 min	Diluted medium for virus replication	Hofmann and Wyler (1989)
SARS-CoV (β)	*Sarbecovirus*	FFM-1	Cellular infectivity in Vero cells	$D_{56°C}$ – >6.15 min (without protein additive); $D_{56°C}$ −14.05 min (20% fetal calf serum)	Cell culture supernatant with or without FCS (fetal calf serum)	Rabenau et al. (2005)
SARS-CoV (β)	*Sarbecovirus*	Hanoi	Cellular infectivity in Vero cells (TCID-50)	$D_{56°C}$ – 1.54 min	Minimum essential medium	Kariwa et al. (2006)
SARS-CoV2 (β)	*Sarbecovirus*	–	Cellular infectivity in Vero cells (TCID-50)	$D_{70°C}$ – 0.75 min	Virus transport medium	Chin et al. (2020)
TGEV (α)	*Tegacovirus.*	D52	Cellular infectivity in RPtg cells	$D_{55°C}$ – 0.43 min	In HEPES solution at pH 7	Laude (1981)

α: Alphacoronavirus; β: Betacoronavirus.

In addition to reduction in virus titers achieved by cleaning, the sanitizers that are traditionally used in the food industry are effective against a variety of viruses, including CoVs and their basic principles of viral inactivation are covered in the section below.

3.2. Operational procedures to mitigate spread

3.2.1. Facility redesign and physical measures

According to the CDC guidance (Centers for Disease Control and Prevention, 2020), approaches to minimize or eliminate exposure risk in food processing facilities include installing engineering controls, effective sanitation and cleaning, and enhanced administrative measures. The purpose of these approaches is to implement procedures that can allow a safe distance (2 m) between workers. Modifications needed in food processing facilities can vary and will range from changes in production practices to feasibility of implementing structural changes.

Operational changes such as alternative work schedule to control number of personnel on premises can be implemented. Additionally, stationing workers to avoid facing each other and positioning fans to restrict air flow from one worker to another can further reduce the exposure risk. Designating outdoor break areas where possible can decrease worker contact. Installing physical barriers (e.g. plexiglass) between workers is a good strategy, however, it might not be practical in all operations.

Use of cloth face coverings should be considered when distancing workers is not feasible, however it is not a replacement for adequate distancing. Socioeconomic challenges amongst workers in food processing facilities can lead them to work while sick, therefore, administrative controls such as encouraging symptomatic workers to stay home should be considered for minimizing the exposure risk.

3.2.2. Sanitation

Equipment repair during regular processing operation may contaminate the equipment via infected maintenance personnel. However, it is routine that such equipment that undergo repairs are cleaned and sanitized prior to re-use, reducing the risk significantly.

3.3. Efficacy of sanitizers & disinfectants

Sanitizers are routinely used in the food industry subsequent to

Table 5
Sanitizer, general use and recommended concentrations, site of action and effect on viruses.

Compound	General use	Recommended Dose or Concentration	Site of action	Effect on viruses
Physical				
UV light	Hard surfaces, packaging film, etc.	200–280 nm; ~10.6 mJ/cm2	DNA/RNA	Formation of pyrimidine dimers (on RNA), e.g., uracil dimers
Thermal (hot water, steam, etc.)	Hard surfaces, food contact surfaces	≥75 °C	Envelope proteins	Protein denaturation
Alcohols				
Ethanol	Hand rub, food contact surfaces	70%	Envelope proteins	Protein denaturation
Isopropanol	Hand rub, food contact surfaces	70%		
Acids & Alkalis				
Acetic, Citric, Lactic acids; NaOH, KOH,	Hard surfaces, cleaning agents		DNA/RNA	Acids: destroy nucleotide bonds of nucleic acids, precipitate proteins Alkalis: saponify lipids, hydrolysis of nucleotides
Quaternary Ammonium Compounds				
QAC	Food contact surfaces	200 ppm	Envelope proteins, DNA/RNA	Degradation of proteins and nucleic acids
Halogens				
Sodium hypochlorite		100–200 ppm	Aromatic amino acids in proteins	Inhibition of key enzymes, modification of structural proteins
Peroxy compounds				
Hydrogen Peroxide	Personal hygiene, hand rub	35% (vapor)	Target: thiol groups in proteins	Inhibition of key enzymes, modification of structural proteins
Peroxy Acetic Acid	Food contact surfaces	Up to 500 ppm		
Ozone	Food contact surfaces	2 ppm		

cleaning of equipment and the processing environment at the end of operations. They rely on various modes of action and vary in their efficacies in reducing pathogens populations. These sanitizers, as well as the antimicrobial interventions such as halogen-based, quaternary ammonium compounds, oxidants are very effective in destruction of CoVs including SARS-CoV-2. The modes of action of these sanitizers and the targets for action are presented in Table 5. Other sanitizers or disinfectants used for inactivation of enveloped viruses include alcohols and hydrogen peroxide-based sanitizers for personal use, and in addition, UVC along with the sanitizers mentioned above can be used for fomite disinfection.

4. Conclusions

The SARS-CoV-2 outbreaks among food processing plant employees have highlighted the potential for contamination of foods with the virus and potential transmission through the foodborne route. While evidence is lacking, the ability of the virus to maintain infectivity in the environment (air) for prolonged periods of time, and on the materials used in food processing equipment may present a potential risk of foods as a source of the infection. However, antimicrobial interventions applied to various fresh foods, the inhospitable intrinsic and extrinsic properties of the foods as well as the unit operations employed during processed foods manufacturing and further consumer food preparation methods significantly reduce the risk of transmission of the SARS-CoV-2.

Acknowledgments

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