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Review

Food Safety Concerns in "COVID-19 Era"

Carlotta Ceniti [1,*], Bruno Tilocca [1], Domenico Britti [1], Adriano Santoro [2] and Nicola Costanzo [1,*]

[1] Department of Health Sciences, University "Magna Græcia" of Catanzaro, Campus Universitario "S. Venuta", Viale "S. Venuta", 88100 Catanzaro, Italy; tilocca@unicz.it (B.T.); britti@unicz.it (D.B.)
[2] Department of Veterinary Medicine and Animal Productions, University of Naples "Federico II", via F. Delpino 1, 80137 Napoli, Italy; adrisant@unina.it
* Correspondence: ceniti@unicz.it (C.C.); costanzo.nic@unicz.it (N.C.); Tel.: +39-09613695817 (N.C.)

Abstract: In March 2020, the World Health Organization (WHO) declared that the COVID-19 outbreak can be characterized as a pandemic. Human-to-human transmission of the SARS-CoV-2 virus may initially be blamed as the first cause of spread, but can an infection be contracted by ingestion of contaminated food or touching contaminated food surfaces? Recently cold-chain food contamination has been indicated as a possible source of many human cases in China. However, the risk of a food-related COVID-19 infection is still debated since the virus may reach people through a fresh product or packaging, which have been touched/sneezed on by infected people. This review summarizes the most recent evidence on the zoonotic origin of the pandemic, reports the main results regarding the transmission of SARS-CoV-2 through food or a food chain, as well as the persistence of the virus at different environmental conditions and surfaces. Emphasis is also posed on how to manage the risk of food-related COVID-19 spread and potential approaches that can reduce the risk of SARS-CoV-2 contamination.

Keywords: SARS-CoV-2; COVID-19; food safety; coronavirus; foodborne disease; guidance

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1. Introduction

At the end of 2019, a new viral pneumonia emerged in China and rapidly diffused worldwide. A novel coronavirus, belonging to the Betacoronavirus genus, was identified as the etiological agent of this pandemic and due to its similarities with the SARS virus it has been indicated as SARS-CoV-2 [1]. Since the first identified cases of SARS-CoV-2 in December 2019, thousands of infections and deaths were reported globally, thus in March 2020, COVID-19 was characterized as a pandemic by WHO. The incubation period is 5–6 days, however, it can take up to 14 days for the onset of symptoms [2]. It was also demonstrated that the virus can be transmitted by asymptomatic and presymptomatic patients during the incubation period [3]. Moreover, many studies reported cases of recurrence or reactivation of SARS-CoV-2 following disease recovery [4–6]. The clinical manifestations of COVID-19 are variable and non-specific and include fever, myalgia, or fatigue, dyspnea, headache, and dry cough. More recently, diarrhea was reported as one of the most frequent signs in both children and adult patients affected by SARS-CoV-2 [7] suggesting a possible role in the viral spread. The diagnosis is usually based on the detection of SARS-CoV-2 with a polymerase chain reaction (PCR) assay [8]. For testing SARS-CoV-2, the collection of nasopharyngeal/oropharyngeal swabs by a healthcare provider is recommended [9].

In fact, Remdesivir and dexamethasone have been approved for treatment in many countries [10,11] and other drugs, such as heparin, are recommended in the prophylaxis of thrombo-embolic events in patients.

More recently, many episodes of human cases have been reported in slaughter facilities in the US and Europe [12,13] speculating that animals can act as vectors of the virus and meat consumption is a potential way of pathogen diffusion. It is now clearer that the slaughterhouse environment is characterized by high aerosol production combined with intense water use that carries materials extensively over surfaces. Additionally, workers produce more droplets since they have to speak loudly and most of the activity has to be carried out without social distancing [14]. Moreover, it has been demonstrated that SARS-CoV-2 persists on surfaces for several hours or days at room temperature and appears to be stable at low and freezing temperatures, indicating the possibility of surface contact transmission and suggesting a potential involvement of food and food packaging [15,16]. This concern has been refuted by EFSA and FDA reports that underlined that there is not yet evidence that the food is a route of transmission for COVID-19 as it was in previous outbreaks of related coronaviruses, particularly the Middle East respiratory syndrome-coronavirus (MERS-CoV) and SARS-coronavirus (SARS-CoV) [17,18].

This review aims at describing (i) the zoonotic role of COVID-19; (ii) exploring the most important available evidence on the possibility of COVID-19 transmission through the food and supply chain; (iii) discussing the persistence of SARS-CoV-2 to different environments and surfaces; (iv) studying the management of the risk of food-related COVID-19 infection; and (v) including the new tools that can contribute to reducing the risk of SARS-CoV-2 contamination.

2. SARS-CoV-2: A New Zoonosis

SARS-CoV-2 belongs to the Betacoronavirus, a genus of virus already known in veterinary medicine as a common infective agent of both synanthropic and companion animals.

Since the recent isolation of the COVID-19 causal agent, several molecular studies have been performed worldwide with the aim of elucidating the viral origin and the most likely transmission routes. A phylogenetic analysis of full-length genome sequences from clinical isolates showed that SARS-CoV-2 is highly similar to severe acute respiratory syndrome coronavirus (SARS-CoV) and likely uses the same cell receptor, angiotensin-converting enzyme-2, for the onset of the infective process [19]. Genome sequence alignments performed against the known CoVs genomes have reported SARS-CoV-2 as highly similar to several CoVs with tropism for wildlife such as bats, pangolins, and masked palm civets [20]. Controversial results have been reported concerning the snake coronavirus [21,22].

The major concern regarding the susceptible species is related to the infection of livestock and the consequent virus shedding in the food of animal origin. Recently, the virus replication and seroconversion in cattle has been demonstrated but no data are available on the possible presence of the virus in milk, although the virus has been isolated in multiple human breast milk samples [23].

Although controversial results are available in the literature regarding the descending ancestor, all the genomic-based studies agree on the zoonotic origin of the SARS-CoV-2 underlining, once again, the role of the human-animal interrelation and the importance of food safety in public health and the control of pathogen diffusion. The epicenter of the current pandemic has been registered indeed, in the Wuhan seafood wildlife animal market where a variety of mammalian animals are sold both alive and for direct consumption. Analogously, previous SARS-CoV and MERS outbreaks dating back respectively to 2002 (China) and 2012 (Saudi Arabia) had their epicenter in wet markets featured by the massive presence of wild and tropical animals [24].

On the other hand, the genomic homologies scored between the circulating SARS-CoV-2 and the animal CoVs enabled the leveraging of previous virus features for the development of studies aimed at innovative diagnostics and/or prophylactic deliverables. In this context, through the One-Health approach Tilocca et al. employed computational immune proteomics to investigate three immunogenic proteins of the SARS-CoV-2 [25–27]. Here, viral protein sequences were compared with the counterparts of other coronaviruses with tropism for animals that the humans are most frequently interacting with such as dogs, bovines, camels, and dromedaries. Interestingly, aminoacidic sequence homologies confirm the genomic-based studies relative to the virus origin and evolution [28–30]. Moreover, epitopes prediction and peptide sequences alignment highlighted a list of peptide sequences with the potential of immune response stimulation [26,31,32], suggesting a partial protective immunity elicited by the previous exposure of humans to the animal coronaviruses, other than explaining, at least in part, the variable clinical manifestation recorded among the COVID-19 patients. Such information is of valuable importance for the clear definition of the SARS-CoV-2 immunogenicity and might also be implemented in the design of diagnostic tools capable of differential diagnosis and/or the sketch of a safe and efficient vaccinal formulation.

3. Can the Virus Be Transferred from the Food Surface to Humans?

Currently, there is no evidence to suggest that handling food or consuming food is associated with COVID-19 [18]. SARS-CoV-2 is primarily spread from human to human interaction, through respiratory droplets, which are usually released when an infected person coughs or sneezes [33]. Since droplets usually are transported by airflow and fall within a few meters, the likelihood of transmission is decreased if people remain at least 2 m apart [34,35]. It may be possible that a person can get COVID-19 by touching a contaminated droplet on a surface or object and then touching their own eyes, nose, or mouth (Figure 1). In this scenario, the handling or consumption of contaminated food products could have the same risk of a surface or an object [36].

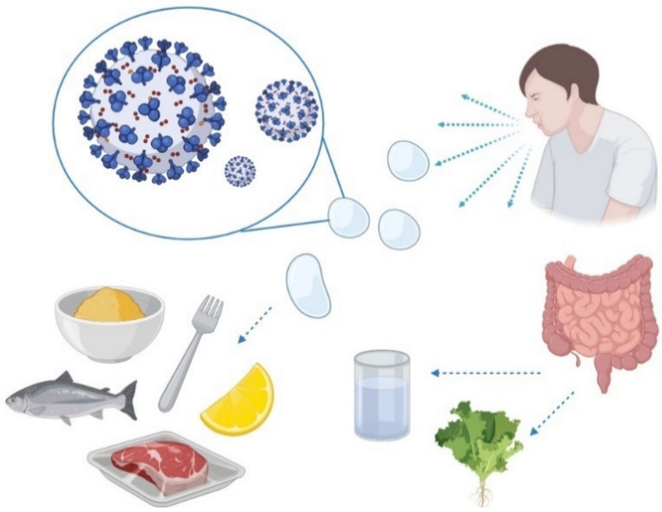

Figure 1. A simplified diagram of the possible transmission of SARS-CoV-2 to food or food supplies.

The outbreaks of COVID-19 occurred among workers in food facilities, representing a concern for consumers and producers, as well. In July 2020, for example, China suspended the import of shrimp, salmon chicken, and other frozen foods from many countries assessing that the presence of new cases was linked to the food import from food packaging and processing plants involved in SARS-CoV-2 outbreaks [37,38].

In a review, Han et al. [39] summarized a series of recent episodes that involved frozen food and storage environment as carriers of SARS-CoV-2 opening the possibility of contamination through the "cold chain". The authors explored the thesis that low temperatures create a favorable condition for prolonging the virus survival. Moreover, the survival of SARS-CoV-2 on refrigerated and frozen meat and salmon over 3 weeks has been reported: Salmon, chicken, and pork samples were artificially contaminated with SARS-CoV-2 showing a constant titer during a 3-week storage at three different temperatures (4, −20, and −80 °C) [40]. Considering this, the authors hypothesized the possible transfer of the virus from different sites and the plausible infection of workers and handlers. Similar results were reported by Harbourt et al. [41] who found that SARS-CoV-2 remains stable on swine skin for 96 h at 22 °C, 8 h at 37 °C and, for 14 days at 4 °C posing a concrete risk of infection and virus shedding by meat handling. Additionally, data on fresh produce such as apples, tomatoes, and cucumbers were reported by Blondin-Brosseau et al. [42].

The authors used a surrogate virus and evidenced that viral infectivity declines within a few hours post-inoculation on apples and tomatoes. No infectious virus was detected at 24 h on apples and tomatoes, while the virus persists in an infectious form for 72 h post inoculation on cucumbers.

Particular attention was also posed to the spread of SARS-CoV-2 in settings where the food is handled or consumed. In a recent study, Pung et al. [43] attributed three clusters of COVID-19 also to shared food practice during a conference in relation to the close and prolonged contact of people.

These recent findings have stimulated the scientific community to question whether the contagion of COVID-19 through food is a plausible event [39,44].

Moreover, it is well known that the most common foodborne virus infections are transmitted predominantly via the fecal-oral route, i.e., through the ingestion of contaminated food and/or water, although infection may occur through a secondary route and/or by person-to-person contact [45]. Furthermore, the fecal-oral route of coronaviruses has been shown in many animals such as swine [46], dog [47], and bovine [48].

A review showed how the fecal-oral route transmission is probable: Evidence of positive stool samples and how these tests seem to remain positive when respiratory tests are, or have become, negative have been reported [49,50]. Additionally, the prolonged persistence of RNA of SARS-CoV-2 in faeces has been reported after 6 and 14 days of getting negative results from the respiratory tract [51]. In addition, the live virus in stool samples from two patients who did not have diarrhea was evidenced by electron microscopy [52]. In light of these pieces of evidence, the concern regarding the possible transmission through the food chain has been raised in the last months, but SARS-CoV-2 cannot be considered a foodborne virus lacking a constant link between contaminated food consumption and illness. Furthermore, though faecal shedding has been demonstrated, a real fecal-oral route is not proved, since an infection occurring primarily in the human digestive tract, to date, has not been reported. However, it should be remembered that regular investigations implemented on foodborne outbreaks are not employed for source tracking of COVID-19.

Detection of the Virus on Different Environments and Surfaces

Consumer concerns regarding the ability of SARS-CoV-2 to survive on air and different surfaces and thus on food surfaces has led to investigating the time of permanence and stability of the virus in different environments. In an review, Aboubakr et al. [53] concluded that SARS-CoV-2 appears infectious in aerosols for 3 to 16 h and can survive at room temperature and a relative humidity (RH) of 65% for a few days suggesting a possible airborne transmission. Fears et al. [54], using nebulizers, measured the dynamic (short-term) aerosol efficiencies of SARS-CoV-2 in comparison with SARS-CoV and MERS and concluded that SARS-CoV-2 has greater or equal efficiencies to produce viral bioaerosols that remain infectious over time.

Guo et al. [55] concluded that SARS-CoV-2 was widely distributed in the air and on surfaces in Wuhan, China intensive care and general COVID-19 hospital wards indicating that the transmission distance of SARS-CoV-2 might be 4 m. It was also established that the virus can remain viable and infectious in aerosols for hours and, up to days, on surfaces [16]. In this last study, two viruses (SARS-CoV-2 and SARS-CoV-1) were tested in different environmental conditions on different surfaces including aerosols, plastic, stainless steel, copper, and cardboards. Both viruses were detected after 72 h after application on plastic surfaces, although the titre greatly reduced after 8 h on copper surfaces. Another study conducted by Chin et al. [15] evaluated the stability of SARS-CoV-2 on inanimate surfaces: A titre of $7 \times 8 \log_{10}$ of 50% $TCID_{50}$ per ml was pipetted on different surfaces as 5 µL droplet and incubated at 22 °C, 65% relative humidity. The virus titre was evaluated after 0, 30 min, 3 and 6 h, 1, 2, 4, and 7 days and was detected (although at 1% of the original inoculum) on the outside of the surgical mask on day 7. SARS-CoV-2 was more stable on smooth surfaces: No infectious virus was recovered after a 3-h incubation on printing and tissue papers, whereas no infectious virus was detected from treated wood and cloth on day 2. On glass and on banknotes, no virus was detected on day 4. Regarding plastic surfaces, no virus was detected on day 7 in line with previous results reported by van Doremalen et al. [16]. However, the high persistence on plastic poses a risk since food packaging is extensively made of this material.

In addition, as reported by Riddell et al. [56], SARS-CoV-2 can remain infectious for a long time on different surfaces: Authors demonstrated that the virus, in a dilution of 4.97×10^7/mL stored at 50% RH at three experimental temperatures (20, 30, 40 °C) can survive up to 28 days, particularly when dried onto non-porous (glass, polymer note, stainless steel, vinyl and paper notes) surfaces at 20 °C. Further studies have demonstrated that the virus can remain vital on many surfaces and proteins can prolong infectivity regardless of the type of surface. In particular, a constant infectivity (<1 $\log_{10}$ drop) on plastic, a 3.5 $\log_{10}$ decrease on glass, and a 6 $\log_{10}$ drop on aluminum was evidenced [57]. Table 1 summarizes the SARS-CoV-2 stability in relation to its surrounding matrix and environmental conditions.

Table 1. Summary of SARS-CoV-2 stability in relation to its surrounding matrix and environmental conditions.

Surface/Aereosol	Detection of Virus	Condition	Virus Load	References
Aerosol Plastic Copper Cardboard Stainless Steel	3 h 72 h 4 h 24 h 72 h	21 to 23 °C Relative humidity 40%	$10^{5.25}$ $TCID_{50}$/L air	[16]
Surgical mask (inner side) Surgical mask (outside) Glass Banknote Paper Tissue paper Wood Stainless stell Plastic	4 d 7 d 2 d 2 d 30 min 30 min 1 d 4 d 4 d	22 °C Relative humidity: ∼65%	$10^{7.8}$ $TCID_{50}$/mL	[15]
Aerosol	16 h	Not displayed	10^2/L aerosol	[54]
Stainless steel Polymer note Paper note Glass Cotton Vinyl	28 d/7/48 h 28 d/7/48 h 28 d/21/48 h 28 d/7/48 h 14 d/3 h/not detected 28 d/3/48 h	20/30/40 °C Relative humidity: 50%	4.97×10^7/mL diluted into a standard solution	[56]
Skin samples (Sus scrofa) Banknote Clothing	14 d/96/8 h 96/8/4 h 96/4/4 h	4/22/37 °C	Vero 76 kidney cells at a multiplicity of infection (MOI) of 0.01	[41]
Metal surface	180 h	4/30 °C Relative humidity of 30–40%, 1 h drying	9.6×10^4 $TCID_{50}$/mL	[21]
Glass Polystyrene plastic Aluminum	96 h °C for 96 h	45–55% relative humidity 19–21 °C	106 $TCID_{50}$/mL	[57]

Temperature dependent stability was also reported by other authors: In a study carried out by Kratzel et al. [21], the stability of SARS-CoV-2 on inanimate surfaces was examined at 4 and 30 °C (9.6×10^4 $TCID_{50}$/mL, after 1 h drying, RH of 30–40%,) and was evidenced that virus titre remained stable for 8 h at 4 °C and slightly reduced at 30 °C. The viral titre showed a decline within 9 days at all temperatures tested indicating that temperatures up to 30 °C do not necessarily inactivate the virus. Moreover, the authors underlined that although SARS-CoV-2 infectivity is greatly reduced in the course of the drying process, the virus remains infectious in a dried state for several days, despite ambient temperature changes. Regarding cold temperatures, SARS-CoV-2 showed high stability under low temperatures [39,58]. In particular, the virus viability, evaluated in nasal mucus and sputum containing 10^5 $TCID_{50}/_{mL}$ on polypropylene surface, was significantly longer at 4 °C/40% RH than at 21 and 27 °C (40% RH) [58]. This is in line with previous studies on coronaviruses that demonstrated that the virus is highly stable at low temperatures, up to 2 years at -20 °C [59]. This evidence poses a serious risk since cold temperatures are usually applied to preserve, store, and transport food and the cold-chain may represent a possible way to transfer infection. Figure 2 summarize evidence of SARS-Cov-2behaviour according to temperature.

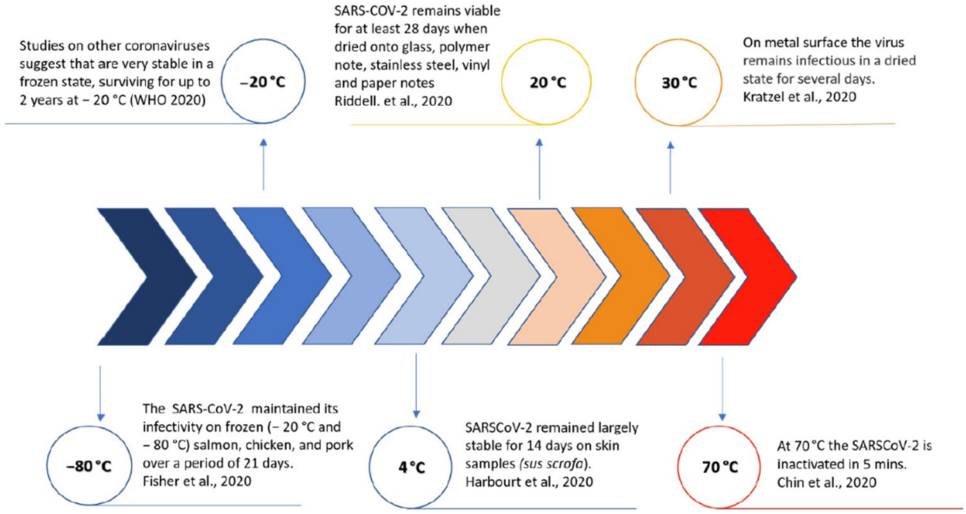

Figure 2. Evidence on coronaviruses, SARS-CoV-2, and temperatures.

4. How to Manage the Risk of Food-Related COVID-19 Infection?

The current food system is interfacing with an unidentified hazard. However, it is essential that consumers preserve trust regarding food safety. Therefore, the Food and Drug administration [17] and WHO [60] suggested additional measures to ensure food safety and to maintain the integrity of the food chain in the COVID-19 era. In addition to the latter, several other guidance documents (Table 2) have been developed to support the food industry in this critical time [61] and the spread of guidelines and question responses available on authorities' websites [62] clearly reveal public worry on the spread of COVID-19.

The scientific community and authorities encourage maintaining physical distancing and the correct use of personal protective equipment (PPE). In addition, the WHO recommends the correct use of masks and gloves, effective and regular handwashing, as well as sanitation at each stage of food processing. The US Food and Drug Administration, [63] suggest maintaining a 6-foot distance from others, while WHO [64] suggests a physical distance of 1 m. In food manufacturing facilities, limiting potential close contact is critically important [37]. Moreover, since the human contact with food is a key factor influencing the risk of contamination of food products, it is recommended that workers use gloves and change them frequently, especially after carrying out a non-food related activity, and wash hands when the gloves are changed or removed. Normal soap and warm running water for 20 s are an adequate hand sanitizer [65]; 60% alcohol, can be used as an additional measure. The WHO guidelines for hand hygiene in healthcare recommend two alcohol-based formulations for hand sanitization consisting of 80% (*v*/*v*) ethanol, 1.45% (*v*/*v*) glycerol, and 0.125% (*v*/*v*) hydrogen peroxide (formula I) as well as 75% (*v*/*v*) 2-propanol, 1.45% (*v*/*v*) glycerol, and 0.125% (*v*/*v*) hydrogen peroxide (Formula II) to reduce the infectivity and spread of pathogens [66]. Kratzel et al. [21] performed a viricidal activity study of these recommended hand rub formulations by WHO, reporting that SARS-CoV-2 was efficiently inactivated after 30 s.

Table 2. Summary of the most relevant guidance in the COVID-19 era.

Topic		Authorities	Reference
Food Safety	COVID-19 and Food Safety: Guidance for competent authorities responsible for national food safety control systems Interim guidance, COVID-19: Animal-human interface and food safety	WHO	[67]
	COVID-19 and Food Safety: Guidance for Food Businesses Interim guidance COVID-19: Animal-human interface and food safety	WHO	[60]
	WHO recommendations to reduce risk of transmission of emerging pathogens from animals to humans in live animal markets or animal product markets COVID-19: Animal-human interface and food safety	WHO	[64]
	Best Practices for Retail Food Stores, Restaurants, and Food Pick-Up/Delivery Services During the COVID-19 Pandemic	FDA	[65]
	COVID-19 Information for Consumers—Shopping for Food	FDA	[68]
	Temporary Policy During the COVID-19 Public Health Emergency Regarding the Qualified Exemption from the Standards for the Growing, Harvesting, Packing, and Holding of Produce for Human Consumption	FDA	[69]
	Temporary Policy Regarding Packaging and Labelling of Shell Eggs Sold by Retail Food Establishments During the COVID-19 Public Health Emergency	FDA	[70]
	Temporary Policy Regarding Certain Food Labelling Requirements During the COVID-19 Public Health Emergency: Minor Formulation Changes and Vending Machines	FDA	[71]
	Temporary Policy Regarding Preventive Controls and FSVP Food Supplier Verification Onsite Audit Requirements During the COVID-19 Public Health Emergency	FDA	[72]
Hand hygiene practice	Recommendations to Member States to improve hand hygiene practices to help prevent the transmission of the COVID-19 virus	WHO	[73]
	Guide to local production: WHO recommended hand rub formulations	WHO	[74]
Personal Protective Equipment (PPEs)	Proper Usage of Face Masks/Coverings to Protect Against COVID-19	FDA	[75]
	PPE guide for community and social care settings	Public Health England	[76]
	Advice on the use of masks in the context of COVID-19	WHO	[77]
Prevention	Water, sanitation, hygiene, and waste management for SARS-CoV-2, the virus that causes COVID-19	WHO	[78]
Sinification	Cleaning and disinfection of environmental surfaces in the context of COVID-19	WHO	[79]
	Food and Agriculture: Considerations for Prioritization of PPE, Cloth Face Coverings, Disinfectants, and Sanitation Supplies During the COVID-19 Pandemic	FDA	[80]
Work	Considerations for public health and social measures in the workplace in the context of COVID-19	WHO	[81]
	Getting your workplace ready for COVID-19: How COVID-19 spreads	WHO	[82]
	Coronavirus disease (COVID-19) outbreak: Rights, roles, and responsibilities of health workers, including key considerations for occupational safety and health	WHO	[83]
	Best Practices for Re-Opening Retail Food Establishments During the COVID-19 Pandemic-*Food Safety Checklist*	FDA	[84]
	Employee Health and Food Safety Checklist for Human and Animal Food Operations During the COVID-19 Pandemic	FDA OSHA	[85]
	Protecting Seafood Processing Workers from COVID-19 Seafood Processing Workers	CDC OSHA FDA	[86]
	Meat and Poultry Processing Workers and Employers	CDC OSHA	[87]

Table 2. *Cont.*

Topic		Authorities	Reference
	Guidance on the Essential Critical Infrastructure Workforce: Ensuring Community and National Resilience in COVID-19 Response	CISA	[88]
	Implementing Safety Practices for Critical Infrastructure Workers Who May Have Had Exposure to a Person with Suspected or Confirmed COVID-19	CDC	[89]
	Guidance on Returning to Work June 2020	OSHA	[90]
	The six-step COVID-19 business continuity plan for SMEs April 2020	ILO	[91]
Diagnosis	Laboratory testing for coronavirus disease (COVID-19) in suspected human cases	WHO	[92]

In a new view of "no-touch", in the last months, food delivery was implemented worldwide allowing physical distancing between customers and sellers. Additional precautions have to be implemented to reduce infection: Drivers and other staff should not leave their vehicles during food delivery, packaging should be used to avoid the need for cleaning of any returns, hygiene and sanitation of transport container should be implemented [90]. It is important also to clean and sanitize all bags employed for food delivery and establish designated pick-up zones to maintain social distancing [17]. Since food delivery is not always possible, a safe environment at a retail shop should be kept to protect staff and consumers from the risk of infection [60]. Regulating the number of customers who enter the retail store is ideal to avoid overcrowding and facilitate physical distancing. Providing wipes, hand sanitizers, disinfectant sprays at store entry points, and keeping doors open minimize the risk of contact and infection. To hygienically manage open food WHO suggests plexiglass installation to avoid contact or to place it in plastic/cellophane or paper packaging [60]. All the surfaces in contact with the food should be sanitized frequently and all the people around the open food area (customers or staff) should observe good personal hygiene practices.

It is fundamental that the food that reaches consumers is safe. Food Safety Management Systems (FSMS) based on the Hazard Analysis and Critical Control Point (HACCP) assure the production of safe food, prevent food contamination, and manage food risk and their implementation is subject to regulatory controls. Food companies, in addition, to implementing these food health checks, should be vigilant about possible food safety risks stemming from the COVID-19, as highlighted by WHO [60]. Reinforcing hygiene measures and providing refresher training on food hygiene principles is necessary to eliminate or reduce the risk of food becoming contaminated by the virus from food workers [83]. For this, the FDA [65] suggests four fundamental steps for food safety: Clean, separate, cook, and chill. This guidance recommends washing, rinsing, and sanitizing all food contact surfaces, dishware, utensils, and beverage equipment. Moreover, WHO [60] suggests advising consumers to wash fruit and vegetables with potable water before consumption. It is also suggested to practice good hand hygiene before eating and to not share plates with others [93]. Moreover, WHO recommends ensuring that cooked food reaches an optimal internal temperature and in the case of later use to cool it rapidly. This is in accordance with Kampf et al. [94] that indicated that infectivity of coronavirus is strongly reduced by thermal disinfection (60 °C for 30 min, 65 °C for 15 min, and 80 °C for 1 min at least 4 $\log_{10}$) and is also in agreement with Chin et al. [15] who demonstrated that SARS-CoV-2 was inactivated at an incubation temperature of 70 °C in 5 min. Ensuring food safety is not the only goal. The greatest challenge for the food industry is to protect food workers from contracting COVID-19, to prevent exposure to or transmission of the virus, and to strengthen food hygiene and sanitation practices. As mentioned before, maintaining physical distancing in retail food premises is critical for reducing the risk of disease transmission. The physical distancing of 6 feet should be kept among food workers but additionally, high standards of the public health measures need to be maintained in work canteens. Furthermore, WHO suggests maintaining a physical distance of at least 1 m, including in seating arrangements between workers. The surface of equipment, premises, high touch points (counter tops/tongs/service utensils/open self-service displays/door handles) should remain a focus of attention since that could be a vehicle of contagion.

The US Department of Labour Occupational Safety and Health Administration elaborated a planning guidance with recommendations and descriptions of mandatory safety and health standards to assure safe and healthful working conditions for workers [90]. This guidance encourages workplace control based on engineering controls (isolate people from the hazard), administrative controls (changes in work procedures to minimize exposure to a hazard), safe work practices (procedures used to reduce the duration, frequency, or intensity of exposure to a hazard), and PPE (protect the worker with personal protective equipment). Additionally, the guidance classifies exposure risk to SARS-COV-2 in very high, high, medium, and low based on the industry type, contact within 6 feet, contact with people infected or suspected to be infected with SARS-CoV-2. The food production environment, due to the industrial typology, require frequent contact with people and it makes difficult to contact within 6 feet, thus we could consider it a fairly high risk. For example, meat and poultry processing facilities may contribute to exposures to the virus, not for the meat they handle, but for processing lines and other areas in busy plants that establish close contact between co-workers [12]. In this case, since meat and poultry processing facilities represent a critical infrastructure, CDC developed a guide to implement safety practices, suggesting also to incorporate relevant aspects of CDC from other authoritative sources [95]. Table 3 summarizes management practice in the food industry.

Table 3. Management of food-related COVID-19 infection in the food industry. Adapted from Nakan and Bou-Mitri 2020.

Activities	Measures	References
Personnel management	- Encourage physical distancing of 6 feet. - Provide face mask, disposable gloves. - Minimize interaction and conversation and restrict non-essential physical contact as much as possible. - Practise proper hand hygiene and encourage frequent use of alcohol-based hand sanitizer. - Encourage the use of text, call video app, phone calling or any remote working tool to bring personnel together remotely and prevent face-to face. - Alternate worker's arrival and exit to avoid simultaneous congregation in common spaces and staggering staff break times to reduce the simultaneous presence of workers in a canteen. - Limit the number of personnel in a food preparation area simultaneously and organize workers into groups or teams to reduce the interaction as much as possible.	[60]
Environment and common space management	- Provide hand sanitizers and encourage hand hygiene. - Use auto open door or remove the door closure/keep doors open to allow employees to move between doorways without touching knobs where it does not impact food safety zoning. - Frequent cleaning/disinfection of work surfaces and touch points. - Human machine interfaces such as keyboards, buttons, and common tools should be sanitized between users especially between two separate users. - Reconfigure workstations to maintain spacing and reduce face-to-face interactions.	[60,95]

Table 3. *Cont.*

Activities	Measures	References
Food retail	- Provide any form of sanitization for customers to clean the baskets or any support for shopping or assigning staff to disinfect it after each use. - Use physical barriers, such as plexiglass, to separate food from any risk of physical hazard and to protect the staff. - Discourage food tasting and promotional food campaign. - Physical distancing should be maintained. - Provide hand sanitizers and disposable towels at store entry points. - Avoid overcrowding by regulating the number of customers who enter/exit the retail shop. - Require frequent washing and sanitizing of all surfaces, equipment, utensils, condiment containers, and everything that is in contact with food.	[9,81]
Food Preparation	- Separate the raw product from cooked products to prevent cross contamination. - Wash, rinse, and sanitize food contact surfaces or utensils, and beverage equipment after use. - Practice good hand hygiene before eating and do not share plates with others. - Wash fruit and vegetables with potable water before consumption. - Apply a high temperature (>70 °C) for food preparation.	[15,65]
Delivery or Receiving	- Limit one driver in one vehicle. - Use a face mask, gloves, and practice physical distancing. - Use disposable containers to avoid the need for cleaning any returns. - Ensure that receiving and delivery employees wash or disinfect their hands and implement appropriate hygiene and sanitation protocols. - Limit the contact point, the common use of writing instruments, and the exchange of paperwork. - Introduce contact free delivery: Wrapping packaged raw materials, limiting touching, and establishing designated pick-up zones to maintain social distancing.	[88,92]

5. Potential Approaches to Reduce the Risk of SARS-CoV-2 Contamination

Although the prevention of viral contamination by good hygiene practices, minimizing interaction, and avoiding physical contact remains the main strategy, the development of methods of viral inactivation could be a promising alternative and remains an open field research.

The use of gamma irradiation, a common method used for the inactivation of infectious specimens, could be proposed to inactivate SARS-CoV-2. Many foods and food ingredients are already authorised for irradiation in the EU such as fruit and vegetables including root vegetables, cereals, cereal flakes, and rice flour, but also poultry meat, fish, and shellfish. Recently, Feldmann et al. [96] evaluated the efficacy of gamma irradiation to inactivate emerging/re-emerging virus families including SARS-CoV, establishing the minimum irradiation doses required to fully inactivate a target dose of 1×10^6 50% $TCID_{50}$/mL of the virus. The results showed that coronaviruses were completely inactivated by a dose of 1 Mrads.

The effectiveness of ultraviolet (UV) radiation was also explored to inactivate the virus. This technique is widely used to kill bacteria, fungi, and viruses without the use of harmful chemicals or heat treatment. The effectiveness of UV on SARS-CoV-2 was recently reported: Heilingloh et al. [97] demonstrated that UV irradiation represents a suitable disinfection method for SARS-CoV-2, since a total inactivation of a viral stock of SARS-CoV-2 at a concentration of 5×10^6 $TCID_{50}/_{mL}$ was achieved after 9 min of combined UVA and UVC exposure. Moreover, we assessed that exposure to riboflavin and ultraviolet light (R + UV) reduces the infectious titre of SARS-CoV-2 below the limit of detection in plasma products [98]. These studies are in line with a previous research that demonstrated inactivation by UV light of closely-related viruses such as SARS-CoV, MERS, and other respiratory viruses [99]. Moreover, the authors determined that the UVC treatment for 15 min inactivated SARS-CoV to the limit of detection of the assay, which is $\leq$1.0 $TCID_{50}$ (log_{10}) per ml, meanwhile the UVA exposure had no significant effect on the virus inactivation over a 15 min period. Duan et al. [100] examined the effect on SARS-CoV-2 of UVC light at an intensity of >90 $\mu W/cm^2$ and at a distance of 80 cm, and determined that inactivation of the virus occurred after 60 min. More recently, Eickmann et al. [101] successfully applied UVC light to SARS-CoV-2 to reduce the potential risk of transmission of coronaviruses via blood products or blood derivatives.

Furthermore, the sunlight showed efficacy on inactivation of SARS-CoV-2: Ratnesar-Shumate et al. [102] reported that sunlight may rapidly inactivate SARS-CoV-2 on surfaces: 90% of the infectious virus was inactivated every 6.8 min in simulated saliva suspension and every 14.3 min in culture media. Additionally, inactivation rates of SARS-CoV-2 by UVB irradiance was significantly faster than that observed in darkness. These findings underlined that the risk of exposure may vary significantly between indoor and outdoor environments.

Recently, the use of gaseous ozone was also evaluated: A reduction in the viral titres above 90% was observed on glass, gauze, plastic fleece, and wool exposed to an atmosphere containing 4 ppm of O_3 for 30 min. The use of a gas concentration non-toxic to humans (0.2 ppm) did not show the same efficacy reaching a titre reduction above 90%, only after 2 h of constant explosion [103].

Heat treatments inactivate viruses by denaturing the secondary structures of proteins, and influence attachment and replication within a host cell altering the conformation of the virion proteins involved. It was demonstrated that the SARS-CoV-2 is highly stable at 4 °C, but sensitive to heat treatment: A reduction of 0.7 log unit of infectious titre was reported at 4 °C on day 14, meanwhile a complete inactivation was shown at 70 °C in 5 min [15].

Another potential approach to contrast virus diffusion and protect food and packaging from SARS-CoV-2 contamination is the application of nanotechnology [104]. No studies were already performed on SARS-CoV-2, however, many polymeric and biopolymeric materials were applied to other virus families such as human noroviruses (HuNoVs) and hepatitis A virus (HAV) [105]. Nanometals, natural extracts, essential oils, or other compounds, with demonstrated viricidal activity can be proposed as potential candidates to develop antiviral biopolymers. Another trend is the chemical release nano-packaging where compounds could directly interact with food. Warnes et al. [106] showed that exposure to copper and copper alloy destroyed the viral genomes of human coronavirus 229E and irreversibly affected virus morphology, including the dispersal of surface spikes and disintegration of the envelope. Nanotechnology-based viral disinfectants can be also used to promote surface oxidation by releasing toxic ions, and thus preventing SARS-CoV-2 dissemination by inhibiting the binding/penetration of viral particles [107]. Nanoparticles could be also effective in reinforcing personal protective equipment as shown by Balagna et al. [108], who applied antimicrobial/viricidal silver nanoclusters/silica composite spit directly on a facial mask, proving the viricidal effect. Although there are few references on SARS-CoV-2, the development of new technologies and multidisciplinary approaches remain a favourable strategy against the spread of COVID-19.

6. Conclusions

Numerous uncertainties remain in understanding the spread of COVID-19. If seems already clear the zoonotic origin of the virus, still debated is the diffusion via food. There are gaps in understanding the virus behaviour in different food matrices, but it is now clear that the virus remains active and stable in many foods in refrigerated and frozen conditions. In particular, frozen food is actually indicated as one of the main sources of the re-emergence of COVID-19 disease in Chinese cities [109,110]. Additionally, this virus stability is already confirmed on many surfaces and different materials most of them already used for food packaging. Moreover, faecal elimination of the virus and the presence of the receptors used by the virus to infect cells in the human gastrointestinal tract has been demonstrated [7,49,50,111].

If these results pose a concern regarding the possibility of a foodborne spread, there is still a lack of a clear epidemiological link between illness and food consumption. Actually, both international organizations and scientific communities report that there is no evidence for foodborne transmission of SARS-CoV-2 and it is very improbable that food or food packaging are sources or routes of transmission of SARS-CoV-2. More attention must be paid to the high stability of the virus at a low temperature, a condition usually adopted in the food chain that can allow virus diffusion through workers, as reported in slaughter facilities. The correct application of the indications provided by the international food security agency is mandatory to avoid viral spread in food facilities and to protect workers. The use of novel technologies, particularly in the food packaging sector can help prevent virus diffusion. A multidisciplinary approach is essential to control this pandemic outbreak and new tools should be implemented for SARS-CoV-2 prevention. Enforcing hygiene standards and sanitation could represent the first step to eliminate the potential COVID-19 risk in food and SARS-CoV-2 spread. Knowledge of the vehicles involved and the environmental factors that contribute to the virus spread allow consumers to be educated on decreasing high-risk behaviours, thus reducing the risk of being affected by COVID-19.

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