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INVITED REVIEW

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Monitoring of new coronavirus (SARS-CoV-2): Origin, transmission, and food preservation methods

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Abstract

Unfortunately, there is limited research on coronavirus survival of food products and also food processing. The knowledge of the physical and chemical characteristics of coronaviruses mostly comes from the study of SARS-CoV and MERS-CoV physical (i.e., thermal processing, chilling and freezing, microwave irradiation, ultraviolet light, gamma irradiation, high hydrostatic pressure) and chemical (acidification and use of common disinfectants in the food industry like chlorinated derivatives and ozone) are means which could be used to inactive the coronaviruses or reduce the infection. These methods can be applied individually or in combination to act better performance. Thermal processing is one of the most effective methods for inactive coronavirus. Heating at 75°C (15–60 min) and 65°C (1 min) was the best temperature for inactive SARS-CoV and MERS virus, respectively. Among irradiation methods (microwave, UV, and gamma), the most effective one is UVC rays. Moreover, the use of disinfectant like chlorinated derivatives is appropriate way to disinfect food product surfaces.

Novelty impact statement

This review provided updated information on effective strategies for inactive coronavirus that can be used in the food industry. SARS-CoV-2 as a new pandemic coronavirus was initiated from contaminated foods and can be transmitted by close contact, aerosols, and food surfaces. Food preservation (physical and chemical) methods could decrease SARS-CoV-2. Probably, heating and UVC are the most effective approach to inactive SARS-CoV-2. Despite the findings of coronavirus inactivation which were here discussed, much research is still needed for the development of new approaches to overcome the coronavirus.

1 | INTRODUCTION

Coronaviruses (CoVs) are spherical, enveloped, single-stranded (ss), positive-sense, with the largest RNA genome (Schwartz & Graham, 2020; Tripp et al., 2005). Coronaviruses were not believed to be highly pathogenic to humans until the emergence of severe acute respiratory syndrome coronavirus (SARS) in 2002 (China) and the Middle East respiratory syndrome (MERS) in 2012 (Saudi Arabia). In December 2019, a highly pathogenic pneumonia outbreak in Wuhan city (China), is caused by a novel coronavirus named 2019 novel coronavirus (2019-nCoV) or severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and the disease was named Coronavirus Disease 2019 (COVID-19) (Chang et al., 2020; Yang et al., 2020). World Health Organization (WHO) announced that COVID-19 rapidly spread in the world. This disease become a pandemic on March 11, 2020 (World Health Organization [WHO], 2020).

Coronaviruses are divided into four general categories such as α-CoVs, β-CoVs, γ-CoVs, and δ-CoVs. The alpha and betacoronaviruses can infect only mammals, while gamma and delta types can infect birds and mammals. Seven common human coronaviruses (HCoVs), named HCoV-229E and HCoV-NL63 (from α-CoVs) and HCoV-OC43, HCoV-HKU1, MERS-CoV, SARS-CoV, and SARS-CoV-2

(from β-CoVs), have been found to infect humans and cause upper respiratory diseases (Chen et al., 2020; Coutard et al., 2020; Decaro & Lorusso, 2020; Menachery et al., 2015; Wu, Liu, et al., 2020). SARS-CoV-2, like other human coronaviruses, has at least four major structural proteins, such as spike protein (S), envelope protein (E), membrane (or matrix) protein (M), and nucleocapsid protein (N). Among these proteins, the spike protein has a tendency to interact with the host cell receptor, which contains angiotensin-converting enzyme 2 (ACE2) for virus entry (D'Amico et al., 2020; Letko et al., 2020; Luan et al., 2020). The genome sequences of SARS-CoV-2 show 79.6% and 96.2% identical to SARS-CoV and bat CoV RaTG13 (Zhou et al., 2020).

Viruses can be transferred from contaminated food products and also from person-to-person contact and environment. Food infections can occur by contaminated meat, water, milk, eggs, and other foods (Bosch et al., ,2016, 2018; Koopmans & Duizer, 2004). Propagation of coronaviruses requires host cells due to their nature of obligate parasites. As a consequence, coronaviruses only survive and cannot grow on surfaces like foods, unlike bacteria, yeasts, and molds (Raj et al., 2015; Rodríguez et al., 2020). The coronaviruses' survival and transferability on surfaces of food or other environmental materials depend on several factors, including pH, storage temperature, relative humidity (RH), type of virus and surfaces, etc.

2 | CORONAVIRUS (SARS-COV-2) ENVIRONMENTAL ORIGINS AND TRANSMISSIONS

Available information indicated that the earliest patients of the COVID-19 in Wuhan were epidemiologically related to the Huanan seafood market (a wet market), were sold a large variety of domestic or wild animals, with live or dead bodies, including seafood, bats, snakes, badgers, pangolins, Chinese bamboo rats, cats, porcupines, dogs, poultry, minks, turtles, etc., in over one thousand stalls in constant close contact and this suggests animal-to-person spread (Brüssow, 2020; Schwartz & Graham, 2020; Shereen et al., 2020). According to researchers, SARS-CoV-2 is primarily transmitted from wild bats to humans, but it can also be transmitted rapidly by person-to-person contact (Ghinai et al., 2020). Generally, airborne routes including droplet (or close person-to-person contact) and aerosol transmission and indirect (touch fomites or contaminated surfaces, eating foods) transmission are different ways to spread 2019-nCoV (like other coronaviruses) from person to person (Figure 1) (Chan et al., 2020; Neeltje van Doremalen et al., 2020; Yang et al., 2020). When an infected person coughs and sneezes, even laughs or talks, virus-containing particles name respiratory droplets (>5 μm), and aerosols (<5 μm) were generated. Droplets are propelled through the air (max 2 m) and fall to the surfaces or mouth, nose, and eyes of susceptible persons as a result of gravity. Aerosols have a low tendency to settle down and may remain and travel in the air for a longer time. So, the danger of virus transmission increased (Anfinrud et al., 2020; Sabino-Silva et al., 2020; Shereen et al., 2020; Singh et al., 2020; Soetikno et al., 2020; van Doremalen et al., 2020). Another possible way is via hand contact by contaminated objects and surfaces (like foods, plastics, steels, fecal, etc.), touching nose and mouth, shaking hand with a person who has COVID-19. When 2019-nCoVs reach noses or mouths of people, they can easily transfer to the respiratory tract, leading to the infection of the patient (Jiang et al., 2020; Wu, Wu, et al., 2020; Yang et al., 2020). The SARS-CoV-2 has been detected in and lower (endotracheal aspirate, expectorated sputum, or bronchoalveolar lavage) respiratory tract of patients, with high viral loads in upper respiratory tract samples (Wu, Wu, et al., 2020; Zou et al., 2020).

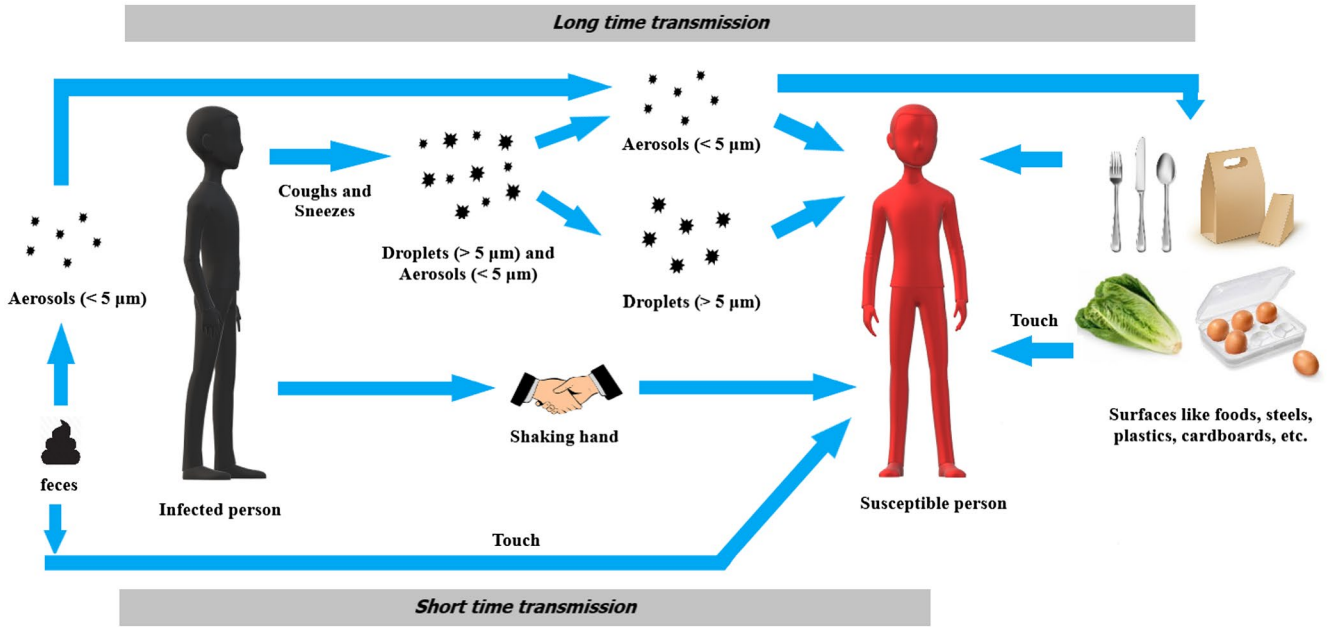

FIGURE 1 Different ways of 2019-nCoV transmission

3 | INACTIVATION OF CORONAVIRUSES BY FOOD PRESERVATION METHODS

Food preservation methods usually used are heating, chilling, freezing, acidification, drying, and packaging. Survival of coronaviruses relies on capsids (virus coats) and genomes. The role of capsids is to protect the genome from environmental parameters like temperature, Ultraviolet light, acids, etc. Moreover, capsids of coronaviruses have agents to bind to host cell receptors. Inactivation of viruses mostly is through the destruction of capsid protein and nucleic acids. Conformational changes in capsids make it no longer binding to host cells, and damage of nucleic acids prevents the replication of its strand in host cells. Viral viability is calculated by $TCID_{50}$ assay, which determined as 50% of tissue culture infective dose ($TCID_{50}$) per milliliter and usually shows as $\log_{10}$ ($TCID_{50}$/ml) (Baert et al., 2009; Eickmann et al., 2018; Hirneisen et al., 2010; Qiu et al., 2020). In this research, the $\log_{10}$ ($TCID_{50}$/ml) is abbreviated as $\log_{10}$ throughout the manuscript. According to European Standards (EN) 14476, the minimum level of reduction ($4 \geq \log_{10}$) is required for appropriate virucidal activity (Eggers, 2019; Eggers et al., 2018; Leclercq et al., 2014).

In recent years, consumers have been demanding convenient and healthy foods which have fresh-like characteristics while still being safe and a long shelf-life. These requirements are hard to achieve using existing traditional food processing technologies (i.e., thermal processing, chilling, freezing, acidification) and the emerging new food process and preservation technologies systems (i.e., ultraviolet light, microwave, and gamma irradiation) are needed. Nowadays, emerging non-thermal technologies have raised great interest as a viable alternative to the conventional thermal methods, since they have minimal impact on the sensorial and nutritional properties of fresh foods (Barba et al., 2015; Kovačević et al., 2018; Zinoviadou et al., 2015).

3.1 | Physical preservation methods

3.1.1 | Thermal processing

The use of high temperature is one of the most effective methods to destruct microorganisms and inactive viruses like coronaviruses. There are many studies that researched thermal processing to inactive bacteria and yeast, but heat function on coronaviruses has been rarely explored. The heating process causes the inactivation of viruses mostly due to the changes in the isoelectric point of capsids, coagulation, and conformational changes in proteins. Researchers studied the effect of heat on severe inactivation of the viruses, indicated the temperatures 90°C for ≥90 s (Codex Alimentarius, 2012; Hazards, 2015) or boiling water for 1 min (Bosch et al., 2018) due to structural changes in their proteins could diminish viruses. However, some viruses are heat-resistant like noroviruses, which can survive in the steaming process. For inactive hepatitis A virus (HAV) in suspension and dried mussels at 85°C, the time reaches 6 and 15 min, and also HAV could be inactive by a 1 min at 100°C (Park & Ha, 2015). So, it is necessary to the internal temperature of food reach a specific temperature to inactive viruses, not only the outer layer. Indeed, as the temperature reduced, the survival of viruses increased. Boiling water for at least 1 min, inactivate viruses (>4 $\log_{10}$) such as enteroviruses, human rhinovirus (HRV), human Noroviruses (NoV), HAV, and hepatitis E virus (HEV). Pasteurization temperature (72°C, 1 min) in some researches indicated inactivation rate >3.5 $\log_{10}$ (Bosch et al., 2018; Hewitt et al., 2009). Generally, conventional bulk pasteurization (63°C, 30 min or 70°C, 2 min) is more helpful than high-temperature short time pasteurization (71.7°C, 15–20 s) (Cappellozza et al., 2012; Croci et al., 1999; Sánchez, 2015). Water Blanching (80°C, 1 min) for spinach decreased murine norovirus (MNV) infection more than 2.4 $\log_{10}$ reductions (Baert et al., 2008). HAV and feline calicivirus (FCV) in various herbs showed inactivation after the steam blanching process (95°C, 2.5 min) (Butot et al., 2009).

Coronaviruses inactivation by thermal processing is influenced by various parameters like food matrix, organic matter, initial levels of virus, and time–temperature relationship. Food product composition like fat content in some researches has a protective effect on viruses. For example, Bidawid, Farber, Sattar, et al. (2000) showed the heat resistance of HAV in table cream (18% fat) was higher than homogenized milk (3.5% fat) and low-fat milk (1% fat) due to more fat content. Water content is one of the other factors that affects the inactivation of viruses. Butot et al. (2009) showed inactivation of HAV in freeze-dries berries compared to fresh herbs needs more time (20 min for dries berries compared to 2.5 min in fresh ones). Sucrose concentration is also useful in surviving viruses. Deboosere et al. (2004) researched on strawberry mashes with various Brix, which indicates the protective effect of sugar to stabilize HAV against thermal processing. Moreover, the protective effect of the mussel matrix was studied. HAV in a mussel homogenate after thermal processing (60°C, 10 min or 80°C, 3 min) showed 2 $\log_{10}$ reductions, whereas in cell culture medium after the same treatments, 4.6 $\log_{10}$ reductions were introduced (Croci et al., 1999; Sánchez, 2015).

Thermal processing had a significant effect on the infectivity of coronaviruses (Table 1), not on the viral genome. During heating, the secondary, tertiary, and quaternary structures of proteins are destroyed. Thus, the virus lost the virus-like particle. Darnell et al. (2004) researched the ability of thermal treatment (56, 65, and 75°C) to inactive SARS-CoV at various time intervals. The results showed that all three temperatures decrease SARS-CoV severally up to 15 min. However, some viruses were stable at 56 and 65°C between 15 and 60 min. Heating at 75°C (15–60 min) was the best temperature to inactive SARS-CoV thoroughly. Besides, 56 and 65°C, even at 60 min could inactive SARS-CoV incompletely. Duan et al. (2003) studied the stability of SARS coronavirus in human specimens and environments. After at least 2 hr, the results were suggested that SARS viruses were stable on the plastic surface at 4, 20, and 37°C. However, at 56°C for 90 min, 67°C for 60 min, and 75°C for 30 min, the viruses lost the infection ability. Rabenau et al. (2005) researched the infectivity of SARS-CoV at different temperatures. The results showed that 56 and 60°C

TABLE 1 The effect of thermal processing on the inactivation of human coronaviruses

Inactivation method	Log_{10} reduction	Coronavirus	Matrix	Reference
58°C, 30 min	4.9	SARS-CoV	Cell culture medium	Pagat et al. (2007)
68°C, 10 min	4.3	SARS-CoV	Cell culture medium	
4°C, 30 min	No change	SARS-CoV	Cell culture medium	Rabenau et al. (2005)
56°C, 30 min	≥ 5.01	SARS-CoV	Cell culture medium	
60°C, 30 min	≥ 5.01	SARS-CoV	Cell culture medium	
56°C, 20–60 min	5	SARS-CoV	Cell culture medium	Darnell et al. (2004)
65°C, 4–20 min	4.5	SARS-CoV	Cell culture medium	
75°C, 15–90 min	4.5	SARS-CoV	Cell culture medium	
4°C, 0–120 min	No change	SARS-CoV	Cell culture medium	Duan et al. (2003)
20°C, 0–120 min	No change	SARS-CoV	Cell culture medium	
37°C, 0–120 min	No change	SARS-CoV	Cell culture medium	
56°C, 90 min	No detectable cytopathic effect	SARS-CoV	Cell culture medium	
67°C, 60 min	No detectable cytopathic effect	SARS-CoV	Cell culture medium	
75°C, 30 min	No detectable cytopathic effect	SARS-CoV	Cell culture medium	
25°C, 120 min	No change	MERS-CoV	Cell culture medium	Leclercq et al. (2014)
56°C, 25 min	4	MERS-CoV	Cell culture medium	
65°C, 1 min	4	MERS-CoV	Cell culture medium	

for 30 min resulted in virus inactivation (≥5.01 log_{10}) compared to the control (4°C), in which no loss of infection was observed. Pagat et al. (2007) achieved 4.9 log_{10} and 4.3 log_{10} reductions of SARS-CoV with 58°C (30 min) and 68°C (10 min) heating, respectively, which represent faster inactivation of viruses at 68°C than 58°C. Leclercq et al. (2014) studied the culture supernatants of MERS-CoV at three temperatures during the time period. The results indicated that 1 min at 65°C was enough to inactive the virus. However, at 56°C, which is used to inactive enveloped virus, almost 25 min should be applied to reduce 4 log_{10}. Moreover, the room temperature (25°C) did not affect the viability of MERS-CoV after 2 hr. It is considered SARS-CoV-2 is sensitive to heating.

3.1.2 | Chilling and freezing

Refrigeration (chilling) and freezing are the ways to preserve food products from spoilage. However, most viruses are so stable in low temperatures (Baert et al., 2009; Bosch et al., 2018; Hirneisen et al., 2010). According to the finding of Chan et al. (2004), SARS-CoV is stable at refrigeration temperature (4°C) in clinical specimens for many weeks. These results are in accordance with other researches (Darnell et al., 2004; Duan et al., 2003; Rabenau et al., 2005) who stated that SARS-CoV had stability at chilling temperature (4°C). HCoV-229E could survive in chilling condition (4°C) for 14 days (Lamarre & Talbot, 1989). Researchers found that SARS-CoV could survive about 2 years on the stool at −80°C (Louie et al., 2006) and for many weeks in clinical specimens at −70°C (Chan et al., 2004). Based on researches, the infectivity of SARS-CoV and HCoV-229E did not change after several freezing–thawing cycles (Lamarre & Talbot, 1989; Louie et al., 2006). Generally, viruses could survive for a long time under chilling and freezing conditions. If food is contaminated before freezing, a particular reduction of the viral load will not occur during storage and viruses maintain the infectious ability. As a consequence, freezing is not a successful solution to inactive coronaviruses despite heating.

3.1.3 | Storage temperature and relative humidity

Relative humidity (RH) is one of the main factors which affected on the growth or survival of microorganism. Generally, the virus could not be replicated out of the cells, whereas, they may survive on the surfaces. As a consequence, storage temperature and humidity on various surfaces have a significant effect on viral viability (Table 2).

Van Doremalen et al. (2013) were reported the stability of MERS-CoV under particular conditions including low temperature and low humidity (20°C, 40% RH), high temperature and low humidity (30°C, 30% RH), and high temperature and high humidity (30°C, 80% RH). The results showed that there was no significant difference in viability of MERS-CoV on plastic and steel surfaces. MERS-CoV could survive after 72 hr at the 20°C −40% RH condition with 4.9 and 5.1 log_{10} for plastic and steel surfaces, respectively. Moreover, close survival reduction (~5.2 log_{10}) was observed among 48 hr-30°C −30% RH and 24 hr-30°C −80% RH, which shows higher stability of coronaviruses at lower relative humidity.

TABLE 2 Inactivation of human coronaviruses by different storage temperatures and relative humidities

Inactivation method	Log_{10} reduction	Coronavirus	Matrix	Reference
65% RH, 21–23°C				van Doremalen et al. (2020)
Plastic, 72 hr	3.1	SARS-CoV-2	Cell culture medium	
Stainless steel, 48 hr	3.1	SARS-CoV-2	Cell culture medium	
Plastic, 72 hr	2.7	SARS-CoV	Cell culture medium	
Stainless steel, 48 hr	3.0	SARS-CoV	Cell culture medium	
Copper, 8 hr	1.7	SARS-CoV-2	Cell culture medium	
Copper, 24 hr	1.8	SARS-CoV	Cell culture medium	
Cardboard, 48 hr	2.2	SARS-CoV-2	Cell culture medium	
Cardboard, 24 hr	2.3	SARS-CoV	Cell culture medium	
Aerosol, 3 hr	0.8	SARS-CoV-2	Cell culture medium	
Aerosol, 3 hr	0.6	SARS-CoV	Cell culture medium	
Plastic, 24 hr				Chan et al. (2011)
28°C, (RH: > 95%, 80%–89%)	0.7, 0.2	SARS-CoV	Cell culture medium	
33°C, (RH: > 95%, 80%–89%)	1.0, 0.8	SARS-CoV	Cell culture medium	
38°C, (RH: > 95%, 80%–89%)	3.4, 2.0	SARS-CoV	Cell culture medium	
21–25°C				Rabenau et al. (2005)
Dried, 9 day	5.2	SARS-CoV	Cell culture medium	
Dried, 3 day	4.5	HCoV-229E	Cell culture medium	
Suspension, 9 day	1.3	SARS-CoV	Cell culture medium	
Suspension, 9 day	4.2	HCoV-229E	Cell culture medium	
Plastic				van Doremalen et al. (2013)
20°C, 40% RH, 72 hr	4.9	MERS-CoV	Cell culture medium	
30°C, 30% RH, 48 hr	5.2	MERS-CoV	Cell culture medium	
30°C, 80% RH, 24 hr	5.2	MERS-CoV	Cell culture medium	
Stainless steel				
20°C, 40% RH, 72 hr	5.1	MERS-CoV	Cell culture medium	
30°C, 30% RH, 48 hr	5.2	MERS-CoV	Cell culture medium	
30°C, 80% RH, 24 hr	5.2	MERS-CoV	Cell culture medium	
Aerosol, 20°C				
40% RH	No change	MERS-CoV	Cell culture medium	
70% RH	1.2	MERS-CoV	Cell culture medium	

Chan et al. (2011) studied the stability of SARS-CoV at various environmental conditions. The results were suggested that high RH (>95%) at low temperatures (28 and 33°C) had no significant effect on virus survival, whereas, high temperature and low humidity (38°C, 80%–89% RH) cause to reduce 2 log_{10} after 1 day. Moreover, at the same temperature and high humidity (38°C, >95% RH) in comparison with previous treatment (38°C, 80%–89% RH), the more (~1.5 log_{10}) loss was observed. SARS-CoV remains viable for more than 2 weeks in air-conditioned humidity (22 ~ 25°C, 40%–50% RH), and in a liquid condition, it can survive even more (3 weeks). Some researchers showed that the human coronaviruses remain viable only for 3 hr on surfaces after drying. As the humidity becomes higher, the stability of the aerosolized form is reduced, while it could survive for many days in liquid suspensions (Chan et al., 2011; Sizun et al., 2000).

The survival of viruses on surfaces is a great threat to fresh-food production. At low temperature and low RH, SARS-CoV can survive on the surfaces. So, countries in which the humidity and temperature are high, the infection can be inhibited more easily. Moreover, in society and locations which are used inappropriate air-conditioning such as hotels, hospitals, and food processing industries, the stability of viruses on the surfaces is prolonged. The solution to this challenge is a high quality ventilation system that could bring the maximum fresh air in and exchange the used air or if it is not possible, at least high efficient antimicrobial filter used for air recirculation. It was reported that SARS-CoV infection in days with lower temperature is 18-fold higher than days with higher temperature (i.e., a temperature > 24.6°C) in Hong Kong and other regions. Generally, various parameters influence on coronaviruses pandemic in the society like wind

velocity, intense of sunlight, RH, air pressure, etc. (Cai et al., 2007; Lin et al., 2006; Sizun et al., 2000; Tan et al., 2005; Yuan et al., 2006).

Rabenau et al. (2005) investigated the stability and inactivation of SARS coronavirus. In suspension, SARS-CoV and HCoV-229E had ~1.3 $\log_{10}$ and ~4.2 $\log_{10}$ during 9 days, but in the dried state, had ~5.2 $\log_{10}$ and ~4.5 $\log_{10}$ during 9 and 3 days, respectively. The results show that HCoV-229E is unstable, while SARS-CoV remains viable during the experiment. This result was in agreement with Sizun et al. (2000). Suspension considerably increased the viability of SARS-CoV and HCoV-229E as compared to the dried state. Other researchers like Pagat et al. (2007) showed that after 72 hr, the virus population at wet form reached ~0.7 $\log_{10}$ reduction. In contrast, at dried form, the virus inactivation was taken place more effectively (~1.3 $\log_{10}$ reduction). As is mentioned above, SARS-CoV survival in dried form is severely increased. Besides, on a glass surface, the SARS-CoV inactivation varies on different days as follows: 2.5 $\log_{10}$ on the first day (passes from liquid to dry form), and 0.07–0.14 $\log_{10}$ for each day of drying (up to 35 to 42 days) (Pagat et al., 2007).

van Doremalen et al. (2020) explored the viability of 2019-nCoV on surfaces and in aerosols as compared with SARS-CoV. The results suggested that 2019-nCoV is almost as stable as SARS-CoV, and these coronaviruses survived in aerosols for 3 hr, on copper for 4 hr, on cardboard for 24 hr, and on stainless steel and polypropylene (plastic) for 2–3 hr. This means that 2019-nCoV and SARS-CoV are more stable on stainless steel and plastic than cardboard.

3.1.4 | Microwave irradiation

Microwaves are electromagnetic radiations, with the frequency change from 300 MHz to 300 GH (wavelength within 1 mm to 1 m), and place between radio waves and infrared waves. Microwave heating has attracted the attention of many manufactures, home users, and researchers. Industrial microwave systems operate at frequencies of 0.915 and 2.45 GHz, while domestic microwave ovens are designed to only work at the frequency of 2.45 GHz. Microwave heating has extensive use in food processing such as cooking (baking, tempering, blanching, rice cooking, etc.), drying (air, vacuum, and freeze drying), thawing, pasteurization, sterilization, etc. (Chandrasekaran et al., 2013; Ekezie et al., 2017; Nüchter et al., 2004). The main benefits of using microwave in food science and technology include easy operating, convenience, and fast heating rate, lead to the fact that microwave is a good choice for "ready-to-eat" meals. However, a major problem related to microwave heating is non-uniform temperature distribution (Tang et al., 2018; Vadivambal & Jayas, 2010).

The formation of microwave heating is because of dipolar and ionic mechanisms. Due to water's dipolar nature, the moisture content of the food products is one of the main factors, which facilitate the formation of dielectric heating. High frequency and polarization effect of electromagnetic waves induce dielectric molecules, especially water, to dipolar rotation, and ionic conduction occurs at million times per second. As a result, interactions of dipolar molecules in foods, increase, and rapid microwave heating generates inside food products (Datta, 2007; Soni et al., 2020; Vadivambal & Jayas, 2010).

In food science, no research has yet been established to control coronaviruses with microwave systems. Wu and Yao (2014) used microwave irradiation (~ 2 min) to inactive airborne viruses, like MS2 virus (MS2 bacteriophage), in aerosol and achieved 50%, 65%, and 90% inactivation at 119, 385, and 700 W, respectively. The mechanism of inactivation might be affected by the damage to viral surface proteins and RNA genome. Elhafi et al. (2004) reported autoclaving (20 min, 15 lb/in^2) and microwave treatment (900 W, ≥ 20 s) reduced the infectivity of Infectious bronchitis virus (IBV) and Avian pneumovirus (APV), which existed on the cotton swab. It should be noted that IBV is an animal coronavirus that attacks chickens and makes respiratory diseases (Zhang et al., 2017).

3.1.5 | Ultraviolet light

Ultraviolet light is electromagnetic irradiation, which wavelength is ranging from 100 to 400 nm. It means that UV occupies the wavelength between x-rays (<100 nm) and visible light (400–700 nm). UV rays can be classified into four distinct spectral areas according to vacuum UV (100–200 nm), UVC (200–280 nm), UVB (280–315 nm), and UVA (315–400 nm). Vacuum UV only propagates under vacuum conditions. UVA and UVB have a lower wavelength (higher frequency) as compared with UVC; thus, the efficacy of UVA and UVB is not appropriate for germicidal action. The UVC (particularly 250–270 nm) has a harmful effect on microorganisms like bacteria and viruses (Dai et al., 2012; Gasperini et al., 2017; Zoschke et al., 2014). Hence, the U.S. Food and Drug Administration (FDA) has confirmed the utilization of UVC for cleaning the surfaces of food products (U.S. Food and Drug Administration, 2021b). The majority of UV-based inactivation studies have been conducted on target viruses suspended in water, thus this approach may be suitable for water-based food and environmental samples. It is known that inactivation doses are generally higher in water than on solid surfaces and various factors such as the type and structure of the surface as well as the relative humidity of the air and the temperature can influence the UV dose to inactivate viruses (Han et al., 2021). UV light is an alternative low cost and easy method to disinfect surfaces; fruits and vegetables and ready-to-eat meals. UV light is one of the methods to control viral infection, which is more effective when it is combining with other methods such as the use of chlorine (Rattanakul et al., 2015).

The performance of UV light depends on various parameters like type of foods or surfaces, the liquid turbidity, contamination level, nucleic acid and proteins of viruses, type of host cells, experimental condition, viral aggregation, UV dose, the distance, and time of UV. The main problem of UV light is that only direct exposure is effective and if the viruses are in cracks, crevices, and corners of the food, surface, and packaging, the direct UV light cannot successfully inactive viruses (Birmpa et al., 2013; Bosch et al., 2018; Guerrero-Beltr·n & Barbosa-C·novas, 2004; Hirneisen et al., 2010). The results of Duan

et al. (2003) suggested that UVC (260 nm) treatment on SARS-CoV in culture medium for 60 min inactive viruses. Researchers evaluated the effect of UVC light on SARS-CoV. The results indicated that exposure of UVC (254 nm) for at least 6 min cause severe reduction of SARS-CoV and 6–15 min UVC had a similar effect on the viability of SARS-CoV (Darnell et al., 2004). It is considered SARS-CoV-2 is sensitive to UVC (U.S. Food and Drug Administration, 2021b; Yan et al., 2020).

The mechanism of UV (> 1,000 mJ/cm^2) to inactive viruses is to destroy viral structures, including nucleic acids and proteins. Pyrimidines of nucleic acids attract UVC rays; thus, thymine and cytosine in DNA and uracil and cytosine in RNA are sensitive to UVC. As a result of cross-linking among the nucleotides, cytotoxic photoproducts of DNA (like thymine–thymine or thymine–cytosine dimers) and RNA (uracil–uracil or uracil–cytosine dimers) increase (Cutler & Zimmerman, 2011; Hirneisen et al., 2010). Coronaviruses have single-stranded RNA genomes. Hence, UVC rays probably induce uracil–complex dimers, which are lethal for coronaviruses. Moreover, UVC rays can also attack capsid proteins; therefore, the virus genome becomes susceptible to Ribonuclease, which is presented in the medium (Baert et al., 2009; Hirneisen et al., 2010).

3.1.6 | Gamma irradiation

Gamma irradiation (mostly ^{60}Co source) is a new technology that is an excellent alternative method to sanitize surface and food products. This method is rather to apply in combination with other methods to achieve better results and facilitate disinfection more thoroughly. The best advantage of gamma irradiation is required low energy and is useful for heat sensitive food products (Meireles et al., 2016; Ramos et al., 2013; Vaz et al., 2011). Gamma irradiation (2–4 kGy) is mostly used to prevent bacteria growth and virus survival in foods (Baert et al., 2009). WHO and European Food Safety Authority (EFSA) announced that irradiation up to 10 kGy is safe for food products, while the maximum absorbed dose of 4 kGy is allowed by the U.S. FDA (Hazards, 2011; US Food and Drug Administration, 2007; World Health Organization [WHO], 1994). The U.S. FDA-approved dose (4 kGy) is reduced to 1 $\log_{10}$ in viruses. So, to obtain a desirable effect on viral reduction, it will be required higher dose (Bidawid, Farber, & Sattar, 2000; Bosch et al., 2018).

The efficiency of gamma irradiation relies on viral size, the suspension medium, food nature, exposure time, and temperature. Most viruses are stable in gamma irradiation treatment. Predominantly, the resistance of viruses is much more than bacteria and fungi due to smaller dimensions and genome (often ssRNA) (Bosch et al., 2018; Parlevliet, 2002; da Silva Aquino, 2012). Darnell et al. (2004) investigated the effect of gamma irradiation (0–0.15 kGy) on the viability of SARS-CoV. The results suggested that the gamma rays did not influence on viral infectivity. Kumar et al. (2015) examined the inactivation of MERS coronavirus by gamma irradiation. The results showed that 10 and 20 kGy (= 1 and 2 Mrad) leads to a reduction of 4–5 and 10 $\log_{10}$ of MERS-CoV, respectively. The gamma rays as ionizing radiation produce free radicals (like OH) which attack viral nucleic acid and capsid and result in nucleotide degradation, disrupting the viral capsid, breaking of the viral envelope, cross-linkage damages, etc.; thus, the virus becomes inactivated (Baert et al., 2009; Feng et al., 2011).

The main drawback of this technology is consumer concern about probable health problems of irradiated foods, their nutritional changes, and quality, particularly at high doses, which is needed to sanitize food products. As a result, further researches are necessary to identify the exact effect of gamma irradiation on health issues, and the studies should be promoted on various food products which extend their shelf life.

3.1.7 | High hydrostatic pressure processing (HHP)

High hydrostatic pressure processing (HHP) is an emerging process to extend food products' shelf life and maintain the quality, appearance, texture, flavor, and nutritional properties. HHP has been used for products such as fruit juices, jellies, yogurt, and meats. HHP is the method to inactive some viruses and microorganisms but is rarely can inactive spore-forming bacteria at 200 to 600 MPa. HHP can mostly inactive viruses by the denaturation of proteins and damage to the envelope and capsids, which the levels of deteriorative effect on viruses depend on the pressure range, the structure of proteins, pH, temperature, presence of salts, and sugar. The protein denaturation by pressure levels has a more pronounced effect in comparison to the time of exposure. Moreover, HHP may make to release nucleic acid from the virus particles. So, the virus misses its ability to replicate (Baert et al., 2009; Bosch et al., 2018; Hirneisen et al., 2010; Kovač et al., 2010). An interesting future approach might be research into the effect of HHP on the reduction of coronavirus infectivity.

3.2 | Chemical preservation methods

3.2.1 | Acidification

Acidification is one of the methods to preserve food products from spoilage. Some foods are naturally acidic like fruit juices and some of them are produced by fermentation to create a favorable sour taste. Fermented food is highly acidic foods in which the acid may be added directly, or the microorganism production lowers the pH, like vinegar and pickled vegetables.

Most enteric viruses are stable at pH 5–9 and also can survive at pH 3–5 more than alkaline pH (9–12). Darnell et al. (2004) explored the SARS-CoV stability at various pH exposures. The results showed that alkaline condition (pH = 12–14) for 1 hr, make SARS-CoV inactive. Pagat et al. (2007) observed the viability of SARS-CoV was not affected by pH 11, while the infectivity of viruses had a severe reduction (~3.5 $\log_{10}$). Moreover, Weismiller et al. (1990) evaluated that pH 8.0 causes the coronavirus protein disconfirmation and changes the infection capacity. Researchers showed that the neutral

pH (5–9) had no significant effect on SARS-CoV survival, while a low range of pH (1–3) cause the inactivation of SARS-CoV in cell culture medium at 25–37°C (Darnell et al., 2004). During the digestion of food, the normal intragastric pH is 1.3–2.5. After eating, the pH of the stomach reaches 4.5–5.8. As time pass (1 hr), the pH of the stomach decrease to lower than 3.1. Thus, based on the studies, it is expected that the pH of the stomach could decrease coronaviruses' viability. However, Xiao et al. (2020) indicated that 23.29% of COVID-19 patients have SARS-CoV-2 RNA in stool for 12 days; thus, sometimes SARS-CoV-2 can pass the gastrointestinal tract.

3.2.2 | Chlorinated derivatives

Chlorine compounds commonly utilized in the food industry are divided into two groups, including sanitizers and disinfectants. Chlorine-based sanitizers are used on a food contact surface, while the disinfectants usually are applied on non-food contact surfaces due to higher antimicrobial capacity. The various forms of chlorine are including chlorine gas (Cl_2), calcium hypochlorite ($Ca(ClO)_2$), sodium hypochlorite (NaClO), chlorine dioxide (ClO_2), etc. Chlorine can be used as a form of spray and flume water to reduce microorganisms in fresh products such as vegetables, fruits, lettuce, potatoes, etc. Diverse parameters influenced chlorine performance like pH, contact time, organic load, free-chlorine content, temperature, etc. Some researchers announced the chlorine concentration, which has been used for food products disinfection is 10–200 ppm (often 50–200 ppm) for 1–5 min exposure time at pH<8 (mostly pH 6–7.5) (Fonseca, 2006; Goodburn & Wallace, 2013; Gulati et al., 2001; Hirneisen et al., 2010; Meireles et al., 2016; Tsai & Lin, 1999). In water, free chlorine involves hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) as two main components. When Cl_2 is dissolved into the water for disinfection, a weak acid named hypochlorous acid is generated according to chemical equation (1):

$$Cl_2 + H_2O \rightarrow HOCL + HCL \quad (1)$$

$$HOCL \text{ partially dissociate in to } H^+ \text{ and} OCL^-: HOCL \leftrightarrow H^+ + OCL^- \quad (2)$$

The degree of hypochlorous acid dissociation (Equation 2) depends on the pH (−log $[H^+]$) of the solution; so, the HOCl to OCl^- ratio relies on pH. Since the pH is higher than 8.0, hypochlorite ion is dominant in the medium while, at pH lower than 6.0, HOCl is available (95%). Based on the findings, pH 6–8 had the highest viral inactivation rate. In other words, the free chlorine level in water is a critical parameter to determine the efficiency of chlorine solutions (Gray, 2014; Hansen et al., 2013; Qin et al., 2015; Shin & Sobsey, 2008).

The application of chlorine in food processing is widespread throughout the world. The disinfection of drinking water by chlorine has a long history with satisfactory results. Grabow et al. (2001) explored the virus presence in drinking water. The findings suggested that the presence of viruses in untreated water with 73% decreased to 23% in chlorinated ones. Researchers had used the coronaviruses inactivation by chlorine. Lai et al. (2005) used different disinfectants on SARS-CoV infection. Treatment with 1:50 and 1:100 of the stock sodium hypochlorite solution, decrease the SARS-CoV viability (>3 $\log_{10}$) after 5 min. Wolff et al. (2005) reported that sodium hypochlorite (1,000 ppm) could reduce HCoV-229E by >3 $\log_{10}$, despite 100 ppm. Based on the studies of Tyan et al. (2018) which evaluated the antiviral capacity of color additive mixed with 0.5% sodium hypochlorite, 0.2% calcium hypochlorite, and 0.5% sodium dichloroisocyanurate on skin product. Sodium hypochlorite without color additive decreases almost ≥3–3.25 $\log_{10}$ of the human coronavirus HCoV-229E population. While 0.5% sodium hypochlorite with color additive reached ≥4.50 $\log_{10}$ reduction and successfully passed U.S. Environmental Protection Agency (EPA) performance criteria in human coronavirus HCoV-229E disinfection. Researchers announced chlorine-containing solutions could be used as a disinfectant to control 2019-nCoV infection (Deng & Peng, 2020; Soetikno et al., 2020; Wang et al., 2020; Yan et al., 2020; Yeo et al., 2020).

Free chlorine influenced both viral genome and protein (Page et al., 2010; Wigginton & Kohn, 2012). The main inactivation mechanism of chlorine on viruses is capsid deformation and RNA fragmentation, which lead to release from capsid to medium. Researchers found the relationship of the RNA content of viruses that were treated by chlorine with viral infectivity. The results showed that the reduction of viral infectivity was not necessarily related to RNA separation from capsid. Nevertheless, based on the studies of chlorine on viruses represented that the main target of chlorine to inactive was probably nucleic acid, rather than capsid (Hirneisen et al., 2010; O'Brien & Newman, 1979; Wigginton & Kohn, 2012). RNA oxidation by free chlorine resulted in some products which had probably effects on virus replication in the host cell, including 5-chlorocytidine, 8-choloroguanosine, and 8-chloroadenosine. These products formation via genome damage force the host cell machinery to make numerous modifications, which finally resulted in virus inactivation. Moreover, free chlorine may attack the backbone of protein due to changing the capsid structure (unfolding the protein) and make cleavage on the protein capsid (Hirneisen et al., 2010; Kingsley et al., 2014; Wigginton et al., 2012).

Chlorine-based sanitizers are commonly used in the food industry. As chlorine-based compounds have low price, easy to use with high antimicrobial effect, etc. However, chlorine leads to produce some carcinogenic and mutagenic components such as chloroform and other trihalomethanes, chloramines, and haloacetic acids, which had several side effects on health. The controlling of chlorine by-products is so critical for environmental concern and processing equipment maintenance. The other limitation of chlorine is inactivation ability dependency on organic matter and pH. Moreover, chlorine is highly corrosive as it is used for stainless steel surfaces. The problem of high chlorine levels when it is used for food products is its effect on their organoleptic properties. As a consequence, there is a great challenge to develop novel alternative sanitizers, which are safe for the food industry (Gray, 2014; Meireles et al., 2016; Wang et al., 2005).

Chlorine dioxide (ClO_2) could be used as an alternative to older chlorine-based compounds and has the following advantages: less corrosive, higher oxidation ability, more solubility in water (up to 5-fold), less reactive with organic matter, inhibition of enzymatic browning, less pH dependence (effectiveness at wider pH range), lower tendency to ammonia, ClO_2 is a disinfectant gas which is approved by U.S. FDA, but it is under consideration by EFSA. In the United States, 200 ppm ClO_2 is approved to be applied in food processing equipment sanitation. But the ClO_2 usage is not allowed for fresh-cut fruits (Hirneisen et al., 2010; Kaczmarek et al., 2019; Meireles et al., 2016; Ölmez & Kretzschmar, 2009).

Some researchers reported the mechanism of ClO_2 is probably via its interaction with the viral protein of capsid, denaturation, inhibit to attach to host cells, and penetration. The others believed that the viruses were inactivated by ClO_2 through the damage of nucleic acid and stop replication (Gerba, 2015; Hirneisen et al., 2010; Wigginton et al., 2012). Wang et al. (2005) evaluated the inactivation of SARS-CoV in wastewater by chlorine solution (sodium hypochlorite) and chlorine dioxide. At a concentration of 10 mg/L (ppm), the infectivity of SARS-CoV was entirely decreased (100% inactivation rate) for ≥10 min by chlorine, while chlorine dioxide could inactive SARS-CoV up to 68.38% in 5–20 min. These researchers found chlorine solution (20 mg/L, ≥ 1 min) and chlorine dioxide (40 mg/L, ≥5 min) were found to inactivate SARS-CoV in wastewater completely. So, SARS-CoV was more sensitive to free chlorine than chlorine dioxide.

Although ClO_2 can be used in food processing, it has several disadvantages, including susceptibility to explode at high concentration, dissociation in sunlight, permission to use at low concentrations.

3.2.3 | Ozone

Ozone (O_3) is an active oxidizing agent that kills various microorganisms like bacteria, viruses, and fungi. Ozone is usually used to disinfect water for many years, and nowadays, the application for food processing is considered (Goodburn & Wallace, 2013; Hasan & Muhammad, 2020; Meireles et al., 2016). Ozone is generated as gas form, which can be dissolved in liquid. Ozone aqueous solutions are applied in food technology, wastewater treatment, laundries, etc., and gas form of ozone is used in places where decontamination tools cannot be utilized. As air humidity also influenced its permeability into the cells, the gas form is needed at higher concentration as compared with aqueous ozone solutions (Hudson et al., 2009; Meireles et al., 2016).

Ozone was approved by U.S. FDA to be used as an antimicrobial agent in food products. Application of ozone in food processing resulted in the disinfection of water, fruits and vegetable surface treatments, carcasses and food products, sanitation of surfaces and food plant equipment, reduce the cost of storing other sanitizers. The main expense of ozone is the cost of ozone generator; which long-term function can justify its cost. Furthermore, the input energy wanted for ozone treatment is much lower than microwave, radiation, and thermal treatment (Hirneisen et al., 2010; Khadre et al., 2001; Meireles et al., 2016).

Ozone can easily and effectively inactive viruses. The performance of viral inactivation relies on the nature of the food surface and the level of viral contamination. Ozonized water could be used for sanitation fruits and vegetables to reduce viral contamination in the food industry. Vaughn et al. (1990) investigated the effect of ozone on HAV suspensions. The results indicated that 1 ppm of ozone could completely inactivate the HAV (5 $\log_{10}$) after 60 s. Herbold et al. (1989) also showed that the effectiveness of ozone at 10°C was more than 20°C. As an example, at 20°C almost 0.25–0.38 mg/L of O_3 was needed to inactive HAV thoroughly. The reactivity of ozone is due to free radicals including hydroxyl ($HO^{\bullet}$), hydroperoxyl ($HO_2^{\bullet}$), and superoxide ($O_2^{\bullet}$) radicals which are generated, as ozone is dissolved (Malik et al., 2020; Miles et al., 2009). There have been limited researches that focused on the virucidal effect of ozone on coronaviruses. Hudson et al. (2009) reported ozone could decrease Murine coronavirus (Surrogate for SARS virus) at least 3 $\log_{10}$, under high relative humidity (RH > 95%). The mechanism of viral inactivation by ozone is via capsid protein, changes the antigenic sites for attachment to host cells, damage to nucleic acid, and prevent viral replication (Hirneisen & Kniel, 2013; Hudson et al., 2009). Generally, the viruses without an envelope are much more vulnerable to ozone than enveloped viruses due to easier access to the nucleic acid. Hirneisen et al. (2010) reported that proteins of capsid decomposed to amino acid as the viruses were treated by ozone. The most susceptible amino acids to ozone oxidation are cysteine, methionine, tyrosine, histidine, and phenylalanine in aqueous solution, whereas the others have not shown significant changes by ozone oxidation. Researchers found cysteine, methionine, tryptophan, and phenylalanine could react very rapidly with ozone (Sharma & Graham, 2010). The SARS-CoV spike protein has a relatively high (3%) content of cysteine, which stalks domain of this protein is rich in cysteine. Palmitoylation of cysteine-rich cytoplasmic tail (near carboxyl terminal) of spike protein probably promotes coronavirus–host cell fusion (Petit et al., 2007; Song et al., 2004). Ozone maybe could react with the cysteine-rich domain of spike protein and decrease the interaction between coronavirus and host cells; thus, the infectivity of coronaviruses declined.

The factors which influenced the act of ozone to inactive viruses are including temperature, pH, and content of organic substance. So that, ozone at high temperature becomes less stable and less soluble in water, but the reactivity raised (Gonçalves & Gagnon, 2011; Khadre et al., 2001). Moreover, organic content like minerals could consume ozone. Thus, as the purity of water increased, the ozone solubility was also enhanced. According to the report of researchers (Alvárez et al., 2006; Gonçalves & Gagnon, 2011), the most stable state of a triatomic oxygen molecule (O_3) occurred at pH < 6 and as the pH increased to 9.0, the stability of ozone reduced due to presence and catalytic activity of the hydroxyl radicals ($HO^{\bullet}$). Ozone kills the microorganisms quickly because of high oxidation potential, but also reacts with other organic compounds of food product so fast, and the organic compounds can consume the ozone which is required

for microorganism inactivation. Hence, the food matrix has a protective effect on microorganism. Besides, some byproducts which were generated from ozone reaction with organic substances changed the sensorial properties of food products, and lowered their shelf life (Hirneisen et al., 2010; Khadre et al., 2001). Another property of the use of ozone as a disinfectant is its rapid decomposition (~20–30 min at 20°C) in the water phase of food, and its antimicrobial capacity, which only occurred on the food surface. However, ozone resolved safety and antimicrobial concerns. Ozone decomposed into oxygen (O_2); so, the residuals of ozone have not safety problems in food products. Besides, the accumulation of waste products due to quick ozone decomposition does not take in the environment (Hirneisen et al., 2010; Khadre et al., 2001). The main disadvantages of O_3 are its potential to corrode the food equipment surfaces like metal, rubber, etc., and health hazards for humans, while long exposure of persons to ozone gas may cause respiratory diseases and eye irritation (Hudson et al., 2009; Valacchi et al., 2005).

3.3 | Food strategies

The trade of commodities among countries has been disrupted; accordingly, import of raw materials and exportation of food products has been stopped. The pandemic has influenced certain food supplies more than others (Coluccia et al., 2021; Ibn-Mohammed et al., 2020; Kumar et al., 2021). Generally, there are four aspects that the food industry and the food supply chain should be considered in the COVID-19 pandemic disaster (Galanakis, 2020). First, the pandemic created opportunities and challenges for the commercialization of innovative functional foods and nutraceuticals containing target bioactive compounds (e.g., Vitamins and antioxidants) and highlighted the development of nutritional and immune-boosting products to improve their overall health and recovery of COVID-19 patients (Galanakis, 2015, 2021; Galanakis et al., 2020, 2021). These prospects are expected to remain high within the post-lockdown and post-pandemic era due to the increased interest of health-conscious individuals (Galanakis et al., 2021). Second, food safety is important in order to avoid the spreading of the virus between producers, retailers, and consumers (Djekic et al., 2021; Galanakis, 2020). After more than a year since the COVID-19 outbreak was declared a global health emergency, the U.S. Department of Agriculture (USDA), the U.S. Food and Drug Administration (FDA), and the U.S. Centers for Disease Control and Prevention (CDC) continue to underscore that there is no credible evidence of food or food packaging associated with or as a likely source of viral transmission of SARS-CoV-2 (U.S. Food and Drug Administration, 2021a). However, moving to a post-lockdown routine, public health surveillance will depend more and more on the development of relevant bioanalytical tools (Rizou et al., 2020). Third, there is a trend toward intensive sustainable food production systems (such as digitization, artificial intelligence, and automation in smart agriculture) with future-proofing for the potential impact of security risks and climate change through the supply chain to mitigate critical needs embrace opportunities. Last but not least, food security issues have emerged due to the lockdown of a billion people inside their houses. Globally, there will be a pressing focus on food security regionally and nationally to mitigate against challenges presented by the potential occurrence of future viral pandemics such as that caused by SARS-CoV-2 to protect vulnerable critical supply chains (Ali et al., 2021; Galanakis, 2020; Galanakis et al., 2021).

4 | CONCLUSION

SARS-COV-2 nowadays has been considered as a huge concern and public health threat in the whole world because of rapid transmission by various ways like person-to-person contact, contaminated surfaces, eating food, and also environment. This global pandemic effect on human lifestyle, economy, and societal views. The survival of SARS-COV-2 depends on its capsid, which protects the genome from different environmental parameters, and genome. Conformational changes and destruction of capsid make it no longer binding to host cells, and damage of nucleic acids prevents coronavirus to replicate in host cells.

Food preservation methods which commonly used are heating, chilling, freezing, acidification, drying, and packaging. In this review, the most effective ones are discussed to evaluate their ability to eliminate or reduce the coronavirus infection. Some methods are in the literature on physical processing like heating, chilling, freezing, microwave irradiation, ultraviolet light, gamma irradiation, high hydrostatic pressure, and the others are chemical methods including acidification and use of chlorinated derivatives and ozone. This review provided available means to inactive coronavirus in the food industry.

Thermal processing is the main way to inactive coronavirus. Heating at 75°C (15–60 min) and 65°C (1 min) was the best temperature for inactive SARS-CoV and MERS virus, respectively. During heating, structures of capsid proteins (secondary, tertiary, and quaternary) are destroyed. As a consequence, the virus lost the infectivity. However, chilling and freezing are inappropriate ways to reduce coronavirus infection. SARS-CoV is stable at 4°C in clinical specimens for many weeks and also could survive about 2 years on stool at −80°C and for many weeks in clinical specimens at −70°C. Moreover, different freezing–thawing cycles did not any effect on SARS-CoV and HCoV-229E.

Among irradiation methods (microwave, UV, and gamma), the most effective one is UVC rays. UVC rays probably induce uracil-complex dimers and attack to proteins of capsid. As a result, the virus genome becomes susceptible to Ribonuclease and finally inactive. However, the resistance of SARS-CoV and found that 0–15000 rad (= 0–0.15 kGy) of gamma rays was determined. In general, viruses due to smaller dimension and genome have more stability against gamma irradiation.

The coronavirus indicated higher stability at lower relative humidity. MERS-CoV could survive at the 20°C -40% RH condition after 72 hr with 4.9 and 5.1 $\log_{10}$ reductions for plastic and steel surfaces, respectively. SARS-CoV preserves the viability for more than

2 weeks in air-conditioned humidity (22 ~ 25°C, 40%–50% RH). So, storage of the food products at high humidity could be an appropriate way to inhibit the infection.

The use of disinfectants like chlorine on SARS-CoV as 1:50 and 1:100 of the stock sodium hypochlorite solution, decrease the SARS-CoV viability (>3 $\log_{10}$) after 5 min. Also, chlorine derivatives could control 2019-nCoV infection. There have been limited researches that focused on the virucidal effect of ozone on coronaviruses. But it is a potent way to eliminate coronavirus which could be explored in the future. More research is required in evaluating the efficacy of food preservation methods to establish coronavirus inactivation.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTIONS

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DATA AVAILABILITY STATEMENT

Research data are not shared.

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