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Review

The role and importance of food industry and food systems during the COVID-19 and the possibility of cold plasma technology for inactivation: a review

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ABSTRACT

This article reviews the role and importance of food systems during the COVID-19 outbreak, the impact of this pandemic on the food industry and chain, and examining the methods and possibilities of using cold plasma technology to deal with this pandemic. Since food plays an essential role in human health as an integral part of human life, food safety is critical in such cases. It is essential to adopt practical strategies in controlling the COVID-19 crisis. In the current situation, several methods are used to disinfect and control the spread of disease, some of which are ineffective and can also have problems and limitations. Therefore, emerging technologies such as cold plasma (CP) technology can help facilitate the control process and reduce pandemics. The capabilities of this method are disinfection of food, equipment, production surfaces, and indoor with poorly ventilated spaces of SARS-CoV-2 through aerosol microdroplets, which can remain in the air for a long time; such as public transportation, production lines, and restaurants where the possibility of transmitting the SARS-CoV-2 is high. On the one hand, this review summarizes all available data related to cold plasma technology as an emerging technology to inactivate SARS-CoV-2. It then gives us a brief explanation of the role and importance of the food industry and food supply chain during the pandemic.

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1.Introduction

Food safety lies in food-related problems and suggested solutions. Despite continued investments, the WHO estimates that there are 23 million cases of food-borne diseases and 5,000 deaths annually in Europe, and Europeans do not trust food systems.

Existing and emerging pathogens, which are produced through food, are changing the epidemiology of food-borne illness.

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The need to provide new solutions and approaches in food safety management to protect nutrients against germs and emerging contaminants is a global challenge. Maintaining food safety is an endless task. There is a need for new risk communication strategies to be able to influence consumer behavior and thus reduce food hazards (1). Food handlers must have sufficient knowledge in safety to minimize the spread of food-borne diseases (2). SARS-CoV-2 is the third pathogenic Coronavirus emerging in the last two decades, and its person-to-person transmission has been observed in both family and hospital settings (3). Since the treatment methods, such as vaccines, have not been fully used in human societies against this disease, the academic community and authorities seek studies and data to manage the current and possible future epidemic crises in the short and long term (4). The use of masks during the COVID-19 epidemic, along with social distancing and hand washing, are useful tools in controlling the spread of this disease (5). A review of 22 studies shows that human Coronaviruses can persist on surfaces like other viruses, such as glass, metals, and plastics, for up to 9 days. Surfaces disinfection methods can effectively inactivate this virus, 62-71% ethanol, 0.5% hydrogen peroxide (H_2O_2), or 0.1% sodium hypochlorite (NaClO) within 1 min (6). Different types of biocidal agents such as hydrogen peroxide, alcohols, sodium hypochlorite, or benzalkonium chloride Mainly are used for disinfection in healthcare settings around the world (7). Each of the disinfection methods, which are currently used, has significant drawbacks. Cold plasma has been introduced as an efficient, inexpensive and, clean solution for inactivating viruses in this field (8).

Thermal food processing technologies currently available have specific limitations, such as affecting the food texture or producing toxic by-products. Therefore, there is a serious need to develop and improve non-thermal technologies to decontaminate without affecting the organoleptic properties and quality of food nutrients (9). As a non-thermal processing technology, Cold atmospheric plasma has a high potential in food decontamination and surfaces in contact with food materials, concerning the ability to produce reactive oxygen and nitrogen species (RONS) and antimicrobial properties in environmental conditions(10).

Concerning environmental protection, new types of environmentally friendly disinfectants are needed. CP should replace current chemical decontamination methods because it does not generate waste and can inactivate viruses more effectively at different levels and environments. In combination with other available technologies, CP can provide the ultimate disinfection tool with a synergistic effect to improve virus inactivation operation (8). This review investigates the role of the food industry and food chain during the COVID-19 pandemic and the possibility of transmitting the virus through food or food packaging. It also introduces non-thermal plasma and inactivation mechanisms as useful tools against SARS-CoV-2.

2. Food-borne viruses

Typically, the spread of outbreak diseases is accompanied by foods eaten raw, like oysters, fruit, and vegetables. Because it is difficult or impossible to cultivate many food viruses outside the human body, alternative viruses are often used in laboratory research to understand viruses' behavior (11). In recent years, viruses have grown increasingly around the world as a significant cause of food-borne illness. Viruses have properties that distinguish them from food bacterial pathogens. Viruses do not have a free life and can only multiply through the living cells of humans, other animals, plants, or bacteria.

For this reason, food-borne viruses, unlike food-borne bacteria, are not able to multiply in food. Most food viruses lack viral coverage and are therefore very stable in the environment. Some food-borne viruses can tolerate and adapt to food processing techniques used to control bacterial pathogens in food. Food-borne viruses can remain in the food, on the hands, in the stool, and on food contact surfaces for a long time (12). Food-borne viruses cause significant disease and mortality. Controlling this virus means trusting and ensuring good personal and food hygiene, good agricultural practice, proper post-harvest controls, and effective human wastewater management to prevent further transmission (11). Human Noroviruses are the leading cause of foodborne disease outbreaks. Furthermore, for this reason, it is known as the food-borne virus with the highest priority around the world. In 2015, the WHO named human Noroviruses as the number-one cause of food-borne diseases (13). Bosch et al. 2018 conducted a study that reviewed the food-borne viruses: detection, risk assessment, and control options in food processing. In addition to Noroviruses, they concluded that food-borne viruses include hepatitis A virus, hepatitis E virus, rotaviruses, astroviruses, etc (14).

2.1. COVID-19 and its outbreak

WHO has introduced COVID-19 as a global pandemic. At the same time, thousands of infection and death cases are reported daily (15). Coronavirus is a disease that transmits easily (COVID-19: caused by new Coronavirus SARS-COV-2). It was identified in December 2019 and declared by WHO on March 11, 2020, as an outbreak (16). According to some evidence (not definitively), the first infections were related to the Huanan seafood market in Wuhan (China). Before freezing, fresh foods can also be exposed to SARS-COV-2 (17).

Coronaviruses include viruses that cause seasonal colds and the flu. COVID-19 belongs to the family of Coronaviruses that cause acute respiratory infections (18). According to the United States, centers for disease control and prevention (CDC), a wide range of symptoms are reported for people with COVID-19. They are ranging from mild symptoms to severe illness. 2-14 days after exposure to the virus, symptoms may appear. Anyone can have mild to severe symptoms. People with these symptoms may have COVID-19. Fever or chills, cough, shortness of breath or difficulty breathing, fatigue, muscle or body aches, headache, the loss of taste or smell, sore throat, congestion, or runny nose, nausea or vomiting, diarrhea (19).

Globally, on May 14, 2021, there have been 160,813,869 confirmed cases of COVID-19, including 3,339,002 deaths, reported to WHO. As of May 12, 2021, a total of 1,264,164,553 vaccine doses have been administered (20).

2.2. The role and importance of restaurants in the outbreak

Restaurants are one of the most common outbreak areas of food-borne diseases. Unlike homemade food, just one mistake by food system staff can affect many people. Although most food-borne diseases that occur in restaurants are at the local level, there are many examples of the outbreak at the regional and national levels. These outbreaks are associated with a variety of food virus pathogens (21).

In the spring of 2006, in two separate incidents at two restaurants in Lansing and Michigan in the United States, more than 600 customers reported becoming ill after eating food. In both restaurants, Noroviruses were declared the disease agents (22). There are at least two reasons to compare the perception of consumer food safety in restaurants with those involved in other parts of the food chain. First, food safety problems can occur anywhere in the food system; because the restaurants prepare and cook the food for customers, they are considered a critical endpoint in the chain from farm to table. The second reason is that food safety issues may affect where consumers buy meals (23).

2.3. COVID-19 outbreak effect on food systems

Food systems include all the different food production stages from the farm to the table, for example, processing activities, distribution, preparation, consumption, and discharge. The different parts involved, for example, infrastructures, inputs to the agricultural sector, prospects, farmers, retailers, transportation, and organizations (24).

To prevent a considerable food shortage, the highest importance for any country is to maintain the flow of food supply chains (25). Food systems, directly and indirectly, affect human health, and today their sustainability is more important than ever (26). The COVID-19 outbreak caused to highlight the shortcomings of current food systems, and it was found that HACCP food systems were not effective enough in reducing unknown hazards. While HACCP is only concerned with food safety, in the current situation, a tool is needed to address all four elements of food protection: food safety, food quality, food support, and food fraud (27).

The new Blockchain system is used in the United States today, an efficient and effective method against diseases and identifying their origin. This method also simplifies the work of regulatory agencies of countries such as the Food and Drug Administration and the countries' agricultural sector. If there is contamination in food sources, it is much easier to track where the products came from and recall-related products. As a result, regulatory agencies can control food-borne diseases much faster (28). The COVID-19 outbreak affects all aspects of human life, including food consumption. According to the FAO, global food consumption will be limited in the world due to various pandemic effects when changing global food patterns. In most countries, access to food markets has been restricted, while restaurants and public places are closed. These cases have a more significant impact on how people buy and consume food. These reasons change the patterns of food consumption towards preparing meals and consuming at home (29).

2.4. The possibility of transmitting the Coronavirus through food

Due to the current outbreak of severe acute respiratory syndrome Coronavirus 2 (SARS-COV-2), there are many concerns about the possibility of transmission of the virus through food or food packaging. The possibility of food-borne transmission for every virus cannot be ruled out. Food-borne viruses have been observed to have high stability and resistance to environmental stresses in food systems. Coronavirus infection has never been linked to food consumption. There has also been no diagnosis of food-borne diseases. However, it has been shown that infection with the Coronavirus can persist on food or food packaging for a sufficient period (several days to several weeks), leading to transmission (30).

2.5. New cold plasma technology, an alternative to conventional disinfection methods

A significant challenge for the food, pharmaceutical, agricultural, and environmental protection industries is microbial contamination. Therefore, scientists are seeking alternative disinfection methods to ensure the definitive destruction of unwanted biological agents. Recently, cold plasma has attracted the attention of a growing group of researchers due to its unique chemical and physical properties (31). Plasma compounds include ionized molecules and atoms, high-energy electrons, and UV photons, which are critical factors in effectively reducing the microbial population. Non-thermal plasma technology is a promising method to inactivate pathogenic viruses that cause infections in humans, animals, and plants (32). Cold atmospheric plasma (CAP) is prominent among new disinfection technologies due to its rapid antimicrobial action against a wide range of food-borne pathogens and, at the same time, the least impact on food and surfaces. In addition, this is low-cost, environmentally friendly, material-free technology that allows scaling and adapting to industrial needs (33). The COVID-19 outbreak has led to limitations in sterilization capacity in hospitals, occupations, and homes. Sterilization with CAP is an alternative to traditional sterilization methods. CAP sterilization is created by reactive plasma species that cause virus leakage and loss of virus function (34). The production of chemically reactive species produced by electrical discharge in a gas leads to microbial inactivation. Because the presence of potent oxidizing agents such as O_3, NO, NO_2, N_2O_5, HNO_2, HNO_3, $ONOO^-$, H_2O_2, OH, and many other reactive species that can react with the airborne particles and mediate various oxidative processes have destructive effects on the cell wall and intracellular components (35).

The versatility of CP generation sources offers unique designs that are compatible with current food industry equipment. Regarding food processing, jet plasma and dielectric barrier discharge (DBD) are the most frequently used (36). Figure 1 shows that; both techniques were used for SARS-CoV-2 inactivation in face masks and other surfaces. CP technology is becoming an encouraging technique to replace conventional disinfection methods of food products, medical equipment, and ambient air in the future. This method has many benefits; high efficiency in reducing the number of microorganisms and viral particles, forming non-toxic by-products, and comparatively low cost of the process (37).

The effects of CAP on SARS-CoV-2 inactivation are summarized in Table 1. Recent research shows that plasma-activated solutions (PAS) can contribute to effective disinfection. The effectiveness of plasma-activated solutions (H_2O, 0.9% NaCl, 0.3% H_2O_2) was evaluated by the inactivation of the Newcastle ND virus. Scanning electron microscopy images have shown morphological changes in virus particles and RNA destruction (38).

The recent outbreak has had a significant impact on supply chains, treatment methods, and medical resources. Due to its many components, including charged particles, electrons, reactive nitrogen species (RNS), reactive oxygen species (ROS), molecules, UV photons, electromagnetic fields, physical forces, and electrical fields, CP has been widely used in a range of applications in medical engineering. Many productivity benefits have been shown using CP devices for the healthcare sector without unique consuming materials supply chains such as hand disinfectants and similar cases (39).

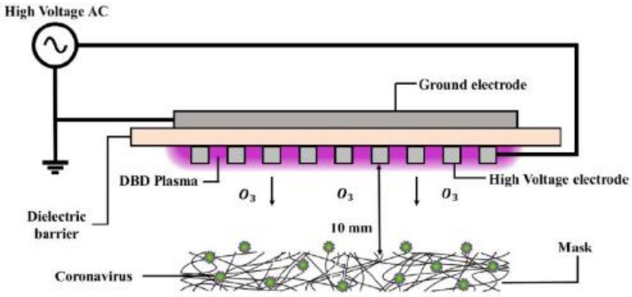
The importance of COVID-19 early infection control measures has come to be essential. WHO has cited frequent handwashing with soap and water or alcohol as one of the most critical health measures to prevent the spread of infection. One of the most common ways of transmitting many diseases is hands; because they directly contact the entrance part of pathogens such as the nose, mouth, and eyes. Recently, plasma-activated solutions are highly considered a fundamental approach in plasma biomedicine (40).

Therefore, plasma-activated solutions can be used to disinfect the hands to prevent transmission of SARS-CoV-2. Inactivation of SARS-CoV-2 by CAP-activated solution results from the combined operation of low pH and reduction potential of favorable oxidation. Such a CAP-based medium will be valuable due to the processing of disinfection functions and sterilization in all places such as homes, offices, public areas, building entrances, laboratories, and hospitals.

Table 1. Summary of outcomes of cold atmospheric plasma (CAP) processing on SARS-CoV-2.

Sample	**Plasma**	**Microbial Observation**	**References**
Bioaerosols	DBD, 56 kV, 14 kHz, residence time (<0.2 s)	• Pathogens studied: • *Staphylococcus epidermidis* or purified SARS-CoV-2 RNA • CAP can induce a log reduction of around 3.76 on bacterial bioaerosol and degrade viral RNA in a short residence time (<0.2 s).	(41)
various surfaces: including plastic, metal, cardboard, basketball composite leather, football leather, and baseball leather	Plasma jet, 16.6 kV (peak-peak) at 12.5 kHz, Argon gas	• SARS-CoV-2 at 2×10^5 PFU in a 25 ul volume. • Ar-fed CAP treatment inactivated all SARS-CoV-2 on the six surfaces in less than 180 seconds	(42)
Face masks	DBD, a high-voltage, high-frequency, 1 min, ozone gas	• Using a human 47 coronavirus (HCoV-229E) as a surrogate for SARS-CoV-2 contamination on face masks. • The virus loses its infectivity to a human cell line (MRC-5) when exposed for a short period (1 min) to ozone gas produced by a DBD.	(43)

(a)



(b)

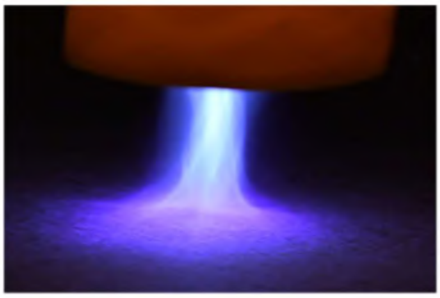


Figure 1. A schematic diagram describing the disinfection of a face mask contaminated by a coronavirus using ozone produced by a DBD plasma generator(a), Adopted from (Lee et al., 2020); (b) Argon-fed cold jet atmospheric plasma.

This method can prevent the need for disinfectants that require consuming materials such as alcohol, which are sensitive to supply chain disruption. CAP has a high potential to prevent the transmission of SARS-CoV-2 and treat patients severely who are infected by the virus (39). Different sources of CP can completely inactivate or significantly reduce multiple disease-causing viruses in different matrices in humans, animals, and plants. As shown in various studies, virus inactivation largely depends on the treatment's characteristics, so it is necessary to select the optimal parameters case-by-case.

3. Conclusion

Extensive pandemics have occurred throughout human life. The battle between humans and microorganisms has always led to the development of human societies. The need for an environment and safe food are essential for survival. Therefore, selecting appropriate decontamination methods to increase immunity to the end of the pandemic seems necessary. Regarding the existing problems and weaknesses existing in some decontamination methods and increasing the possibility of harm to the environment and people, emerging decontamination technologies seem necessary.

Non-thermal plasma is an emerging technology for decontamination of food before or after processing, equipment, and airborne microorganisms without significant effect on the other aspects of food. The use of non-thermal plasma has high potential due to the low cost of production, non-production of harmful wastes for the environment, and inactivation of a wide range of microorganisms, including the SARS-CoV-2. Cold plasma can be decontaminated in high-risk environments, such as public transportation, work environments with improper ventilation, food production halls, and restaurants, which are the main places of transmission of this virus. Using this method breaks the virus transmission chain and reduces the transmission rate from person to person. Therefore, using WHO recommendations and non-thermal plasma can be very useful in preventing the transmission of Covid-19 disease and the resulting pandemic.

Conflict of interest

The authors declare that there is no conflict of interest.

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