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Can food matrices be considered as a potential carrier for COVID-19?

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SUMMARY

Humanity is currently facing a life-threatening challenge from the infectious and epidemic disease SARS-CoV-2. To date, the various modes of transmission of the virus have not been fully elucidated. In this regard, there is a possibility of transmission of the virus through food products. The COVID-19 pandemic disease, like those associated with SARS and MERS, is transmitted mainly through the respiratory tract and airborne aerosol particles, but the presence of fragments of the genetic virus (RNA) in the feces of numerous patients proposes that their fecal-oral pathway may be expanded. In addition, people with gastrointestinal disorders such as atrophic gastritis and metaplasia may be susceptible to COVID-19 infection. Accordingly, food may act as a potential carrier of COVID-19 due to environmental or cross-contamination. According to the available evidence, the spread and possibility of transmission of COVID-19 contamination from humans to food products are possible. Beyond that, there is some evidence that some food sources of animal origin, such as pigs and rabbits, can be contaminated by COVID-19. Therefore, the transmission of the virus through some meat products may be conceivable. Due to the rapid release rate of COVID-19 and its stability in various milieus, especially food manufacturing circumstances, it may enter the matrix during different stages of traditional or industrial food processing. Therefore, preventive measures are recommended to be utilized in the food manufacturing sector. The present study explored the risk of different food matrices, including dairy products, bread, meat and meat products, vegetables, fruits, and processed foods, as potential carriers for the transmission of COVID-19.

Keywords: foodborne diseases, COVID-19, food safety, food carriers, health.

INTRODUCTION

Even though food seems safer than ever, foodborne diseases' prevalence is characterized as one of the most common causes of malady and mortality [1-3]. The outbreak of foodborne diseases can be associated with eating foods containing microbial agents (bacteria, viruses, and parasites), chemical or/and biological toxins [4]. Viruses can be considered substantial factors in the field of food infections around the world [5, 6]. However, viruses are not able to spread or produce toxins in the food matrices, and food only possesses the carrier role [7, 8]. Therefore, foodborne viral infections are usually transmitted through the fecal-oral pathway.

Presently, the population of all countries is affected by the unusual species of coronavirus, known as SARS-CoV-2, which has caused massive human deaths and the global economic crisis. Coronavirus are RNA viruses belonging

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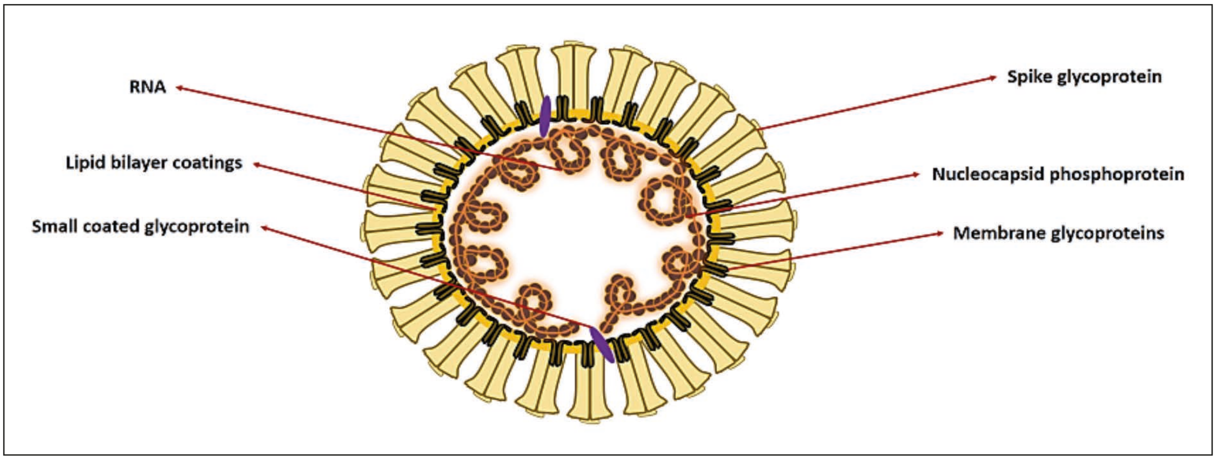
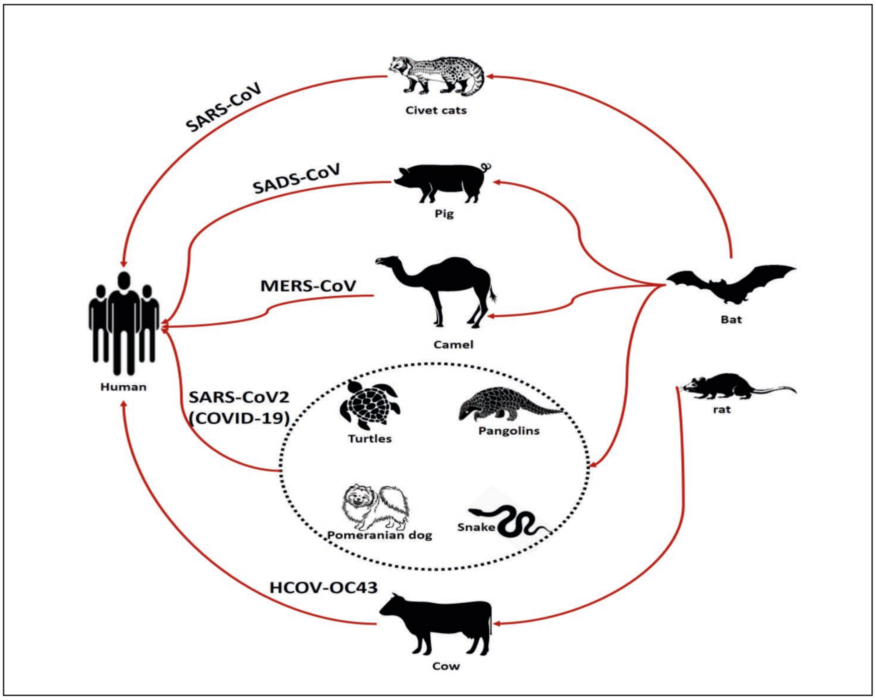


Figure 1 - Schematic illustration of the coronavirus' structure.

to the family Coronaviridae, order Nidovirales, and SARS-CoV-2 is considered a new species of the coronavirus, which can mediate various acute/chronic infectious diseases such as respiratory [like as middle-east respiratory syndrome (MERS) and severe acute respiratory syndrome (SARS)], hepatic, enteric, and neurologic complications in various cold-blooded and warm-blooded hosts such as humans, cows, pigs, horses, birds, dogs, and mice (Figure 1) [9, 10]. Although COVID-19 is generally associated with respiratory symptoms, the result of some investigations demonstrated that some patients with gastrointestinal symptoms contained viral components in their feces [11, 12]. This observation reinforces the hypothesis of transmission of this virus from the fecal-oral pathway. Therefore, the food matrices may act as a potential vector of COVID-19. In this regard, significant food contamination may be through food processing,

Figure 2
Human coronaviruses with animal origin.



asymptomatic carriers of food-processing staff, and consumption of animal-based foods that are infecting with the virus (zoonotic transmission) [5, 13, 14]. Hence, due to the widespread consumption of animal-based foods, some concerns are raised regarding their potential carriers' role (Figure 2) [15-17].

FOODBORNE VIRUSES

According to the outcomes from investigations, some viruses such as Hepatitis A, Norovirus, Rotavirus, Adenovirus, Astrovirus, and Enterovirus can be transmitted through some raw foods/without proper cooking (oysters, bivalves, salads, shellfish, mollusks, leafy greens, fruits, ice-slush beverages, sandwiches, etc.) [18]. Since these intestinal viruses tend to be transmitted from person to person, food products can be considered a desirable vector for their transmission [19]. Therefore, establishing appropriate hygienic measures during food processing by employees and people working in the production/distribution unit and observance of hygienic methods of food preparation by consumers before consuming food products can be a significant recommendation to prevent the risk of infection outbreaks (Table 1) [20].

Table 1 - Some of the important foodborne viruses. According to references: [15, 18, 21-25].

Virus	*Genomic type*	*Family*	*Disease*	*Transmission*	*Main contaminated foods*	*Clinical symptoms*
HAV	Single-stranded RNA	Picornaviridae	Hepatitis A	Fecal–oral route (eating contaminated food or water) Rarely by infected blood products	Ice-slush beverages, milk, hamburgers, seafood, green onions, strawberries, pomegranate arils, and frozen berries	Vomiting, nausea, malaise, low-grade fever, anorexia, fatigue, and myalgia
HEV	Single-stranded RNA	Hepeviridae	Hepatitis E	Fecal-oral route (contamination of drinking water supplies with human feces) Zoonotic foodborne Person-to-person Iatrogenic	Undercooked meat (pork, wild boar, or Sika deer), water, raspberries, shellfish (oysters, bivalves, and mussels), strawberries, and vegetable	Body aches, nausea, fever, dark-colored urine, malaise, jaundice, and vomiting
Astrovirus	Positive-sense single-stranded RNA virus	Astroviridae	Astroviral diarrhea	Fecal-oral route (contaminated food, water, and fomites)	Shellfish (clams, mussels, and oysters), sandwiches, salads, garnishes, soft fruits, water, turkeys, and leafy green vegetables	Abdominal pain, gastroenteritis, fever, mild watery diarrhea, loss of appetite, and vomiting
Sapovirus	Linear positive-sense single-stranded RNA	Caliciviridae	Gastroenteritis	Fecal-oral route (contaminated food and water) Environmental sources Person-to-person contact	Oyster, river water, and Salad	Diarrhea, fever, and vomiting
Norovirus	Single-stranded RNA	Calciviridae	Gastroenteritis	Directly from person-to-person By contaminated water and food	Frozen strawberries, oysters, leafy greens, shellfish, bottled water, mollusks, imported frozen raspberries, crustaceans, and lettuce	Abdominal pain, nausea, occasionally low-grade fever, non-bloody watery diarrhea, and vomiting

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Virus	*Genomic type*	*Family*	*Disease*	*Transmission*	*Main contaminated foods*	*Clinical symptoms*
Human rotavirus	Double-stranded RNA	Reoviridae	Rotaviral enteritis	Fecal-oral route Via aerosol droplets between people	Water	Watery diarrhea, nausea, low-grade fever, and vomiting
Human parvovirus	Single-stranded, mostly negative-sense DNA viruses	Parvoviridae	Erythema infectiosum Gastroenteritis	Respiratory secretions Blood Maternal-fetal pathway Fecal-oral route (not zoonotic)	Shellfish	Thrombocytopenia, lymphopenia, fever, and neutropenia
Aichi virus	Positive-sense single-stranded RNA	Picornaviridae	Gastroenteritis	Fecal-oral route	Seafood and oysters	Abdominal pain, fever, vomiting, diarrhea, and nausea
Adenovirus	Double-stranded DNA virus	Adenoviridae	Respiratory tract infections Gastroenteritis Ocular infections	Waterborne and foodborne transmission	Shellfish (clams, mussels, and oysters), sausage dish, frozen berries, ice, water, leafy green vegetables, and strawberries	Gastroenteritis, ocular infections, pancreatitis, hemorrhagic cystitis, upper and lower respiratory tract infections, nephritis, meningoencephalitis, hemorrhagic colitis, and hepatitis
SARS-Co-V	Positive-sense single-stranded RNA	Coronaviridae	Respiratory infection Gastroenteritis	Respiratory secretions Person-to-person Fecal-oral route (zoonotic, or food handler transmission)	Civets, bats, or raccoons	Fever, diarrhea, loss of appetite, fatigue, dry cough, and breathing difficulties, chills, muscle pain, headaches, and fecal shedding
MERS	Positive-sense single-stranded RNA	Coronaviridae	Respiratory infection Gastroenteritis	Person-to-person Zoonotic transmission Fecal-oral route (zoonotic, or food handler transmission)	Bats and dromedary	Shortness of breath, and cough, and fever
SARS-CoV-2	Positive-sense single-stranded RNA	Coronaviridae	Respiratory infection Gastroenteritis	Zoonotic transmission Person-to-person Fecal-oral route (zoonotic, or food handler transmission)	Pangolins, rabbits, bats, snakes, turtles, and pigs	Chest pain or pressure, dry cough, aches and pains, loss of taste or smell, diarrhea, fever, sore throat, fatigue, a rash on the skin, or discoloration of fingers or toes, headache, breathing difficulties, and conjunctivitis

THE EFFECT OF FOOD COMPOSITIONS ON THE SURVIVAL OF COVID-19

SARS-CoV-2 is generally sensitive to low pH values. However, it has been suggested that SARS-CoV-2 is stable in a wide pH range from 3 to 10. Therefore, it is likely that this virus is resistant to almost all food products. Reducing the pH value will make the destructive effects of high temperatures on the virus more pronounced [26, 27]. On the other hand, higher water activity in the plant, fruits, and vegetable tissues may increase intestinal viruses' sensitivity to heat treatment. Besides, a direct relationship between protein, fat, and sugar contents of foods with the virus' stability against thermal treatment has also been observed [28, 29].

DIFFERENT FOOD PRODUCTS AND COVID-19

Meat and meat products

Meat and meat products deliver many macronutrients (essential lipids, proteins) and micronutrients (some vitamins and iron) to humans, which are very important for creating or/and maintaining the health status of the host. Meats such as beef, pork, seafood, and poultry are rich sources of heparin and heparan [30]. These compounds play a crucial role in the binding of viruses to target cells. Therefore, the transmission of the virus through meat and meat products may be possible. Hence, proper heating (60°C for at least 30 minutes) of raw meat before consumption can ensure its safety [31]. Besides, the consumption of raw meat products (*e.g.*, kibbeh nayyeh, crudos, raw oysters, steak tartare, sashimi, sushi), and the preparation of smoked and cooked meat products should also be done at appropriate temperatures, as well as the consumption of game meat should also be limited in these conditions and case of consumption, food safety, and hygiene practices should be observed [32].

Dairy products

Milk is one of the most widely used dairy products in the world. The use of milk heat treatment is mandatory in most countries and ensures the safety of its consumption. However, some people may consume milk in raw form due to a lack of trust in industrial processing and the possibility of fraud [33]. Consumption of raw milk without an appropriate heating process always carries the risk of cross-contamination with viral agents, and this is very important during the COVID-19 pandemic, and it is recommended to avoid consuming raw milk. Besides, heating raw milk at home is also not a good option, as it may significantly reduce its nutritional value. Therefore, consumption of milk under commercial heating in pasteurized or sterilized form can be a logical choice. Yogurt is another popular dairy product. In yogurt matrices, the viral load of COVID-19 is expected to decrease significantly to an indistinguishable amount during our heat treatment (90°C, 15 min) before fermentation [34]. However, the risk of cross-contamination after heat treatment and the ability to survive the virus in refrigerated conditions should also be taken into account. So far, at least nine cases of food contamination with COVID-19 have been identified in frozen foods imported in China, in which some dairy products such as frozen yogurt, frozen dairy desserts, and ice cream played the role of new carriers [35]. As COVID-19 is mainly transmitted through human activity, industrial food manufacturing units with lower staff as well as processing more machinery distinctly reduce the risk of food contamination by COVID-19.

Bread

Although the baking process may eliminate the COVID-19 virus, cross-contamination of the final product by the infected person can be probable. Also, it is assumed that the risk of contamination in traditional processing units is higher than in industrial units. Therefore, precautions are to monitor the personnel working in the relevant units, maintaining personal hygiene and household heating of bread before consumption of items that can be used at the moment [36].

Vegetables and fruits

These products of natural origin are often considered healthy foods by consumers. Contamination of vegetables and fruits is often caused by irrigation with wastewater. Since evidence suggests that patients infected with COVID-19 can excrete viral particles, there is concern about the presence and stability of the virus in wastewater and subsequently in these products [37]. Precautions can be taken through several methods, including supplying commodities from gardens, farms, and greenhouses with Good Agricultural Practices (GAP) certificates, refraining from consuming unwashed fruits and vegetables and peeling the skin of some commodities such as oranges, lemons, bananas, potatoes, and onions. For products that can't be peeled (parsley, basil, chive, and berries), adequate washing with suitable disinfectants such as chlorine solution (about 30 mg/L), chlorine dioxide (dilute performed with water in a ratio of 1: 2.5) and sodium hypochlorite (0.25%) [38].

Other foods

Consumers consider nuts such as walnuts, pistachios, peanuts, almonds, and hazelnuts to be microbiologically safe due to low humidity. However, confectionery stores are usually crowded places where if nuts are exposed to air in these conditions, there is a possibility of cross-contamination. Therefore, these materials should not be exposed to direct contact. Besides, the same precautions should be taken regarding dates, dried fruits, and other ready-to-eat (RTE) food products [39].

DIETARY HABITS (FAST FOODS) AND COVID-19

Today, all sections of society are affected by different strains of COVID-19, but the incidence and mortality rate is still disproportionately high in the elderly and those with underlying diseases. Metabolic disorders such as obesity and type 2 diabetes are important risk factors for the pathogenesis of acute forms of COVID-19 [40]. Epidemiological studies have linked the existence of numerous reports of the high incidence of these risk factors around the world, especially in Iran and other developing countries, to the increase in the consumption of typical fast-food diets. There are several types of fast-food diets, all of which are low in fiber, unsaturated fats, and antioxidants, and high levels of Saturated Fatty Acids (SFAs), refined carbohydrates, and sweets [41].

Fast foods typically lead to chronic-stimulating and inhibitory responses in the innate and acquired immune systems, respectively [42]. As an immune mechanism, activation of Toll-Like Receptor 4 (TLR-4), which is typically expressed on dendritic cells, neutrophils, and macrophages, can result from lipotoxic status induced by overuse of SFA [43]. Simultaneously with the stimulation of these elements of the immune system, various types of generation-responses are created to produce pro-inflammatory mediators and other responses affecting the innate immune system [44]. On the other hand, the increased penetration of macrophages into lung tissue, especially in the alveoli following the consumption of a High-Fat Diet (HFD) in the rat model, indicates an association between the consumption of this type of diet and immune function even away from the gastrointestinal tract [45]. In this regard, the results of the study by Siegers et al. confirmed the synergistic effect of HFD with the influenza A virus in causing cardiovascular damage in mice [46]. This is especially true for COVID-19 patients, which in acute cases a huge involvement of lung tissue and inflammation responses in the alveolar epithelial cells, and their damage are detectable [47]. It is noteworthy that the inhibition of the biological function of T and B lymphocytes in the adaptive immune system can follows the consumption of fast food and HFD, which usually triggers an increase in oxidative stress markers [48]. Looking deeper, HFD-induced oxidative stress disrupts immune function by inhibiting T and B cell proliferation and maturation and causing apoptosis in B cells. Hence, one of the vital pathways in protecting the host against viruses becomes ineffective [49].

In an intervention study in an animal model, it was observed that HFD aggravated the pathology of lung tissue stimulated by influenza infection following the suppression of adaptive immune responses [50]. Therefore, the unusual inclusion of fast foods in the diet of individuals, while disrupting the functioning of the adaptive immune system, becomes a chronic inflammatory factor and in turn reduces the host's resistance to viral diseases.

One of the key elements in the immune system responses in obese people is Interleukin (IL)-1ß [51]. The upregulation of this cytokine in lung tissue as well as activation of some proinflammatory markers and Nuclear Factor Kappa B (NF-κB) have been reported and confirmed in some animal studies [52, 53]. According to the results of recent studies, the association between the presence of fast foods in the diet of individuals and the development of inflammatory responses in lung tissue is mediated by pro-inflammatory cytokines such as IL-1β, IL-6, and NF-κB [54, 55]. Besides, it has been shown that during different stages of enteroviral infection, neutralization of IL-1β by the mechanism of reducing the inflammatory response prevents the creation and development of chronic viral myocarditis [56]. In the current pandemic situation, researchers are looking for a safe and specific chemical compound that can affect IL-1β signaling and reduce inflammatory pathways in people with COVID-19 [57]. Therefore, from the point of view of nutritionists and food safety experts, people in the community should reduce the presence of HFDs such as fast foods in their diet to suppress IL-1β expression and reduce the relevant pro-inflammatory processes, and this may be a desirable and available option in the existing pandemic situation. In this regard, the results of a study showed that the T and B cell populations in patients with an acute form of COVID-19 are significantly affected and reduced [58]; hence, unconventional and unhealthy diets may play a significant role in the pathogenesis of SARS-CoV-2 by weakening the function of the immune system as a negative environmental stimulus. Given that excessive consumption of fast foods increases the risk of obesity, it should also be noted that in obese people the response to antiviral and antimicrobial drugs is weaker and the response to vaccines is diminished [59, 60].

The production of high amounts of Trans Fatty Acids (TFA) in the fast-food matrix is one of the most unavoidable things during their production process. Consumption of such food products, especially in people with diabetes, is directly related to the production of pro-inflammatory mediators [61]. Also, the association between TFAs overdose and the risk of weight gain and abdominal obesity in all age groups has been shown in previous studies. It is noteworthy that there is also a consistent and direct link between TFAs and the increased risk of asthma and pneumonia. Therefore, it can be thought that abnormal intake of fast foods in the diet of people and excessive consumption of TFAs indirectly can intensify the inflammatory pathways in the lung tissue of people with COVID-19 and while increasing the complications of the disease, the response to treatment also decreases [62].

In a deeper look, it can be considered that fast foods can contain high amounts of toxic heavy metals for human hosts, especially children [63]. Chromium (Cr), Nickel (Ni), Lead (Pb), and Cadmium (Cd) are unnecessary elements for the physiology of the body, and depending on the amount received through different sources, they accumulate in their target tissues and consequently cause poisoning and inflammation [64]. As a clear example, lead can stimulate and initiate Mitogen-Activated Protein Kinase (MAPK) inflammation *in vitro* and *in vivo* by activating oxidative stress and miRNA-155 expression [65]. Cadmium is also a highly toxic compound and prolonged exposure through a wide range of sources can cause serious damage to host lung tissue [66]. In this regard, it was observed in a study that the presence of heavy metals such as mercury, lead, cadmium, and nickel in the diet of experimental mice, increases the mortality rate due to virus-induced encephalomyocarditis [67]. So far, the complex relationship between the presence of heavy metals in the various food matrices and infections caused by coronaviruses is not known, but from a food safety perspective, it is desirable that people in the community should limit the intake of fast foods in their daily diet, while reducing their intake of these toxic metals, also enhancing the immune system function against viral infections.

According to the results of clinical studies, the intestinal microbiome also plays an important role in creating and maintaining host homeostasis. It is noteworthy that the composition of the intestinal microbiota in each person is affected by her/his lifestyle and is also changed by factors such as diseases and daily diet. In this regard, in a study, it was observed that the inclusion of fast foods in the diet of experimental animals caused significant changes in the composition of the intestinal microbiome over a period of four days [68]. According to the results of the study by Mosquera et al., changes in the intestinal microbiome of antibiotic-treated or engineered mice caused chronic inflammation, which in turn reduced the immune response to nanopolymer vaccines [69]. It is noteworthy that the vaccination-induced dysfunctional immune response due to microbiota changes can be eliminated by a new immunomodulatory nanomaterial that agitates immune cells [70]. On the other hand, recent studies have highlighted the role of the gut microbiome in lung disease. In connection with respiratory infection caused by SARS-CoV-2, it has been shown that it has a negative effect on the microbiome composition of infected people and causes a kind of intestinal dysbiosis [71]. Zuo et al. in a pilot study of 15 patients with COVID-19, examined persistent changes in the fecal microbiome of patients during hospitalization compared with controls [72]. The results were interesting and showed that fecal microbiota changes were associated with fecal levels of SARS-CoV-2 and the severity of COVID-19. Due to the development of research tools and methods at the cellular and molecular level, it is now known that in addition to the activity of the intestinal microbiome, metabolites derived from them, such as short-chain fatty acids (butyric acid, propionic acid, acetic acid, and valeric acid), are involved in regulating the physiological activities of the host. Short-chain fatty acids can be considered as important mediators between intestinal microbiome and immune system elements that modulate T cell activity by various molecular mechanisms and also play a role in inflammatory pathways caused by viral infections [73]. In this regard, we can point to the positive activity of short-chain fatty acids in cases of animal allergic airway disease and human asthma, which are mainly related to their anti-Tumor Necrosis Factor-alpha (TNF-α) characteristics [74-76]. Although therapeutic evidence for short-chain fatty acids is being compiled. Therefore, it can be concluded that a high intake of fast foods in the daily diet may increase the consequences of the disease and reduce the response to treatment and vaccination by activating pro-inflammatory pathways and stimulating intestinal dysbiosis in patients.

THE ROLE OF FOOD BIOACTIVE COMPOUNDS IN SUPPORTING THE FUNCTION OF THE IMMUNE SYSTEM

According to clinical studies, bioactive compounds such as vitamins and folate, polysaccharides and dietary fiber, lipids, peptides, and natural polyphenols are abundant in fruits and vegetables, which play a known role in strengthening the immune system against viruses [77]. In this regard, we can mention some vegetables such as broccoli and citrus fruits such as kiwi, which contain large amounts of vitamin C (ascorbic acid) and can be involved in the repair of body tissues and proper immune function [78]. Also, in certain conditions, vitamin C can limit lower respiratory tract infections and prevent colds [79]. Other items include vegetables such as carrots, spinach, and sweet potatoes, which contain large amounts of vitamin A (including fat-soluble compounds such as beta-carotene, retinol, and retinoic acid). This vitamin, when administered at a drug dose or higher (10 nM or higher), due to its functional properties, participates in the regulation of humoral immune processes and cellular immune responses, and while strengthening the immune responses created, protects the host body against infections [80].

Bioactive peptides with a molecular weight of <3 and 3-10 kDa are composed of several amino acids that are arranged in different configurations and are usually obtained as the final fermentation product of milk treated with specific strains of *Lactobacillus plantarum* [81]. However, there are other animals and plant sources for bioactive peptides, including fish, eggs, meat, gelatin, cow blood, rice, pumpkin, mushrooms, sorghum, and soy peanuts. The fermentation process of various dairy and non-dairy products can also be considered as one of the most important routes for the production of bioactive peptides. As a practical example, a wide range of bioactive peptides can be produced during the fermentation process using lactic acid bacteria during cheese ripening. Also, some specific strains of *L. plantarum* have the ability to produce a variety of peptide fractions with anti-inflammatory activity [81]. Some probiotic strains, such as *L. gasseri* SBT2055 (LG2055), can reduce viral respiratory infections by suppressing virus replication. Outcomes exhibited that following the respiratory syncytial infection, LG2055 promoted the expression of IFN-γ and IFN-β at the gene level in the mice's lungs. Another investigation established that numerous lactic acid bacteria-stimulated small protein molecules are known as immune interferon (IFN-β or IFN-γ) in the mice's lungs, contributing to clearance of respiratory virus [82]. Furthermore, another study has revealed that *L. paracasei* strains co-cultured with the artichokes' phenolic extracts (4 mg/mL) possess anti-inflammatory activities on dendritic cells, signifying potential synergistic effects between different bioactive compounds [83].

Polysaccharides are polymers of complex carbohydrates that are always found in the matrix of various foods, including cereals and seaweed, and microorganisms such as lactic acid bacteria are also among the main factors producing polysaccharides. Polysaccharides have many bioactivities such as immunomodulatory, anticancer, antioxidant, antidiabetic, as well as renal and liver-protective functions. Nearly forty polysaccharides have been isolated and identified from oral and medicinal fungi during various studies. In addition, these investigations have revealed that polysaccharides from mushrooms have antivirus function versus an extensive variety of viruses, including enterovirus, herpes simplex virus, hepatitis B, rotavirus, porcine circovirus, influenza, and others. For example, polysaccharide peptide derived from *Coriolus versicolor'*s has been established to possess immunomodulatory characteristics with the capability to trigger a Toll-like receptor 4 showing insignificant toxicity [84]. One clarification for this antiviral function could be attributed to the restriction of adsorption and penetration of the virus. The polysaccharides derived from mushrooms displayed potential anti-HIV function via upregulating certain antiviral chemokines (Stromal Cell-Derived Factor-1 alpha, SDF-1α, and Macrophage Inflammatory Protein, MIP-1α/β) and downregulating replication of the virus. These chemokines block the coreceptors of HIV-1 in THP1 cells from leukemia patients and blood mononuclear cells [84].

Bioactive lipids include numerous endogenous molecules influencing an extensive array of biological processes. Typical examples of lipids include carotenoids, phytosterols, fat-soluble vitamins, phenolic lipids and acylglycerol derivatives, omega-3 fatty acids, and their metabolic products. Several investigations have found a relation between the intake of certain bioactive lipids and the prevention, delay, or treatment of acute/chronic disorders such as osteoporosis, cancer, cardiovascular disease, and immune dysregulation. The process of preventing inflammation is one of the possible protective mechanisms for biologically active lipids against viral infection. Bioactive lipids such as oleic acid have shown antiviral activity via stimulating leakage and even lysis of cell membranes including the virus lipid membrane. It is also known that these bioactive lipids demonstrate the phagocytic activity of macrophages and can facilitate the elimination of any harm by viral infection [85].

Polyphenolic compounds derived from plant foods, food processing by-products, and extracts possess significant antioxidant properties [86]. Polyphenolic compounds can be sectioned into phenolic acid, flavonoids, resveratrol, polyphenolic amides, and other polyphenols. These compounds are known as common natural antioxidants and also have antimicrobial and antiviral activity. Numerous recent investigations discovered the *in vitro* antiviral capacity of different polyphenols [87]. Besides, Vázquez-Calvo et al. performed a study associated with the effect of polyphenols (*e.g.*, epigallocatechin gallate, catechin, delphinidin, cyanidin, epicatechin, and epigallocatechin) on Zika, Dengue, and Nile viruses [88]. These enveloped plus-strand RNA viruses are usually transmitted by mosquitoes and therefore pose a serious health threat. The outcomes of this study exhibited that the aforementioned polyphenols that affected the connection and entrance step of the RNA into the host cells were dose-dependent in a 1-10 μM range and thus diminished the infectivity of the viruses.

The promising results of the mentioned investigations along with the well-documented role of food bioactive constituents in supporting the immune system and the supplementation of consumers' diets with bioactive lipids, polyphenols, vitamins, flavonoids, tannins, and herbs are driving current market growth trends in the food and nutraceutical sector. Besides, these trends will most likely remain to drive the market in the post-lockdown era [89]. The evidence from randomized population and clinical trials confirms the role of vitamin D versus COVID-19 disease. In addition, several theoretical investigations have recommended polyphenolic compounds (mostly flavonoids) as potential inhibitors of SARS-CoV-2 transmission. The potential for utilizing β-glucan to address COVID-19 has also been recommended by taking into account the variability in immune feedback rising from heterogeneity in polysaccharide branch and chain lengths of diverse origins. Scientists have suggested drinking plenty of water, along with intaking foods rich in minerals such as zinc and magnesium and vitamins D, C, and E, in addition to a better lifestyle that can increase immunity to help fight infection [90]. Given that these supplements can improve the functioning of the immune system at any stage, so the market outlook for nutrients and functional foods in the post-quarantine period is still high and this is a kind of consumer behavior to increase awareness. Businesses will thus be seeking to fill the demand for new knowledge surrounding consumer preferences, requirements, and attitudes toward nutraceuticals and functional foods in order to address the challenges and opportunities created by COVID-19 disease. The above-mentioned changes that are coming will also tend to inform or even accelerate innovation across the food industry ecosystem including advances in Internet and Communication Technologies (ICT) and manufacturing.

NOVEL FOOD PROCESSING METHODS UTILIZED TO REDUCE VIRAL LOAD

The conditions created during the design and production of Modified Atmosphere Packaging (MAP) are such that it significantly increases the shelf life of a wide range of foods, but the presence of safe and permissible gases in this technology does not show a noticeable effect on the inactivation of viral particles [91]. Today, various technologies including MAP, High-Pressure Processing (HPP), Pulsed Electric Field (PEF), Pulsed Light, Cold Plasma, or UV light are applied in the food industry to ensure food safety (especially fresh or high a_w foods). In addition to heat treatment, HPP and cold plasma can be good options for inactivating some food-borne viruses [92, 93]. According to the results of a study by Li et al., the HPP method can inactivate the human norovirus (HuNoV) by causing damage to its capsid structure [94].

Hepatitis A (HAV) contamination is common in seafood, and several investigations have described the effects of HPP or UV light treatment during shellfish depuration [91]. Kingsley and co-workers as reviewed by Kingsley (2013) have evaluated the influences of HPP on various nonenveloped enteric viruses in foods. Kingsley (2013) established that enteric viruses as nonencapsulated viruses require to become inactivated as a result of alterations in protein conformation [92]. This conclusion may follow the principle that intestinal viruses have no lipid-specific components and HPP is not effective in breaking covalent nucleic acid bonds. According to the results of Sánchez's study, HPP treatment at values above 400 MPa shows an appropriate response to HAV inactivation. Pulsed UV light or UV-C light treatments have also diminished HAV contamination in vegetables, fruits, and other foods [91]. It is noteworthy that in HPP and UV light treatment methods, as in other stability studies, virus inactivation depends on the chemical conditions (*i.e.*, food chemical composition, pH, etc.) of the environment in which it is located [91]. Also, according to the available evidence, studies on the effect of pulsed electric fields, ultrasound, and other emerging technologies on a variety of viral particles are very limited. In the case of irradiation technology, gamma radiation is also possible, but it should be noted that high doses of gamma radiation are always required, even in aqueous suspensions, for the effective decomposition of virions, which may have adverse effects on the sensory properties of the food product at the same dose [95]. Novel processing technologies would be applicable pretreatments before thermal processing, dehydration, freezing, and other food preservation to ensure virus inactivation and ensure minimal losses in food quality. Furthermore, the combination strategy in processes in the control of foodborne infections may display more usage in diminishing infection risks. On the other hand, the refrigerated temperature in calicivirus's HPP treatment has been unexpectedly found to enhance loss of virion infectivity [92]. HPP treatment parameters for virion inactivation also seem to vary substantially among various virus species.

Consequently, food-borne viral particles can be present in a variety of environments such as food, and water and usually show high stability. Fresh food products are usually contaminated with several uncoated intestinal viruses, which in most cases also show high resistance to inactivation [96]. It is noteworthy that the thermal process within the normal denaturation temperature range of the protein is often detrimental to the genomic elements and dramatically reduces the number of viruses and ensures food safety. Moreover, virions are structured to protect their genome outside infected cells. Loss of virus infectivity is a result of physicochemical changes and chemical reactions. Such changes and reactions include, for example, hydrogen bonding, electrostatic changes, dehydration, hydrophobic interactions, and molecular conformations. Thus, virus inactivation requirements are to be considered in a similar context as loss of nutrients or bioactive ingredients. Virion inactivation, however, requires to take into account virion stability in aerosols and droplets besides survival in food and surfaces. Little is known about the effects of water on virions' stability or loss of infectivity. Dehydration of virions in aerosols and droplets has similarities with spray drying but it may affect both virion stability and loss of infectivity. Kinetics of loss of virions infectivity suggest differences in inactivation mechanisms at lower temperatures below common pasteurization temperatures and higher temperatures applicable to pasteurization and thermal processing. Activation energies are little affected by virus strains which, however, show large differences in thermal processing needs [97]. Novel food processing technologies provide additional means to control viral food safety. HPP and cold plasma treatment are examples of new technologies which may be used in food pretreatment without compromising food quality before subsequent food preservation [98].

CONCLUSIONS

Consequently, it seems that the industrial approach of food processing may have advantages over the traditional manner in the prevention of primary or cross-contamination of COVID-19 due to the replacement of staff by machinery, reduction of direct contact with products, and preservation of nutritional value. In the case of food production/preparation units, ISO-22000 and HACCP guidelines are recommended to be implemented precisely. Also, different methods of preparing food or cooking should be implemented at temperatures above 60°C for at least 30 minutes. Besides, according to the positive effect of some food-based bioactive components in the reduction of viral (COVID-19) invasion to target sites hence, it is suggested that foods containing active elements such as postbiotics and probiotics can be used daily, as the role of these compounds in strengthening the immune system has been fully demonstrated [99, 100].

Conflict of interest
None to declare.

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