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Food Safety and Toxicity during Covid-19 Crisis

Behrouz Tajdar-oranj [a] | Parisa Sadighara [b] | Raziyeh Barzegar-bafrouei [c] | Pourya Pezeshgi [d] | Naiema Vakili Saatloo [e] | Vahide Oskoei [f] | Nader Akbari [b] | Sara Mohamadi [g] | Tayebeh Zeinali [h] *

a. Department of Food Science and Technology, School of Nutrition Sciences and Food Technology, Research Center for Environmental Determinants of Health (RCEDH), Health Institute, Kermanshah University of Medical Sciences, Kermanshah, Iran.
b. Department of Environmental Health, Food Safety Division, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran.
c. Department of Food Safety and Hygiene, School of Public Health, Shahid Sadoughi University of Medical Sciences, Yazd, Iran.
d. Student Research Committee, Maragheh University of Medical Sciences, Maragheh, Iran.
e. Food and Beverages Safety Research Center, Urmia University of Medical Sciences, Urmia, Iran.
f. School of Life and Environmental Science, Deakin University, Geelong, Australia.
g. Department of Food Hygiene and Quality Control, Faculty of Veterinary Medicine, Shahre-kord University, Shahre-kord, Iran.
h. Department of Nutrition and Food Hygiene, School of Health, Social Determinants of Health Research Center, Birjand University of Medical sciences, Birjand, Iran.

***Corresponding author:** Department of Nutrition and Food Hygiene, School of Health, Social Determinants of Health Research Center, Birjand University of Medical sciences, Birjand, Iran. Postal Code: 9717853577. E-mail: ta.zeinali@bums.ac.ir

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A B S T R A C T

The COVID-19 pandemic resulted in significant effects on individuals involved in various aspects of the food supply chain, including production, processing, marketing, transportation, and consumption. Recent findings have demonstrated the survival rate of the virus on food surfaces is limited to hours and it can remain viable for several days in the optimum moisture and temperature. Consequently, health organizations in many countries have encouraged the public to heat food before consumption. Food safety specialists declared that heating food is a proper approach to significantly inactivate viruses. It has been recommended that meat products must not be eaten raw or undercooked. However, the increased emphasis on reheating food at home, driven by consumer concerns regarding food safety, has introduced a new set of challenges. It is estimated that this trend may lead to a higher intake of chemically hazardous substances, especially polycyclic aromatic hydrocarbons, due to the potential formation of heat-induced toxicants. Accordingly, this phenomenon is projected to have significant negative effects on public health during the post-pandemic phase of COVID-19. This paper aims to shed light on the changes in household food preparation habits following the widespread transmission of the virus, while also addressing the concerns surrounding food chemical safety that have arisen as a result of reheating practices during the COVID-19 pandemic.

1. Introduction

Coronaviruses belong to the *Coronaviridae* family in the *Nidovirales* order and possess a size of 65-125 nm in diameter with a single-stranded RNA as a nucleic material [1]. In December 2019, an outbreak of a new pathogenic coronavirus known as *COVID-19* or *CoV-2019* emerged in Wuhan, the capital of Hubei Province in China, rapidly spreading across the world and becoming a significant global health threat [2, 3, 4] It was initially diagnosed in customers of a local seafood wholesale market [5]. Infected respiratory droplets from cough or sneeze and direct contact with the infected individuals have the leading role in transmitting the virus, which could cause severe respiratory failure with common symptoms of fever and cough [6, 7]. The long incubation period of this virus suggests a higher rate of

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transmission, particularly in asymptomatic patients [8]. Mota *et al.* (2021) reported that the number of infected people by COVID-19 has exceeded 274 million globally, with over 5 million deaths [9]. It is worth noting that an earlier outbreak within the *Coronaviridae* family occurred in 2002, known as the severe acute respiratory syndrome coronavirus (*SARS-CoV*) outbreak in Guangdong province of China [7, 10]. Additionally, a significant outbreak in 2012 originated in Saudi Arabia, referred to as the Middle East respiratory syndrome coronavirus (*MERS-CoV*) infection, which resulted in acute lung injury [11, 12]. On January 30, 2020, the World Health Organization (WHO) announced the outbreak of COVID-19 infection as a public health emergency of global issues [13]. To prevent the introduction of the disease to new areas, precautionary measures such as quarantine have been implemented to restrict movements and reduce human-to-human transmission [7]. One of those limitations that was imposed was quarantine periods. In this respect, most of the markets were closed by the government's decision, and limitations were carried out on meetings and trips outside. Households across the country were faced with drastic changes in many aspects of their lives [14]. All of these are throwing countries into an economic depression and an imbalance in food supply [15]. This pandemic has significant negative effects on people along the food supply chain (such as production, processing, marketing, transportation, and consumption). The Food and Agriculture Organization of the United Nations (FAO) is concerned about the possibility of a food crisis as a result of the virus and related limitations on food production, security, and the livelihoods of vulnerable families [16]. Given the uncertainty about the future trajectory of the pandemic, individuals have had to adapt their lifestyles and behaviors in response to the Covid-19 pandemic. In addition to quarantine measures, another precautionary measure was the heating of food before consumption, which was confirmed by food safety specialists as a proper preventive strategy to significantly inactivate viruses. Accordingly, individuals rapidly altered how they prepared their meals to ensure food safety. However, despite the benefits of this measure, concerns have been raised about the effects of reheating foods, as there have been instances of the formation and increase of harmful compounds during the preparation and consumption of reheated foods, such as aromatic cyclic hydrocarbons or amines, which pose potential risks [16-20]. Given these concerns, the current paper was designed to demonstrate how the habitual behaviors of households about preparing food were changed after the virus spread as well as explain the food chemical safety concerns that have arisen from reheating food during the COVID-19 pandemic.

2. Discussion

2.1 Food processing conditions to avoid viral contamination

To reduce the risk of exposure to microorganisms, particularly viruses, it is important to ensure that food processing conditions are optimized. Typically, cooking temperatures above 70 °C are effective in inactivating viral contaminants. However, it is important to note that transmission of viruses from frozen food is possible, as freezing and refrigeration only preserve the viruses; therefore, hand washing after handling raw food is necessary. This includes proper handling of raw animal products to avoid cross-contamination with other foods, washing vegetables and fruit before eating, and ensuring that food is cooked to the appropriate temperature [21]. Cooking methods that effectively destroy viral infectivity in most foods include reaching an internal temperature of at least 90 °C for a minimum of 90 seconds [22]. In addition, it is important to have proper hygiene practices in place, such as washing hands and surfaces often and separating raw meat, poultry, seafood, and eggs from ready-to-eat foods. Guidelines on the application of general principles of food hygiene to the control of viruses in food suggest that sources of viral contamination of food at the primary production site include water, soil, manures (not properly treated), sludge, or fertilizers contaminated by viruses [22].

2.2 Food Heat-Induced Chemical Toxins

Eating habits have changed due to the global prevalence of COVID-19 infection [23]. Concerns regarding safety of foods have resulted in the development of a new issue, namely the reheating of food at high temperatures or for long periods of time. International organizations have acknowledged that there is no evidence of COVID-19 transmission through food or food packaging [16-18]. However, precautions during food shopping may prevent viral transmission. Recent data suggestshat the COVID-19 virus can survive on plastic surfaces for 72 hours and on cardboard for up to 24 hours [16, 24]. The previous findings have indicated the survival rate of the virus is limited to hours on the food surface and could be viable for days in the optimum moisture and temperature [25]. In the research performed by Mullis *et al.* (2012), the stability of bovine coronavirus (distant relative to *SARS-CoV*) in household refrigeration conditions over the lettuce surfaces was investigated. Results showed that after 25 days viral plaques could be recovered [26]. Touching contaminated plastic surfaces of food packages by customers and then touching the mouth, nose, or eyes is also one potential way of transmission in the groceries [17]. As a result, the public has come to believe that touching food or food packaging handled by salesmen and buyers in the grocery can transmit the virus. Consequently, health organizations in all countries may encourage people to heat food before consumption. The Centers for Disease Control (CDC) have recommended cooking meat at the proper temperature (50-60 °C) and avoiding raw or undercooked meat [18, 27, 28]. Moreover, health authorities, particularly in countries where bread is a staple food, advise people to heat bread before eating it [28]. Also, food safety specialists declare that if people are concerned about their food, heating it at 65 °C for 3 min would substantially reduce the levels of any viruses [25, 28-30]. Table 1 shows the heat treatment inactivation of viral foodborne pathogens in some studies.

Accordingly, Darnell *et al.* (2004) supported the finding that thermal exposure above 65 °C could inactivate *SARS-CoV* [31]. Consequently, the application of microwaves, toasters, and stoves for reheating food has gained attention. It is noteworthy that the consumption of fried, canned, and frozen foods has increased compared to fresh food since the outbreak of the novel coronavirus [32]. Belgians and Canadians have been encouraged to consume more fried potatoes than fresh ones due to the higher temperatures involved in frying, which helps inactivate any viruses. Therefore over 750,000 tons of potatoes in Belgium and about 90,000 tons in Canada are at risk of spoilage and disposal [33, 34]. On the other hand, a fall in demand for other processed potato products has left potatoes at risk of spoilage and waste [33]. Besides, the COVID-19 pandemic impacts the online grocery delivery sector [35]. Based on Uber Eats, French fries are the most popular food delivered in the United States [32]. Frozen pizza sales have also doubled [36]. While COVID-19 is not a food-borne disease, food safety remains a significant concern. The authors believe that finding a solution to the increased use of thermal processes at home for destroying pathogens is crucial, as extensive heating can lead to the formation of toxic substances. While food is processed or cooked at high temperatures (higher than 150 °C), particularly meat and bakery products, chemical reactions occur between amino acids and diminishing sugars, called the Maillard reaction, which generates flavors and brown colors of foods [37]. Due to the reheating of food as an emerging habit, some food ingredients tend to form toxic substances through this reaction, such as polycyclic aromatic hydrocarbons (PAH), heterocyclic aromatic amines (HAA), and acrylamide (AA). Table 2 shows the thermal-induced toxins in some foods. These substances are regarded as harmful to human well-being. High consumption of fried and high-temperature cooked food may cause adverse toxicological effects on human health. Therefore, it is important to observe the time and temperature for reheating or preparing food. The production of these toxins is accompanied by changes in the aroma and color of food [38]. Recognizing these changes can inform the consumer of the formation of these toxins during cooking and prevent further formation of toxins. The main heat process-induced toxicants and their impact on flavor, color, and carcinogenicity risk are summarized as follows.

2.3 Polycyclic aromatic hydrocarbons (PAHs)

Intense heat treatments such as grilling, broiling, frying, barbecuing, toasting, and roasting of meat, fish, and other food products may form PAHs [39]. High temperatures of about 500-700 °C are confirmed as optimal conditions for PAHs creations, but it was observed that this might occur at lower temperatures in various sources [20]. High PAH concentrations have been reported in charcoal grille or barbecued foods, including fatty meat and meat products grilled under extended and extreme heat treatment conditions [19]. The International Agency for Research on Cancer [13] has considered PAHs in the list of pollutants because of their carcinogenic and mutagenic characteristics. For instance, Benzo (a) pyrene is genotoxic and belongs to group 1 carcinogenicity [40]. PAHs exposure may increase the risk of lung and stomach cancer. Benzo (a) pyrene has adverse and toxic health effects that impact cells and tissues, reproduction, development, and animals' immune systems [41]. Globally, PAHs' average intake is estimated in the range of 0.02 to 3.6 µg/person/day [42]. PAHs and their derivatives, such as nitro-PAHs or oxygenated PAHs, have shown smoke flavor [43].

2.4 Heterocyclic aromatic amines (HAAs)

HAAs are formed when high-protein foods, particularly meat products, are exposed to high temperatures [44]. HAAs are stratified into two categories: thermic HAAs, which are formed at temperatures between 100 and 300 °C, and pyrolytic HAAs, which are created through the pyrolysis of proteins and amino acids at temperatures higher than 300 ˚C [45, 46]. The International Agency for Research on Cancer (IARC) has classified 2-amino-3 methylimidazo [4, 5-f] quinoline (IQ) as a predictable carcinogen for humans (class 2A), and several types of HAAs, (class 2B) including 2-amino-3, 8-dimethylimidazo [4, 5-f] quinoxaline (MeIQx), 2-amino-3, 4-dimethylimidazo [4, 5-f] quinoline (MeIQ), and 2-amino-1-methyl-6-phenylimidazo [45-b] pyridine (PhIP), as possible human carcinogens [13]. Previous studies have demonstrated that HAAs can cause breast, stomach, colon, and pancreatic cancers [47-49]. The Council of Europe stated that HAAs intake should be below 1 µg per day [50]. During cooking, sugars and free amino acids react on the surface of the meat through the Maillard reaction, resulting in the formation of a diversity of new compounds, which are essential for the flavor and color of cooked meat and meat products. In a study by Gibis and Weiss (2012), the authors indicated that the preference for roasted flavor and color has essential roles in the high daily intake of HAAs [51]. Free amino acids, such as Cysteine, undergo various reactions through the Maillard reaction on the surface of meat, including heterocyclic compounds in their structure revealing strong-smelling notes, roasted and toasted foods, popcorn, and hazelnut aroma [52-54].

2.5 Acrylamide

Acrylamide is found in plant-based foods and cooked starchy foods, including potatoes, cereal, and bakery products, that are cooked at temperatures above 120 ˚C [55, 56]. The production of acrylamide increases in fried potatoes and foods with high carbohydrate content, including fructose and glucose [57]. By frying, deep-frying, and baking foods that were riched with carbohydrates, particularly foods with amino acid asparagine, acrylamide is formed [58]. Based on the European Food Safety Authority (EFSA), the amount of acrylamide in food ranges from under 30 µg/kg to 4700 µg/kg [59]. Previously published studies demonstrated acrylamide neurotoxicity, genotoxicity, carcinogenicity, and reproductive toxicity [60-63]. IARC categorized acrylamide as probably carcinogenic to humans (group 2A) [64]. Mercapto flavor compounds are sulfur-containing flavors that constitute the main flavor of onion, garlic, and sesame oil. In addition, mercapto flavors are spontaneously produced with acrylamide during the thermal processing of food via the Maillard reaction [65]. Therefore, mercapto flavor and acrylamide may coexist in thermally processed foods. The intensity of thermal processing may significantly affect the acrylamide content and food color. Extensive frying, in particular, can cause browning of the food and produce acrylamide.

Table 1. Heat treatment inactivation of viral foodborne pathogens

	Viral type	Food- samples	Kind of Heat treatment	Inactivtion	Reference
Rabenau *et al*, (2005)	SARS-CoV	Milk	60 °C for 30 min	complete inactivation	[66]
Gamble *et al*. (2021)	SARS-CoV-2 strain HCoV-19 nCoV-WA1-2020	cell culture (Dulbecco′ s modified Eagle medium cell culture medium)	70 °C heat under different procedures (Uncovered plate, oven; Covered plate, oven; Closed vial, oven; Closed vial, heat block)	Median Half-life of SARS-CoV-2; (minutes) Uncovered plate, oven: 37.04 Covered plate, oven 3.94 Closed vial, oven 0.91 Closed vial, heat block 0.86 0.09 1.77	[67]
Norouzbeigi *et al*. (2021)	SARS-CoV-2	toast bread hamburger sausages	microwave oven at power of 630 watt for either 30 s or 1 min 225 °C for about either 6 or 10 min cooking process at 78 °C for either 20 or 30 min.	Inactivation of viral load of 5.70 log fifty percent tissue culture infective dose (TCID50)/mL	[68]
Bhattacharya *et al*. (2004)	Hepatitis A Virus (HAV)	cell culture	70 °C for 15 min	94% reduction in infectivity	[69]
Bhattacharya *et al*. (2004)	Hepatitis A Virus (HAV)	cell culture	95 °C for 3 min	did not result in complete inactivation	[69]
Bidawid *et al*. (2000)	HAV	Skimmed milk-Homogenised milk-Cream	85 °C for 1 min	Approximate overall log decline in infectivity 6 in 1 min	[70]
Bidawid *et al*. (2000)	HAV	Milk	71.6 °C for 1 min	Approximate overall log decline in infectivity 2 in 15 sec	[70]
Hewitt and Greening (2006)	HAV	shellfish	Boiling 3 min	Approximate overall log decline in infectivity > 3.1	[71]
Hewitt and Greening (2006)	HAV	shellfish	Steaming 3 min	Approximate overall log decline in infectivity 1.5	[71]
Schielke *et al*., 2011	Hepatitis A Virus (HEV)	liver suspensions	Storage at 37 °C	Initial log decline 1.24 in 7 d. In 43 days no further decline was observed	[72]
Schielke *et al*., 2011	HEV	liver suspensions	60 °C for 60 min 95 °C for 1 min	3-4 log reduction	[72]
Luz and Miagostovich (2022)	norovirus genogroup II (GII)- murine norovirus 1 (MNV-1)	Tomato sauce and ground meat	tomato sauce: 72–74 °C for 1 min at water bath, simulating pasteurization. ground meat: a heating temperature of 100 °C in a drying oven for approximately 30 min	Success rate tomato sauce: GII: 37.5% MNV-1: 100% ground meat: GII: 62.5% MNV-1: 83.33%	[73]
Thomas and Swayne, 2007	avian influenza virus strain H5N1(AIV H5N1)	Chicken	70 °C for 5 s or 73.9 °C for 0.8 s	Log $_{10}$ inactivation: 11	[74]
Barnaud *et al*., (2012)	HEV	Pork meat	71°C for 20 min	Complete inactivation	[75]

Table 2. Thermal induced toxins in foods

	Toxin	foods		Measured amount	Reference
Hokkanen *et al.* 2018	Polycyclic aromatic hydrocarbons (PAHs): BaP and PAH4	meat	Smoking: 400 -600 ◦C	BaP (µg/kg) (Minimum-maximum) Large fish products: 0–4.9 Small fish products: 0–3.8 Pork products: 0–40 Other meat products: 0–6.8 PAH4 (µg/kg) (Minimum-maximum) Large fish products:0–26 Small fish products:0–21 Pork products: 0–200 Other meat products: 0–38	[76]
Ahmad *et al.* 2022	Acrylamide by HPLC	Bakery products (Pizza- Cakes- Muffins- Biscuits) Snack/fried products (Samosas- Pratha rolls - Chicken nuggets -Potato cutlets)	Baking: 170, 190 , 210 ◦C for 20 min Frying: 180 ◦C for 3 to 5 min	pizza (62.42 in 190◦C and 65.21 in 210◦C µg/kg); cake (71.21 in 170◦C and 81.19 in 190◦C µg/kg), and muffins (84.24 in 170◦C and 102.84 in 190◦C µg/kg), biscuits (126.52 in 170◦C and 151.52 in 190◦C µg/kg); paratha roll (165.92 in 4 min & 168.24 µg/kg in in 5 min), samosa (100.43 in 4 min & 121.29 µg/kg in 5 min), chicken nuggets (43.04 in 3 min & 48.27 in 4 minµg/kg), potato cutlets (135.71 in 3 min & 148.21 µg/kg in 4 min).	[77]
Ashouri *et al.* 2021	Acrylamide by GC-ECD (µg/kg)	fried potatoes under different oil (µg/kg)	Frying at 180 ◦C	Sunflower oil: 71.80±1.55 in 1 hour (h) 285.31±8.80 in 4 h; 692.03±5.25 in 7 h; 963.34±1.01 in 10 h. Soybean oil: 72.80±0.78 in 1 h; 301.98±10.53 in 4 h; 792.81±5.37 in 7 h; 1055.51±29.75 in 10 h. Canola oil: 57.40±1.39 in 1 h; 143.27±5.58 in 4 h; 320.40±4.64 in 7 h; 394.06±3.57 in 10 h; Frying oil: 60.11±0.51 in 1 h; 190.82±1.24 in 4 h; 340.21±33.97 in 7 h; 464.99±12.28 in 10 h.	[78]
Cieślik *et al.* 2020	Acrylamide by GC-MS (µg/kg)			Bread: 29.74±24.72 (Min-Max: 0.00-77.7) Fried fish preserves: 22.7±8.3 (9.11- 34.1) Cookies: 0.00±0.00 (0.00-0.00) Cheesecakes: 19.46±0.29 (19.0-20.1) Salty sticks: 44.55±11.66 (23.3-65.0)	[79]
Akbari-Adergani *et al.* 2020	Acrylamide by HPLC (mg/Kg)	Bread and potatoTahdig	cooked for 30 min at 180 °C	Sunflower oil: bread 7.33 ± 105.042; potato 8.55 ± 194.091 Corn oil: Bread 2.19 ± 72.603; potato 2.94 ± 103.97 Frying oil: Bread 17.6 ± 60.913 potato 3.73 ± 70.003 Canola oil: Bread 11.63 ± 49.606; potato 8.95 ± 65.78 Solid oil: Bread 3.35 ± 48.54; potato 5.4 ± 54.28	[56]
Choroszy and Tereszkiewicz, 2020	PAHs (included benzo(a)pyrene, chrysene, benzo(a)antracene and benzo(b)fluoranthe ne) by HPLC (µg/kg)	Sausage	Smoking; temperature in the furnace: between 600 and 850°C; duration of smoking: 4-5, 5-6, 6-7 and 7-8 hours	The concentration of PAHs in products with the smoking time of 6-7 and 7-8 hours was higher than the concentration observed in products with a shorter smoking time Benzo(a)anthracene: 11.17 and 14.19 µg/kg benzo(a)pyrene: 4.15 and 7.69 µg/kg benzo(b)fluoranthene: 4.99 and 7.75 µg/kg Chrysene: 9.85 and 10.77 µg/kg	[80]
Ledesma *et al.* 2014	Benzo(a)pyrene by GC-MS	Chorizo	smoking time (0, 1, 3, 5 and 7 days)	BaP content increases by increasing days of smoking until the 5th day (from < 0.24 µg/kg LOQ for 0 and 1 days of smoking to 0.37 ± 0.05, 0.75 ± 0.05 and 0.75 ± 0.05 for 3, 5 and 7 days of smoking, respectively).	[81]
Akbari-Adergani *et al.* 2021	PAHs by GC-MS (µg/kg)	Bread and potatoTahdig	cooked for 30 min at 180 °C	Sunflower oil: bread 17.9 ± 1.2; potato 68.9 ± 6.2 µg/kg Corn oil: Bread 42.6 ± 19.2 ; potato 59.2 ± 1.9 µg/kg Frying oil: Bread 165.6 ± 5.9; potato 291.1 ± 9.1 µg/kg Canola oil: Bread 550 ± 3.9; potato 220 ± 17.8 µg/kg Sesame oil: Bread 366.4 ± 13.2; potato 408.3± 4.1 µg/kg Solid fat: Bread 70.7 ± 10.1; potato 58.6 ± 4.1 µg/kg	[82]

3. Conclusion

Since the WHO's announcement of the COVID-19 pandemic, international authorities have constantly declared that the disease is not a food-borne infection. However, there has been an increased focus on food safety among the general population. It seems that the cooking method, duration, and internal temperature of food may be important to the inactivation of HAV, NoV, and other viruses. Food safety specialists have stated that people can heat food at 65 °C for 3 min to inactivate viruses and significantly ensure food safety. However, there is a concern that due to the fear of COVID-19 infection, extensive reheating of food may lead to the formation of carcinogenic compounds. It is estimated that the intake of chemically hazardous substances, including polycyclic aromatic hydrocarbons, heterocyclic aromatic amines, and acrylamide may increase as a result. Consequently, it is possible to increase the cancer rate in the post-pandemic phase. Therefore, the authors recommend a general awareness of food heating time and temperature and the consequences of food reheating.

Authors' Contributions

Behrouz Tajdar-oranj: Writing-original draft. Parisa Sadighara: conceptualization and project administration. Raziyeh Barzegar-bafrouei: Methodology and Investigation. Pourya Pezeshgi: Methodology and Investigation. Naiema Vakili Saatloo: Writing-original draft. Vahide Oskoei: Methodology and Investigation. Nader Akbari: Methodology and Investigation. Sara Mohamadi: Writing-original draft; Writing -review & editing. Tayebeh Zeinali: Writing-review & editing. All authors verified the last version.

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Conflicts of Interest

The authors declare no conflict of interest.

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Ethical considerations

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