Transmission of SARS-CoV-2 on Cold-Chain Food: Precautions Can Effectively Reduce the Risk

Meiyue Guo1 · Junfeng Yan1 · Yuan Hu1 · Lu Xu1 · Jinling Song1 · Kun Yuan1 · Xiangru Cheng1 · Sui Ma1 · Jie Liu1 · Xianbing Wu1 · Lielang Liu2 · Shuang Rong3 · Di Wang1,4

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Abstract
The COVID-19 pandemic has generated a new era in the world, also in the food safety. Up to now, there is no evidence to suggest that people can infect COVID-19 via food contaminated by SARS-CoV-2. Here, we analyzed the results of regular SARS-CoV-2 nucleic acid testing of considerable cold-chain food practitioners, cold-chain food surfaces, and their internal or external packaging as well as their associated environments, aiming to explore the risk of cold-chain food being contaminated by SARS-CoV-2 and the probability of people infecting COVID-19 through contaminated cold-chain food in the context of COVID-19 epidemic. This study found that only two batches of cold-chain food were contaminated by SARS-CoV-2, none of the cold-chain food handler were infected due to effective regulatory measures for cold-chain food. Therefore, effective supervision and preventive methods could effectively reduce the transmission risk of SARS-CoV-2 on cold-chain food.

Keywords COVID-19 · SARS-CoV-2 · Cold-chain food · Transmission risk

Abbreviations
COVID-19 Coronavirus disease 2019
FAO Food and Agriculture Organization
FSMS Food Safety Management Systems
HACCP Hazard Analysis and Critical Control Point
RT-PCR Reverse transcription polymerase chain reaction
SARS-CoV-2 Severe acute respiratory syndrome coronavirus-2
USDA United States Department of Agriculture
VOC Variant of concern
WHO World Health Organization

Introduction
At the end of December 2019, coronavirus disease 2019 (COVID-19) caused by severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) broke out and became a public health emergency worldwide (Eurosurveillance Editorial, 2020; Gorbalekya et al., 2020; Zhu et al., 2020). More than 225 million confirmed cases including 4.6 million deaths have been reported as of September 15, 2021 (https://covid19.who.int). SARS-CoV-2 is the member of the coronavirus family belonging to the genus Betacoronavirus and the only one with a high infection rate in humans (Yang & Wang, 2020), with fever and cough, influenza-like symptoms, the primary and the most prevalent of COVID-19 infection (Li et al., 2020).

In respect of the transmission, SARS-CoV-2 spread principally through person-to-person transmission by direct
contact with respiratory droplets released from an infected individual or aerosols with virus suspended (Bourouiba, 2020; Chan et al., 2020; Tang et al., 2020). Other possible routes of transmission include surfaces contaminated by droplet or aerosols (Van Doremalen et al., 2020) or the fecal–oral route (Gu et al., 2020). It has been identified that SARS-CoV-2 can survive on inanimate surfaces and objects, which implies that people may be infected via their eyes, noses, and mouths after touching these fomites by hands. The World Health Organization (WHO) and Food and Agriculture Organization (FAO) stated that “It was extremely improbable that people could be infected with COVID-19 from food or food packaging (WHO–FAO, 2020).” In a recent survey conducted by Faour-Klingbeil et al. (2021), it has been shown that 70% of the 1074 subjects surveyed in Lebanon, Jordan, and Tunisia were worried about the possibility that SARS-CoV-2 could be transmitted through contaminated foods. Moreover, the perception of risk was even higher when considering transmission by touching contaminated surfaces and being exposed to infected people during shopping.

Since the beginning of July 2020, multiple incidents about imported food contaminated by SARS-CoV-2 have been reported in China, mostly on their packaging materials (Han et al., 2020). The risk of cold food supply chain in the global epidemic cannot be ignored (Han & Liu, 2021). From the beginning of July 2020 to January 26, 2021, 51 positive SARS-CoV-2 nucleic acid cases from the 1369,666 tested imported cold-chain foods have been reported in China, mostly on their packaging materials and fish and beef accounted for the largest proportion (https://www.jiemian.com/article/5644680.html). Moreover, in the Xinfadi agricultural produce wholesale market in Beijing, SARS-CoV-2 was detected on a cutting board used for processing imported salmon, from which cold-chain food contamination was considered as the possible origin of this COVID-19 resurgence (Global Times, 2020; Pang et al., 2020). After that, the live COVID-19 virus was first successfully isolated and cultured from samples taken from imported frozen seafood packaging (Liu et al., 2020), which raised an alarm that fomites might be as viral vectors for SARS-CoV-2 transmission and “material-to-human” transmission might be possible for the COVID-19 (Yuan et al., 2020).

In our previous study, SARS-CoV-2 nucleic acid amplification test results for the 601 batches of frozen food were negative (Guo et al., 2021). Though Sobolik et al. (2021) reported that the risk of SARS-CoV-2 transmission via fomite was low, even in cold-chain, the epidemiological evidence is still urgent for the regular epidemic prevention and control. Therefore, we designed the present study to analyze regular SARS-CoV-2 nucleic acid testing results of considerable cold-chain food practitioners, cold-chain food surfaces, and their internal or external packaging as well as their associated environments, aiming to explore the risk of cold-chain food being contaminated by SARS-CoV-2 and the probability of people infecting COVID-19 through contaminated cold-chain food in the context of COVID-19 epidemic. Meanwhile, it is also urgent to provide guiding opinions or direction to ensure the safety of cold-chain foods and the health of related practitioners and formulate safety precautions to prevent the localized outbreak epidemic caused by the imported cold food supply chain at any time.

### Experimental

#### Data Collection

The study was conducted in Xiangyang city, the second largest city located in Hubei province, P.R. China, which is 350 km far from Wuhan city. The information on COVID-19 pneumonia cases from January 21, 2020 was collected from Xiangyang Center for Disease Control and Prevention. A pneumonia case was defined as a laboratory-confirmed 2019-nCoV infection case with related respiratory symptoms and direct contact with patients. Detailed epidemiological investigations including clinical symptoms, family information, job occupation, contact history, and active trajectory were collected in all of 1,175 confirmed cases.

#### Sample Collection

All samples were collected from November 19, 2020 to February 28, 2021. A total of 2,039 cold-chain food handlers, respectively, worked in different locations including 45 trade markets, 96 supermarkets, 3 logistics companies, 16 cold storages, and more than 300 restaurants or food companies were recruited in this study. Clinical symptoms such as body temperature, cough, and diarrhea were recorded every day. Importantly, nasopharyngeal or oropharyngeal swabs were collected to detect SARS-CoV-2 nucleic acid once a week. Every batch of cold-chain foods’ surface and their internal or external packaging were selected to make spot checks for SARS-CoV-2 RNA, including meat, seafood, fresh water products, refrigerated drinks, fruits, and vegetables. All of cold-chain food and environmental surface samples were collected using dacron swabs moistened with virus preservation solution to smear the surface (with an area of at least 100cm²) of cold-chain food or material 5 times horizontally and vertically and put the swab into a virus preservation tube containing 6 mL virus preservation solution, which were transferred on ice to the laboratory, kept refrigerated at 4 °C, and detected within 12 h. No more than 10 swabs could be put in one tube and 200 μL virus preservation solution was taken for extracting virus RNA.
Reverse Transcription PCR (RT-PCR)

Reverse transcription PCR (RT-PCR) was conducted, using procedures recommended by the Chinese Center for Disease Control and Prevention. Briefly, the SARS-CoV-2 nucleic acid detection kits (Shanghai BioGerm Medical Technology Co., Ltd, China) were used to extract viral RNAs. Viral RNA was detected by TaqMan real-time RT-PCR (RT-qPCR) on LightCycler® 480 II instrument (Roche Diagnostics, Germany) with LightCycler® 480 Software 1.5 for all reactions. Two different targets on the SARS-CoV-2 genome (the ORF1ab and N genes) were detected by commercial diagnostic kits (DAAN Gene Co., Ltd, China). The sequences of primer and probe for the ORF1ab and N genes are shown in Table 1. The PCR cycling protocol consisted of reverse transcription at 50 °C for 15 min, pre-denaturation at 95 °C for 15 min, 45 cycles of denaturation at 94 °C for 15 s, and annealing and extension at 55 °C for 45 s in a 25-μL reaction system. The $C_t$ value of the amplification curve was defined as positive if less than 40 and negative if greater than 40. Both positive controls and negative controls were routinely included in each test.

Genome Sequencing

The suspected positive environmental smear swab samples were sent to Hubei Provincial Center for Disease Control and Prevention and adopted Next-generation sequencing technology for genome sequencing. All samples were sequenced on an Illumina MiSeq platform using a 300-cycle MiSeq V2 Reagent Kit.

Statistical Analysis

All data were analyzed by SPSS 15.0 software. Differences in the infection rates of COVID-19 were assessed using Chi-Square tests and/or the Fisher’s exact test. The $P$ values smaller than 0.05 were considered statistically significant.

Table 1 Primer and probe sequences of target genes for SARS-CoV-2

| Target       | Sequences(5′–3′)                  |
|--------------|----------------------------------|
| ORF1ab gene  | CCCTGTGGGTTTACACTTAA             |
| Forward primer| ACGATTGTCATCGCTGA                 |
| Reverse primer| FAM-CCGTCGTGGTATGGAAAGGTTATG-BHQ1 |
| Probe        | GGGGAACCTTCTCCTCGCTAGAAT          |
| N gene       | CAGACATTTTTGCTCTCAAGCTG          |
| Forward primer| FAM-TTGCTGCTTGACAGATT-TAMRA      |
| Reverse primer|                                 |
| Probe        |                                 |

Results and Discussion

Results

A total of 1,175 confirmed COVID-19 cases were diagnosed in Xiangyang city between January 21, 2020 and March 15, 2020. There are 5.6 million people in Xiangyang and the occupation distribution of the 1,175 confirmed COVID-19 cases is shown in Table 2, including food handler ($n=20$), cold-chain food handler ($n=1$), health care worker ($n=34$), police ($n=2$), teacher ($n=36$), student ($n=31$), civil servant ($n=101$), farmer ($n=271$), factory practitioner ($n=105$), and others ($n=574$). The overall prevalence of COVID-19 was 0.0021%, and the prevalence in food handler was 0.020% ($n=1$, $P>0.05$). Based on the epidemiological investigation, none of cold-chain food handlers diagnosed with COVID-19 in our study had ever been in contact with SARS-CoV-2 contaminated cold-chain food before getting sick. Epidemiological investigation results showed that

Table 2 Data on characteristics of COVID-19 cases in the area of study

| Occupation                  | Total in Xiangyang, No. | Infected case, No. (%) | $P$ value |
|-----------------------------|-------------------------|------------------------|-----------|
| Total                       | 5600,000                | 1175 (0.021)           |           |
| Food Handler                | 687,000                 | 20 (0.003)             | <0.001    |
| Cold-chain food handler     | 4,935                   | 1 (0.020)              | 0.972     |
| Health care worker          | 44,160                  | 34 (0.077)             | <0.001    |
| Police                      | 9,000                   | 2 (0.022)              | 0.935     |
| Teacher                     | 82,600                  | 36 (0.044)             | <0.001    |
| Student                     | 960,000                 | 31 (0.003)             | <0.001    |
| Civil servant               | 74,458                  | 101 (0.14)             | <0.001    |
| Farmer                      | –                       | 271 (–)                | –         |
| Factory practitioner        | –                       | 105 (–)                | –         |
| others                      | –                       | 574(–)                 | –         |

All data were collected from Xiangyang Center for Disease Control and Prevention

"–" Indicated that the number was not counted
the most important pathogenetic factor was “human-to-human” in Xiangyang COVID-19 transmission. There was no evidence that the cold-chain food handler got infected with COVID-19 from cold-chain food contaminated with SARS-CoV-2.

In the study, a total of 2,039 cold-chain food handlers who came from different working places were recruited. Their nasopharyngeal or oropharyngeal swabs were collected to detect SARS-CoV-2 nucleic acid once a week for 16 weeks. As shown in Table 3, we analyzed 20,325 times SARS-CoV-2 nucleic acid results about cold-chain food handlers, and no positive specimen was detected.

We further detected a total of 9,354 batches cold-chain food-related environmental specimens for SARS-CoV-2, including 4,708 batches of dining utensils, 1,933 batches of supermarket environment, 1,543 batches of food freezers or fish tanks, 1,032 batches of sewer or fire hydrant, and 138 batches of clothing for food workers (Table 4). The results of SARS-CoV-2 RNAs detection in different food-related environments were all negative.

In order to ensure the safety of cold-chain foods as much as possible, a total of 23,187 batches of various cold-chain foods with different sources and different business premises were detected for SARS-CoV-2 RNAs, shown in Table 5. The 23,187 batches of cold-chain foods consisted of 13,859 batches of meats, 3,483 batches of seafoods, 2,973 batches of fresh water products, 1,661 batches of refrigerated drinks, 1,046 batches of fruits, and 164 batches of vegetables, which were sold in different business premises such as restaurant, wholesale market, supermarket, freezer, and fresh retail store. The original place of these cold-chain foods covered Asia, Africa, North America, South America, Europe, and Oceania. The detection results indicated that SARS-CoV-2 was found on the outer packaging of two batches of cold-chain foods. One was frozen raw South American white shrimp from Guayaquil, Ecuador stored in the freezer, and the other was frozen boneless beef steak from Argentina also stored in the freezer. In terms of the SARS-CoV-2 detection results of RT-PCR, the frozen raw South American white shrimp was positive just in N gene ($C_t$ value: 37.65) and the frozen boneless beef steak was both positive in N gene ($C_t$ value: 37.12) and ORF1ab gene ($C_t$ value: 38.02).

Given the discovery of cold-chain foods positive for SARS-CoV-2, the relevant close contacts, cold-chain foods, and environment were immediately sampled and tested for SARS-CoV-2. There were 78 close contacts, 65 cold-chain foods, and 10 environments related to the frozen raw South American white shrimp as well as 10 close contacts, 551 cold-chain foods, and 23 environments related to the frozen boneless beef steak, which were all not detected for SARS-CoV-2 RNAs (Table 6).

To further identify the type of new coronavirus on the outer packaging of the frozen boneless beef steak, its smear swabs were sequenced and analyzed with three parallels. The sequencing results showed that the three frozen beef outer packaging smear swab samples all had low coverage and completeness of new coronavirus sequences. Alpha new coronavirus mutant (B.1.1.7), Beta new coronavirus mutant (B.1.351), Gamma new coronavirus mutant (P.1), or Delta new coronavirus mutant (B.1.617.2) were not detected (Table 7). It was not possible to determine the VOC of the virus strain due to the poor quality of the genome sequence. The phenomenon indicated that there might be weak virus, dead virus, or virus fragments on the surface of cold-chain food, which could be detected for SARS-CoV-2 RNAs.

**Table 3** Results of SARS-CoV-2 RNAs detection of cold-chain food handlers from different working places

| Working place of cold-chain food handlers | Total, number of testings | Positive, No |
|------------------------------------------|---------------------------|--------------|
| Total                                    | 20,325                    | ND           |
| Restaurant                               | 9310                      | ND           |
| Supermarket                              | 5092                      | ND           |
| School and other unit canteens           | 2709                      | ND           |
| Agricultural market                      | 1163                      | ND           |
| Freezer                                  | 1133                      | ND           |
| Food companies                           | 448                       | ND           |
| Braised vegetable shop                   | 233                       | ND           |
| Fresh seafood shop                       | 118                       | ND           |
| Food logistics chain                     | 74                        | ND           |
| Others                                   | 45                        | ND           |

ND not detected

“Number of testings” represents the total number of testings. In this study, 2,039 cold-chain food handlers coming from different working places were collected nasopharyngeal or oropharyngeal swabs to detect SARS-CoV-2 nucleic acid for 20,325 times in total.

**Table 4** Results of SARS-CoV-2 RNAs detection in different cold-chain food-related environments

| Food-related environments                | Total, No | Positive, No |
|------------------------------------------|-----------|--------------|
| Total                                    | 9354      | ND           |
| Dining utensils                          | 4708      | ND           |
| Supermarket environment                  | 1933      | ND           |
| Food freezers or fish tanks              | 1543      | ND           |
| Sewer or fire hydrant                    | 1032      | ND           |
| Clothing for food workers                | 138       | ND           |

ND not detected

Discussion

In our study, none of the confirmed COVID-19 cases in Xiangyang were related to contaminated food. Only two
batches of cold-chain food outer packaging samples were positive for SARS nucleic acid in a large number of routine tests about cold-chain food workers, cold-chain food, and cold-chain environments. In addition, the personnel and environment in close contact with the positive cold-chain food outer packaging were all negative. Overall, the risks of cold-chain food being contaminated by SARS-CoV-2 and food handlers being infected with COVID-19 due to contaminated food were low in Xiangyang city.

It is well known that individuals may be infected with COVID-19 indirectly by touching a contaminated surface before touching their mouth, nose, or their eyes (Cai et al., 2020).

**Table 5** Results of SARS-CoV-2 RNAs detection in cold-chain foods with different sources and business premises

| Sample characteristics | Total, No | Positive, No |
|------------------------|-----------|--------------|
| Classification         |           |              |
| Total                  | 23,187    | 2            |
| Meat                   | 13,859    | 1            |
| Seafood                | 3483      | 1 (Single gene positive) |
| Fresh water product    | 2973      | ND           |
| Refrigerated drink     | 1661      | ND           |
| Fruit                  | 1046      | ND           |
| Vegetable              | 164       | ND           |
| Source                 |           |              |
| Total                  | 23,187    | 2            |
| China                  | 13,525    | ND           |
| Asia (excluding China) | 4245      | ND           |
| Africa                 | 67        | ND           |
| North America          | 425       | ND           |
| South America          | 2576      | 2            |
| Europe                 | 1875      | ND           |
| Oceania                | 473       | ND           |
| Business premises      |           |              |
| Total                  | 23,187    | 2            |
| Restaurant             | 7840      | ND           |
| Wholesale Market       | 2965      | ND           |
| Supermarket            | 3621      | ND           |
| Freezer                | 6283      | 2            |
| Fresh retail store     | 2477      | ND           |

*ND* not detected

**Table 6** Results of SARS-CoV-2 RNAs samples in close contacts, cold-chain foods, and environments related to the frozen raw South American white shrimp and the frozen boneless beef steak

| Problematic cold-chain food | Related samples | Total, No | Positive, No |
|----------------------------|-----------------|-----------|--------------|
| the frozen raw South American white shrimp | Close contacts | 78 | ND |
| Cold-chain foods | 65 | ND |
| Environments | 10 | ND |
| the frozen boneless beef steak | Close contacts | 10 | ND |
| Cold-chain foods | 551 | ND |
| Environments | 23 | ND |

*ND* not detected

**Table 7** The sequence results of frozen boneless beef steak outer packaging smear swab

| Sample name | Sample type | Coverage (%) | Analysis of VOC mutations in new coronaviruses |
|-------------|-------------|--------------|---------------------------------------------|
| Frozen outer packaging smear swab-01 | Environmental smear swab | 63.38 | Alpha B.1.1.7 Beta B.1.351 Gamma P.1 Delta B.1.617.2 |
| Frozen outer packaging smear swab-02 | Environmental smear swab | 65.83 | – – – – |
| Frozen outer packaging smear swab-03 | Environmental smear swab | 23.32 | – – – – |

*Alpha, Beta, Gamma, Delta” is the WHO recommended nomenclature for new coronaviruses and “B.1.1.7, B.1.351, P.1, B.1.617.2” is the Pango lineage nomenclature for new coronaviruses

“–” indicates that sufficient valid gene sequences were not detected to perform genotype analysis

“Coverage” means that the sequence obtained by sequencing accounts for the proportion of the entire genome sequence
The potential infectivity through contaminated cold-chain foods and the risk of cold-chain foods as remote carriers and transmitting media of COVID-19 are gaps in the current knowledge of the transmission of respiratory viruses. The review summarized all literature on COVID-19 and food industries from the beginning of the crisis to June 5, 2020, and concluded that infected food workers may spread the virus through person-to-person transmission rather than from and to contaminated food or food packaging material (Nakat & Bou-Mitri, 2021). Food contaminations may occur in any procedure of the food supply chain, including pre-, and post-harvest, production, distribution, and even before consumption (Mousavi Khaneghah et al., 2020). Contamination of foods may happen via three routes, including within the food processing, infected food staffs, and ingestion of animal-based foods that have a zoonotic virus (Yekta et al., 2021). It can be implied that the SARS-CoV-2 RNA detected on the surface of cold-chain food samples most likely originated from an infected food handler’s droplets expelled from their breathing, coughing, singing, sneezing, or talking somewhere along the processing chain in the facility, before packaging. Consequently, there is a hypothetical route of transmission that the contaminated cold food or food packaging material can transmit the virus, and an infected worker will spread the virus through “person-to-thing-to-person” (Han & Liu, 2021). However, it should be noted that SARS-CoV-2 identification is often achieved by rapid and sensitive molecular methods to detect viral RNA, but does not necessarily give any information on its infectivity (Rose-Martel et al., 2021). Moreover, the infectivity potency on food and food packaging of CoVs declines as time goes by (Li et al., 2021) and the chance of transmission through inanimate surfaces are very small (Goldman, 2020). Neither epidemiological data nor case reports of clear foodborne transmission proved that some human respiratory viruses, particularly human coronaviruses had the ability to spread via food (O’Brien et al., 2021).

In the context of the global COVID-19 epidemic, the foreign epidemic situation is severe, and cold storage and freezing temperatures will prolong the survival time of SARS-CoV-2 (Chin et al., 2020). Therefore, imported cold-chain foods should be strictly checked and treated with caution. The research in this article found that the risk of cold-chain food being contaminated by SARS-CoV-2 was low, and no relevant food handlers have been infected with COVID-19 due to contaminated food, benefiting from effective government regulation. In order to prevent the outbreak and control the spread of the SARS-CoV-2 virus in the cold food supply chain, it is imperative for the relevant government departments to formulate the epidemic regulatory system, regulatory process, and traceability system. The regulatory authority has carried out effective control for cold-chain food in terms of personnel, material, and geography (Fig. 1). The overall requirements are full coverage of sampling, full testing of samples, full decontamination of packaging, and full traceability of products.

For consumers who buy imported cold-chain food at wholesale or retail, it is necessary to implement the real-name registration system. Food operators should record the sales of imported cold-chain food and register the name of imported cold-chain food, sales time, purchaser’s name, purchaser’s ID number and contact information, purchase

![Fig. 1 Government interventions for cold-chain food in terms of personnel, material, and geography](image-url)
quantity, and other relevant information, so that the source of imported cold-chain food can be checked and the destination can be traced. For cold-chain food workers, especially those who have direct contact with commodities outside China and in medium- or high-risk areas, their health management systems include the following: 1. Implement the health access system for employees and cold-chain food practitioners need to hold a negative report of SARS-CoV-2 nucleic acid test within 7 days; 2. Enforce daily health monitoring of the practitioners; 3. Do a good job in the registration and management of outsiders; 4. Establish an employee risk exposure information account system; 5. Clarify the procedures for reporting health abnormalities; 6. Clarify the procedures for returning employees to work; 7. Strengthen the publicity of prevention and control knowledge; 8. Be well-trained in emergency response to health conditions.

In China, it is compulsory for market entities to report to the local market supervision department before purchasing imported cold-chain foods. For imported cold-chain food entering the sales, customs quarantine certificates, customs clearance certificates, sterilization certificates, and nucleic acid test reports (including products, environment, and workers) must be checked. To ensure that the source can be traced and the whereabouts can be tracked, operators of imported cold-chain foods should record the product name, place of origin, quantity, imported product information, whereabouts, contact person, telephone number, etc. in detail. Preventive disinfection, as well as sampling and testing in proportion, must be carried out on outgoing and incoming imported cold-chain food. Management measures during storage are strictly implemented and it is very necessary to strengthen the assessment of disinfection effects, ensure disinfection effectiveness, and avoid risks and hidden dangers.

During the transportation and the storage of imported cold-chain food, the carrier cannot open the food container. The transportation management department should supervise and guide the cold-chain logistics enterprise to strictly inspect the customs quarantine certificate, customs clearance certificate, disinfection certificate, and SARS-CoV-2 nucleic acid test report (including products, environment, and employees). It is recommended that the transportation vehicles of cold-chain foods should be disinfected and nucleic acid test for cold-chain environment should be carried out once a week.

The results prove that it is necessary for the relevant government departments to formulate the epidemic regulatory documents, operation process, and traceability system, which has been proved to be highly efficient in China.

In some international institutions, their primary protection against contracting COVID-19 from food is to follow good hygiene practices such as America (USDA, 2020), Canada (Government of Canada, 2021), and WHO (WHO–FAO, 2020). It is recommended that other countries conduct nucleic acid testing for SARS-CoV-2 appropriately before products enter the market to assure a maximal protection. Although the appearance of SARS-CoV-2 variant Omicron (B.1.1.529) caused panic responses around the world because of its high transmission rate and number of mutations (Ren et al., 2022), no cases about Omicron (B.1.1.529) found in cold-chain food have been reported up to now. We have been constantly doing the regular SARS-CoV-2 nucleic acid testing for cold-chain food and we do not find Omicron (B.1.1.529) in cold-chain food as of press time. It can be speculated that our data are compatible with the current Omicron epidemic.

Although many publications pointed out that infection risk from SARS-CoV-2 through contaminated foods and packaging is very low (Anelich et al., 2020; Ceylan et al., 2020; Hakovirta & Hakovirta, 2020; Olaitam et al., 2020), consumers and food practitioners are still worried about the food safety under the background of COVID-19 pandemic. For the purpose of managing food safety risks and the chances of food contamination, the food industry should strictly follow the Food Safety Management Systems (FSMS) based on the Hazard Analysis and Critical Control Point (HACCP) principles (Djekic et al., 2011; Tomasevic et al., 2016). Food companies should improve food safety and staff management, including temperature monitoring, sickness reporting, sanitization, and so on to maintain a virus-free working environment (Chowdhury & Nandi, 2021). Importantly, food practitioners should wear protective equipments such as masks and gloves and avoid touching their face, eyes, nose, or mouth with hands when contacting frozen imported products to effectively fight COVID-19 (Mitze et al., 2020). Moreover, employees should keep social distance and be screened for the nucleic acid of SARS-CoV-2 (at intervals of at least 14 days) to find the infected persons and control the epidemic as soon as possible (Ji et al., 2021), especially cold-chain food handlers. Our previous study found that the risk of microbial contamination in packed food could be reduced by effective precautions (Wang et al., 2010). Furthermore, the environment of the cold-chain industry should be tested and disinfected regularly, and the imported cold-chain products and their packaging should be sampled and tested to find the contaminated product on time (Ji et al., 2021).

**Conclusions**

By analyzing the results of regular SARS-CoV-2 nucleic acid testing of considerable cold-chain food practitioners, cold-chain food surfaces and their internal or external packaging as well as their associated environments, it showed that the risk of cold-chain food being contaminated by SARS-CoV-2 was slight and the likelihood of infecting
COVID-19 via contaminated food or food packaging was low, which benefited from government’s effective regulatory measures for cold-chain food.

Consequently, the supervision of imported food should be strengthened, especially the detection and monitoring of SARS-CoV-2 nucleic acid in imported cold-chain food. It is imperative for the relevant government departments to establish a scientific and routine entry testing mechanism and formulate the epidemic regulatory system, regulatory process, and traceability system. The food practitioners who often have close contact with cold-chain products with high possibility of COVID-19 contamination, such as handling, processing, and marketing of cold-chain products, should be conducted nucleic acid screening regularly. Nucleic acid sampling inspection should be inducted on the imported cold food, including surfaces, inner and outer packaging, containers, etc. It is crucial to strengthen the sanitation and disinfection of all stages in the cold food supply chain logistics, as well as the regular cleaning and sanitizing of the related environment.

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Availability of Data and Material The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Code Availability Not applicable.

Declarations

Conflict of interest The authors declare that they have no conflict of interest in this work.

Ethical Approval Not applicable.

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