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Letter to the Editor

The global concern of food security during the COVID-19 pandemic: Impacts and perspectives on food security

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ABSTRACT

COVID-19 is having a far-reaching negative impact on global economic and social development. One of the challenges arising from the pandemic is ensuring food security, especially with respect to cold chain food. Given the current situation of high contagion and large numbers of infected people, the perspective briefed emergency management measures of cold chain food, compared the development of accurate and rapid detection methods of COVID-19 and hazards in foods. In addition, we proposed three-dimensional-printing of foods as a promising candidate for ensuring food security during the current pandemic because it uses locally-obtained raw materials and does not need long-distance cold chain transportation.

1. Introduction

The COVID-19 pandemic is a global crisis. The pandemic has grown from a single public health event into a multi-faceted crisis, with serious negative effects on the global food industry. Food security is an important aspect of the Sustainable Development Goals of the United Nations. The combined forces of the global economy, politics, society and trade will be required to combat the broad effects of the pandemic. The potential risks of offsetting the negative effects of the pandemic are instability and uncertainty in the global economy. With the increasing global population and increasing risk of climate change, the challenge of food security is very severe.

In times of COVID-19 pandemic, the increasing demand for staple foods in some areas that can destabilize local supply chains and may lead to local and global social unrest (Ali et al., 2020). Therefore, prevention of contaminated staple foods and keeping it away from heavy metal ions, pesticide residues, mycotoxins or other hazards are the focus of the government. International organizations including the International Monetary Fund, International Fund for Agricultural Development, and the World Bank have all made major funding commitments and are supporting governments to safeguard against food insecurity impacts of the COVID-19 pandemic (https://go.nature.com/3jXBVXE). COVID-19 can survive at a low temperature for a long time, so cold chain foods and its outer packaging may become the carrier of COVID-19. Some countries, especially China, are more concerned about the security of cold chain foods. To ensure the food security of cold chain food, we must standardize the procedures of sampling, monitoring and disinfection, and strengthen the whole chain prevention. However, the most important part of this process is to improve the detection performance of COVID-19. The rapid, efficient and accurate detection methods based on visualization technology, lab-on-a-chip technology, and smartphone-sensors, will continue to come out to ensure food safety. In addition, we proposed three-dimensional-printing of foods as a promising candidate for ensuring food security because it uses locally-obtained raw materials and does not need long-distance cold chain transportation.

This paper discusses the potential impacts of COVID-19 on food security, and analyzes the solutions from three perspectives of cold chain food, rapid detection methods, and three-dimensional-printing of food.

2. Cold chain food security

The cold chain system, a specialized department of the food system supply chain, aims to guarantee food security and reduce the food waste caused by changes in physicochemical properties, which is both a reactive and preventive approach. The cold chain system includes pre-cooling/freezing, cold storage of chilled and frozen food, refrigerated logistics transportation, distribution and home storage (James & James, 2010). The cold chain system meets the security, freshness and quality standards of consumers of perishable foodstuffs. China imported nine kinds of fresh, cold and frozen meat (including beef, pork, chicken, mutton, duck, horse, donkey and mule meat) from 41 countries (including the United States, Canada, Argentina, Brazil and Costa Rica). The import value and weight of fresh, cold and frozen meat in 2020 were 172.6 billion RMB and 7.3 million tons, respectively (http://www.customs.gov.cn/). The importance of the cold chain system to the import industry is vital.

The COVID-19 pandemic has caused an unprecedented threat to the security of foods relying on the cold chain and long-distance transportation. COVID-19 cases resurged on October 17, 2020, in Qingdao, China. China's Center for Disease Control and Prevention commenced a study of the origin of the new cases. Live virus was isolated from positive samples of frozen cod imported from infected workers. This was the first time in the world that the live COVID-19 virus was isolated from cold chain food packaging. This finding confirms that people can become infected by exposure to a package contaminated with COVID-19 live virus. Because many food suppliers worldwide have been infected with COVID-19, many countries have begun to trace the origin of frozen foods and expand the scope of detection to include the packaging of frozen pork, poultry and seafood. Some countries have begun to tightly control the quantity of imported frozen foods. This raises concerns about the

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wider impact of the pandemic on global exports of meat and other foods. The global meat supply has been reduced since the spread of African swine fever in 2007. Now, the COVID-19 pandemic has caused restaurants around the world to shut down, and some meat companies have reduced their production capacity. The global meat supply is in unprecedented shortage. This is a very unfavourable situation for development; producers are at risk of losing their property, while consumers are at risk of rising prices.

It should be noted that coronaviruses cannot multiply in food; they need an animal or human host to multiply. But when an infected worker in the cold chain system coughs or sneezes, the generated respiratory droplets are too heavy to be airborne and land on the surfaces of foodstuffs in the work environment. The low temperature environment created by the cold chain food system prolongs the survival of the coronaviruses, which increases concern for food security during the outbreak. Imported frozen foods such as meat are facing substantial challenges in this outbreak because of the increased risk of contamination by coronaviruses despite no clear evidence that coronaviruses could be transmitted through food or food packaging. Artificial meat, including plant-based meat and cell-cultured meat, is emerging as a sustainable alternative to specific types of meat (Choudhury, Singh, Seah, Yeo, & Tan, 2020; Stephens, Di Silvio, Dunsford, Ellis, Glencross, & Sexton, 2018). Artificial meat is an effective tool to alleviate the increasing demand for meat caused by population growth. It is also a promising candidate for ensuring food security during the current pandemic because it uses locally-obtained raw materials and does not need long-distance cold chain transportation.

Numerous efforts have been made to ensure food security throughout the cold chain since the outbreak of the COVID-19 pandemic. Maintaining food security along the cold chain is an essential function to which all authorities responsible for national food security must contribute. As the densely populated country in the world to have an outbreak of COVID-19 and effectively contain it, China has paid considerable attention to cold chain food security. Chinese provinces such as Shaanxi Province, Anhui Province and Henan Province have established a cold chain food tracing system, in which a traceability code is assigned to cold chain food. This code contains information on the food's source and its certificates of inspection, quarantine, nucleic acid test, and proof of preventive disinfection (http://www.samr.gov.cn/). This cold chain food traceability system ensures the traceability of information along the whole chain and the quality management of the whole process. In addition, the rapid detection of cold chain food for coronaviruses has increased during the pandemic, which has resulted in the reduced testing capacity of food laboratories reassigned to COVID-19 clinical testing. Therefore, the development of rapid detection technology for COVID-19 to ensure food security is very important.

3. Rapid detection for food security

COVID-19 is a severe global challenge; rapid diagnosis and timely treatment are essential to fighting the pandemic. Given the current situation of high contagion and large numbers of infected people, the development of accurate and rapid detection methods is crucial. Before the pandemic, only national-level regulatory agencies were concerned with improving the system for the rapid detection of food security, including risk prevention and control. The sudden emergence of the pandemic has led to more businesses thinking about better prevention about it. Standardizing process management and preventing measure, rather than simply detecting the result will improve the overall level of food security. This is an opportunity for the food industry to improve its standards and efficiency.

At present, the main methods used to detect the novel coronavirus in food or its packaging include nucleic acid sequencing and antigen–antibody testing and are made into portable detection kits, which are constantly updated. Nucleic acid detection is a method of pathogen diagnosis, and it is also the most important method for diagnosis at present. It is the most important standard for detection. The State Food and Drug Administration continues to approve the novel coronavirus nucleic acid detection kits for emergency use. These kits mostly use the fluorescent polymerase chain reaction (PCR) method, in which the amplified target genes are concentrated in ORF1ab, S, N, E and other genes. This method uses reverse transcription to convert the extracted viral genomic RNA into complementary DNA and then uses it as a template. Pathogen-specific primers are used to amplify the pathogen's nucleic acid sequence. Because the fluorescent dye can be integrated into the product simultaneously during the amplification process, real-time detection can be performed based on the strength of the fluorescent signal. The advantages of short testing time, fast processing, and low cost make it suitable for the detection of the COVID-19 pandemic (Corman et al., 2020). Another common technique for developing nucleic acid detection kits is constant temperature amplification. For example, loop-mediated isothermal amplification technology (LAMP) can amplify the target DNA from a few copies to 109 copies in one hour at a constant temperature of 65 °C (Hou et al., 2020). Changes are observed with the naked eye, the detection speed is fast, the sensitivity is relatively high, and it is widely used in nucleic acid detection kits (Liu et al., 2020).

PCR technology has played an important role in the early nucleic acid diagnosis of patients and is the most effective method of detecting COVID-19. When the virus infects the human body, it stimulates immune cells to produce specific antibodies, mainly IgM and IgG, and immunological detection methods can be used. IgM and IgG antibody detection kits relying on enzyme-linked immunoassay (ELISA) and colloidal gold detection have been updated in the market. This detection technology is highly complementary to the molecular biology detection of viral RNA. Mass spectrometry analysis of the SARS coronavirus found that N protein is the main antigen that causes SARS patients to produce antibodies. Based on the high sequence similarity between the novel coronavirus and the SARS-CoV N protein, it is speculated that N protein can also be used as an antigen for the ELISA method of the novel coronavirus (Notomi et al., 2000). This method of detection has the advantages of easy collection of clinical specimens and reduced risk of infection among test personnel (Xu, Li, Ramadan, Li, & Klein, 2020). The principle of the detection of IgM/IgG antibodies by the colloidal gold method is based on the immunochromatographic platform. In a weak alkaline environment, colloidal gold has a negative charge and binds firmly to the positively charged groups of protein molecules. Therefore, the COVID-19 antibody detection kit based on the colloidal gold method is easy to commercialize and standardize. It can use a drop of serum, plasma or whole blood to achieve naked-eye observation within 10 min. It is simple to operate, provides rapid screening, and is suitable for screening large populations (Yakoh, Pimpitak, Rengpipat, Hirankarn, Chailapakul, & Chaiyo, 2021).

Immunological detection methods can detect harmful substances in food from multiple angles, and the detection results are more accurate. At present, this food testing method is mainly divided into colloidal gold test cards and ELISA kits. The immune colloidal gold technology is mainly used to detect the presence of pesticide residues, harmful microorganisms, morphine, papaverine and other harmful substances in food. The advantages of this kind of testing are clear: strong sensitivity and specificity; ease of operation; high accuracy; and detection without the use of special reagents. The ELISA kit technology is relatively mature. When applied to the detection of food components, as long as the specific antigen or antibody of the detection component is obtained, the rapid detection ELSIA kit can be developed. In the field of food security, common detection mechanisms include the direct method, the indirect method, the double antibody (antigen) sandwich method or the competition method. The appropriate immunoassay method is selected according to the nature of the substance to be measured and the experimental conditions. It is widely used in the detection of organic toxic substances, residual drugs, illegal additives or pathogens in food.

The kit is used in the clinical diagnosis of the novel coronavirus and

Table 1
Comparison of rapid detection methods for hazardous substances in foods and COVID-19.

Methods	COVID-19		Hazardous		Characteristics	Instruments	Mechanism
	Targets	Specimens	Targets	Samples			
high-throughput sequencing (HTS)	DNA	Upper or lower respiratory tract	Foodborne pathogen, genetically modified composition, foodborne composition, etc.	Fermented food, meat products, etc.	No need to culture, no preference, can complete the detection of a variety of pathogens such as bacteria, fungi, viruses and parasites at one time	Sequencer	After the target RNA is made into a DNA library that can be identified and analysed by a sequencer, the simultaneous detection of millions of nucleic acid sequences can be achieved
Real-time fluorescent quantitative PCR (RT-PCR)	DNA complementary to RNA	Upper or lower respiratory tract	Foodborne pathogen, genetically modified composition, foodborne composition, etc.	Fermented food, meat products, etc.	Not time-consuming, many test samples, simple and fast result judgment, low test cost, need professional instruments and operators	UV analyser, electrophoretic instrument	The complementary DNA obtained by the target genome RNA restore is used as a template to amplify the nucleic acid sequence of the pathogen, and the intensity of the fluorescent dye and the product is successfully detected by the intensity of the fluorescent signal
Loop-mediated isothermal amplification (LAMP)	DNA complementary to RNA	Upper or lower respiratory tract	Foodborne pathogen, genetically modified composition, foodborne composition, etc.	Fermented food, meat products, etc.	Fast amplification, simple operation, simple detection, and intuitive judgment of detection results	Turbidity or visualization	Design specific primers for specific areas of the target gene, then use strand-displacement DNA polymerase, and keep it at constant temperature for 10 min to achieve nucleic acid amplification
Recombinase polymerase amplification (RPA)	DNA	Upper or lower respiratory tract	Foodborne pathogens, genetically modified crops, food microorganisms, etc.	Fermented food, meat products, etc.	Sensitive amplification is achieved at normal temperatures, no equipment is required, the limit is low	RPA analyser	After the recombinase is involved, the protein-DNA complex is formed, the DNA chain substituted by the strand displacement enzyme is bonded to the SSB protein, and the DNA chain extends with the template DNA double helix continuously restricted to achieve product amplification
Constant temperature amplification chip	RNA	Upper or lower respiratory tract	Food microorganisms	Fermented food, meat products, etc.	High sensitivity, strong specificity, no complicated sample processing, easy to miss the detection of rare pathogenic pathogens	Analyser	Nucleic acid amplification and nucleic acid extraction were performed using a chain shift DNA polymerase under constant temperature conditions, and perform corresponding labelling by means of fluorescein
Detection technology based on Cas enzyme	RNA	Upper or lower respiratory tract	–	–	Low-cost, accurate, time-saving but requires high specificity of crRNA target recognition	Fluorescence analyser	CRISPR RNA binded the target sequence while the nonspecific endonuclease activity of Cas13 or Cas12 started, which led to the cleavage of nearby reporter RNAs and generated the signal
Colloidal gold immunochromatography assay (GICA)	IgM, IgG, total antibody	Blood or serum samples	Pesticide residues, veterinary drug residues, hormones	Meat products, crops, etc.	Quick and easy, no special equipment is needed, no quantification, risk of exposure, low sensitivity, and easily interfered with by environmental factors	Colloidal immunoassial analyser or visualization	Based on the antigen–antibody specific immune response, colloidal gold particles are used as a tracer to mark one of them The marker is driven by solvent chromatography and immune response occurs on the C/T line
Enzyme linked immunosorbent assay (ELISA)	IgA, IgM, IgG, total antibody, plasma cytokines	Whole blood, serum or plasma	Veterinary drugs residue, antibiotic, pesticides residue, protein, offending drug, genetically modified, toxins, etc.	Meat products, crops, etc.	Highly sensitive and specific, many options for different determination and analysis, few requirements for reagents, the reproducibility of data is higher	Enzyme detection instrument or visualization	The principle of colour change occurs through the binding of antibodies and enzyme complexes while maintaining immunoactivity of antibodies
Fluorescence immunochromatography	Total antibody and IgM	Blood or serum sample	Foodborne pathogen, metals ions, pesticides/herbicides/	Fermented food, meat		Fluorescence spectrophotometer	Use fluorescent substances as tracer markers to label specific antibodies (or antigens), and

(*continued on next page*)

Table 1 (*continued*)

Methods	COVID-19		Hazardous		Characteristics	Instruments	Mechanism
	Targets	Specimens	Targets	Samples			
			metabolites residues, preservatives, protein, etc.	products, crops, water, etc.	High sensitivity, high resolution, wide detection range and low reagent cost		then combine with the antigens (or antibodies) to be tested, and detect the specific fluorescence reaction with a fluorescence detector
Electrochemical biosensor	Reactive oxygen species (ROS) in the sputum sample	Sputum	Foodborne pathogen, metals ions, pesticides/herbicides/ metabolites residues, preservatives, protein, etc.	Fermented food, meat products, crops, water, etc.	Simple structure, convenient assembly, sensitive and accurate detection results	Visualization	Identifying the interaction of the target analyte and the biosensor to convert the chemical amount of the analyte to the electrical signal to achieve the monitoring of the target
Lateral flow immunoassay (LFIA)	IgM, IgG, total antibody	Blood or serum sample	Proteins, pathogens, toxins and antibiotics	Processing food, dairy products, etc.	Low sensitivity, material errors will affect the test results	Visualization	Based on a sandwich immunoassay that captures the target molecule and shows different signals (colours) on the test and control line using colloidal gold, carbon, or latex as commonly labels
Chest computed tomography (CT) scan	Virus-infected lung	Lung	–	–	Painless, non-invasive, requiring highly trained personnel and sophisticated instrumentation	Computed tomography scanner	The detection of the virus in a patient is based on identifying the possible abnormalities caused by the viral infection in the chest by cross sectional X-ray images taken from different angles

detection of harmful substances in food. Other detection methods such as electrochemical biosensors can establish specific interactions with the target components after the identification element is fixed on the electrode surface through physical or chemical methods. The electrical signal generated by this biological interaction is proportional to the concentration of the target analyte (Yan et al., 2020). According to the type of biological recognition element on the modified electrode surface, the electrochemical immunosensor is obtained. The SARS-CoV-2 antibody is used as the sensitive material. When the electrochemical detection system is used as the transducer, the immunoglobulin of SARS-CoV-2 can be successfully detected. The presence of the SARS-CoV-2 antibody will interrupt the redox conversion of the redox indicator and result in a decrease in the current response, which will provide a new possibility for the diagnosis of COVID-19 (Zhao et al., 2020). Based on similar detection mechanisms, biosensors have been developing rapidly in the field of food security. Food-borne pathogens usually use the food chain as a medium to transmit food-borne diseases directly or indirectly through infectious agents, which endangers human health and causes economic losses. Because some viral pathogens mutate quickly into many types, the detection of food-borne pathogens based on biosensors is of great significance. It has been successfully applied to the detection of pathogens in actual samples such as milk, serum and lake water.

Experts have pointed out that the initial cause of the outbreak is related to the local wholesale market. Therefore, to ensure food security, it is important to prevent the novel coronavirus from detecting bacteria on the market. At this stage, although there is no proof that the spillover of the novel coronavirus to humans occurred via food, there have been many reports confirming pathogen contamination in common foods in the market. It is therefore of great significance to detect foodborne pathogens in food. We summarized the rapid detection methods and mechanisms used in monitoring COVID-19 and the hazards in foods, including their similarities and differences. (Table 1). The rapid detection methods of food security are constantly improving, including visualization technology, lab-on-a-chip technology, and the emergence of miniaturized mobile phone reading application software, which all provide technical support for rapid detection. Food security standards are constantly improving, so we should constantly adapt to the new development and constantly improve food security awareness and security level. Whether it is the COVID-19 pandemic or other public security threats that may arise in the future, we are confident that we can overcome them by using these advanced methods.

4. Three-dimensional-printing of food

In the face of the rising risks associated with health and food shortage, the emerging technique of three-dimensional printing (3D-printing) should be considered as a possible solution. Three-dimensional-printing of food might not only be a practical strategy to prevent being exposed to infected food but also a feasible way to ensure the food supply by reducing the cultivation and stockbreeding process. Three-dimensional-printing was introduced by Hull in 1986 and has been ongoing for decades (Hull, & Lewis, 1993). Coupled with digital design platforms like Computer Aided Design (CAD), 3D-printing technology, also known as additive manufacturing (AM), presents as a promising technique for creating complex material objects layer by layer (Dankar, Haddarah, Omar, Sepulcre, & Pujolà, 2018). This data-driven design system has surpassed conventional manufacturing approaches owing to its unique advantages such as freedom of design, variability of materials, precision and rapidity of operations, maximization of material savings, and high degree of automation (Portanguen, Tournayre, Sicard, Astruc, & Mirade, 2019). Therefore, 3D-printing technology is a vital process across various fields. Given the wide availability of ingredients, the shortened supply chain (meaning fewer opportunities for contamination), and customization for the individual, 3D-printing of food has attracted much attention from the scientific community. With a

Fig. 1. 3D-printed foods and devices: (a) 3D-printed beef; (b) 3D-printed pizza built by Anjan Contractor; (c) Rosa Pasta from Loris Tupin; (d) 3D-printed chocolate rose designed by 3D Systems Co.; (e) 3D-printed mashed potatoes; (f) 3D-printed vegetable (broccoli, spinach, and carrot) with hydrocolloid matrices; (g) ChefJet from 3D Systems Co.; (h) A disinfection device with ultraviolet light embed.

surge in publications on the subject between 2010 and 2020, 3D-printing of food also has the potential for use not only in an emergency but in daily life in the future (Fig. 1).

Because 3D-printed meat products could be obtained in a consumer's kitchen instantly, 3D-printing is a viable way of preventing COVID-19 from attaching to foods in the global or local food supply chains. Another burgeoning application of 3D-printing technology is cultured meat, which can be used to alleviate shortages of meat products. Three-dimensional-printed cultured meat is different from 3D-printed meat in that it focuses on the growth and proliferation of printed cells that then mature to become meat. In contrast with conventional meat, 3D-printed cultured meat does not need to be transported from the farm to consumers' tables, which provides a safer source of protein and nutrients for consumers (Dong et al., 2020). Additionally, the realistic texture and taste, as well as the sustainable approach to meat harvesting without slaughter increase consumer acceptance (Dick, Bhandari, Dong, & Prakash, 2020).

Three-dimensional-printing is being used to produce traditional staple foods and snacks. Three-dimensional -printed pizza is an example of a traditional staple food that has been printed with a high level of success (Sun, Zhou, Yan, Huang, & Lin, 2018). NASA's food scientists have accelerated the development of 3D-printed food because they want to provide astronauts with meals that are safe, nutritionally diverse and stable. What astronauts need from their meals is, to some degree, similar to what people in a pandemic need from theirs. Staple foods like baking dough, pizza, rice-based foods, dumplings and pasta are already available for both restaurants and home kitchens. As reported, cake and chocolate were the earliest applications of 3D-printed food and have improved continuously. Spurred by the outstanding advantages of 3D-printed food, scientists, scholars and related companies have developed a range of recipes for snacks like candy, cookies, cheese, mashed potatoes, and meat paste. Three-dimensional-printed foods have been supplied among thousands country (Liu, Zhang, Bhandari, & Wang, 2017). Researchers are also committed to changing non-printable materials like fruits and vegetables into printable food and promoting product innovation (Severini, Derossi, Ricci, Caporizzi, & Fiore, 2018).

Moreover, the most attractive application of 3D-printed food is in combination with "big data", in which a personalized diet can be determined via digitalized smart analysis of an individual's health and nutritional requirements. Taking into account limited resources, 3D-printing of food might be the best method to integrate positive components (such as vitamins) into food and confront the challenge of food insecurity in the pandemic and beyond. With the rapid development of a wide range of printable ingredients and recipes, 3D-printing technology could produce foods from meals to supplements, allowing people to survive even in difficult situations such as a pandemic or environmental disaster.

5. Conclusions

During the COVID-19 pandemic, the highly interconnected food system suffers from food security problems, which are vulnerable to COVID-19 via processes of manufacture, distribution, and consumption. It is also plagued by the lack of foodstuffs due to shortages in labour (farmers and workers might be infected, confined by travel restrictions or needing to self-isolate). Three-dimensional-printing has been used in manufacturing meat, staple foods, snacks, novel foods and supplements for the public, as well as customized food for special groups successfully. With its further development, there is no doubt that all sorts of food could be made available via 3D-printing. It might be a potent weapon against the food insecurity caused by COVID-19 and the post-COVID-19 era. It is also necessary to strengthen the rapid detection and prevention of food security and build a perfect food traceability platform, which would improve food security and ensure food's good nutrition and healthfulness.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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