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Short communication

Climate change-related foodborne zoonotic diseases and pathogens modeling

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A R T I C L E I N F O

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A B S T R A C T

Foodborne zoonotic diseases and pathogens related to climate change are of considerable concern for public health because they have impacts on food systems at the production, transportation, processing, storage, preparation and consumption levels. These impacts all can stand in the way of sustainable socioeconomic development and progress. Various multidimensional variables associated with the diseases and pathogens can be categorized in six subsystems: (i) ecological degradation, (ii) extreme weather events, (iii) supply chain management, (iv) food safety, (v) disaster management and (vi) public health policy. The variables related to these categories interact in a nonlinear way in complex adaptive systems. Various multidimensional variables, data management systems and advanced methods are required to model this complex issue. Hence, a model based on complex adaptive systems and blockchain technology-enabled agent-based modeling is proposed in this paper in order to assess the public health impact of foodborne zoonotic diseases and pathogens related to climate change. This model can be useful for identifying the risks and vulnerabilities related to the diseases and pathogens present in food systems.

1. Introduction

Climate change enhances the threat of foodborne zoonotic diseases and pathogens (FZDP) [1]. FZDP, defined in this study as infectious diseases that directly or indirectly jump from food to humans, are a major concern, because they hinder global food systems and impact public health management through food safety issues and food insecurity [1,2]. FZDP contribute to illnesses in 600 million people worldwide each year and cause major socio-economic impacts [3]. For instance, FZDP in low- and middle-income countries cost US $110 billion each year in productivity and medical expenditures [3], and can hinder fulfillment of United Nations Sustainable Development Goal (SDG) 1 (no poverty), SDG 2 (zero hunger), SDG 3 (good health and well-being for people), and SDG 12 (responsible consumption and production).

Various socio-ecological factors associated with climate change are related to FZDP (Climate Change Foodborne Zoonotic Diseases and Pathogens, or CCFZDP) and their management. These can be categorized into six subsystems that can influence such diseases and pathogens: (i) ecological degradation, (ii) extreme weather events, (iii) supply chain management, (iv) food safety practices, (v) disaster management and (vi) public health policy. Conceptually, the individual factors within these subsystems interact with the entire system as well as across the subsystems in a nonlinear way, creating complex adaptive systems as portrayed in Fig. 1.

A holistic approach considering factors from six subsystems is required to manage the effects of CCFZDP. To address these issues, a holistic conceptual model framework is proposed based on complex adaptive systems thinking, blockchain technology and agent-based modelling.

Variables (factors) from the six subsystems can be exchanged/shared through blockchain technology for modeling and managing CCFZDP. Blockchain technology is used in the context of information storage. Simply put, it is a digital ledger comprised of parcels of information (or records or transactions), called blocks, with a defined storage limit. When a newly formed block is created, it is added to the previous block to form a "chain". "Block chain technology", also sometimes called "distributed ledger technology", is not centrally stored but instead is distributed around a whole network of peers who share access to the entire "chain of blocks". Every time someone from the peer-group adds a new block to the chain, it is added to everyone's copy concurrently, maximizing transparency, immutability, security, verifiability, and resilience [11]. The decentralized nature of blockchain and its peer-to-peer (P2P) network-based management system creates an inclusive environment by promoting collaboration from multiple parties across the wide scale which is vital in managing CCFZDP. In P2P, network computers are connected with

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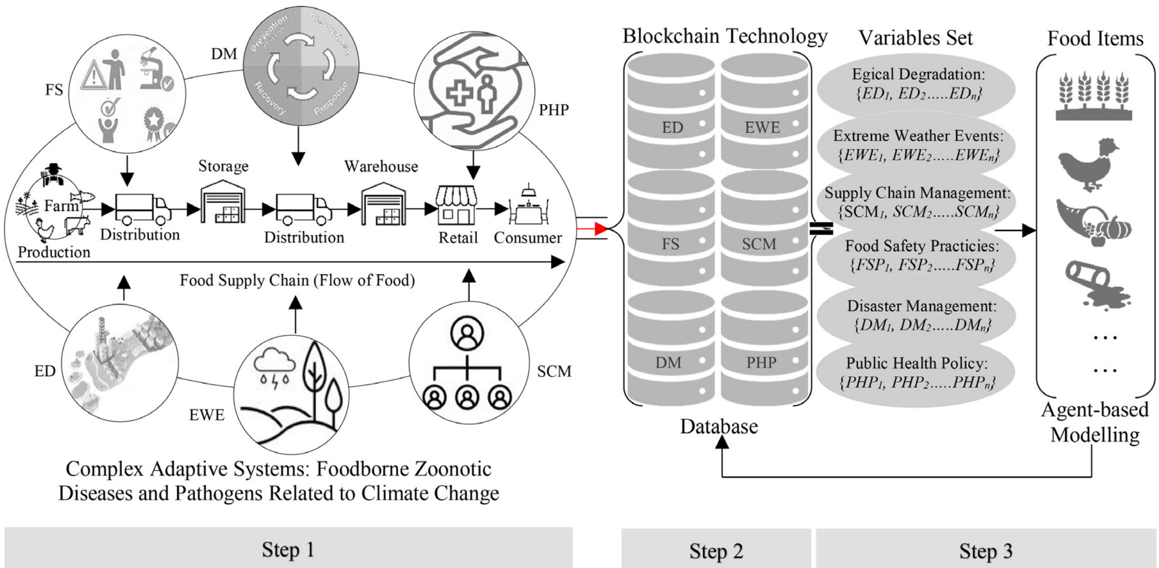

Fig. 1. Complex adaptive systems of climate change related foodborne zoonotic diseases and pathogens (CCFZDP). Various variables in the contexts of ecological degradation (ED), extreme weather events (EWE), food safety Practices (FSP), supply chain management (SCM), disaster management (DM) and public health policy (PHP) subsystems (as shown in step 1) are accountable for the overall status of FZDPCC. Multidimensional data are required from the six subsystems to model FZDPCC of the food items of the food systems. The values of the variables of the subsystems can be stored in a blockchain (as shown in step 2). From a blockchain technology-enabled database, the values of the variables of ecological degradation (*ED_1 to ED_n*), extreme weather events (*EWE_1 to EWE_n*), food safety practices (*FSP_1 to FSP_n*), supply chain management (*SCM_1 to SCM_n*), disaster management (*DM_1 to DM_n*) and public health policy (*PHP_1 to PHP_n*) can be used to generate agent-based modelling of the food items of food systems (as shown in step 3).

each other *via* internet in a system to share information directly without having a central server. Such a network system also could create an ideal stage for knowledge dissemination amongst the most vulnerable populations, provided that resources and accessibility are simultaneously developed.

The proposed model, described in more detail below, creates an analytical and procedural conceptual methodology for forecasting FZDPCC. It offers the capacity to undertake a risk analysis of FZDPCC by identifying the probability of occurrence of primary, secondary and tertiary vulnerabilities specific to products across the food supply chain.

2. Discussion

Food from crops, plants, vegetables, animals, livestock, poultry, fish and other aquatic species are subject to CCFZDP as the result of the effects of various variables from six interactive and dynamic subsystems as described below.

2.1. Ecological degradation

Climate change impacts ecosystem structure and function with potential severe downstream effects on animal health. It can also function as an ecological driver for pest invasion and pathogen spillover. For example, climate-induced degraded ecosystems experience a higher risk of high-profile spillover events, including outbreaks of avian influenza, Ebola and Hendra viruses [4]. Also, changes in temperature and humidity can amplify the proliferation of pathogens such as aflatoxins in crops like rice, and can modify consumption behaviour in ways that increase risk [5].

2.2. Extreme weather events

Extreme weather events such as high temperatures, excessive rainfall and humidity, floods, and cyclones hamper agricultural productivity and change the range, persistence, and patterns of occurrence of bacteria, viruses, parasites and fungi and their corresponding microbial hazards [6]. For instance, increased temperatures promote the spread of anthrax [7], and floods are often followed by a general increase of diarrhoeal diseases.

2.3. Supply chain management

Beyond agricultural production, the food supply chain consists of handling and processing centers, storage facilities and warehouses, transport and distribution, retail outlets and consumers. At different stages of the supply chain, food can be contaminated by FZDPCC due to temperature and other climatic factors [6,8]. For example, the 2018 Romaine Lettuce contamination in the USA and Canada was arguably caused by drought conditions in California that led to increased concentrations of *E. coli* contaminants in the water source used for irrigating the lettuce [9]. In that case, food was contaminated at the farm level, but contamination at other stages of the supply chain also is possible.

2.4. Food safety practices

The effects of climate change, such as increased temperature and humidity, make the implementation of various food safety measures difficult. The trend in antimicrobial resistance worldwide might increase vulnerability in the food system to climate impacts, adding further complexity to food safety regimes [10]. These include sanitation and documented operating procedures, hazard analysis and critical control points (HACCP), traceability protocols, certifications, and current good manufacturing practices (CGMPs).

2.5. Disaster management

Around the world, climate change will lead to more frequent weather-related disasters. During and after disasters, food safety throughout the food systems is a crucial health concern. If there are no appropriate guidelines for food storage, handling, preparation, awareness, inspection and so forth for food safety within disaster management protocols, the impacts of FZDPCC potentially can increase.

2.6. Public health policy

Standard monitoring systems, appropriate regulations and laws for promoting food safety and cleanliness are essential initiatives of public health policy needed to manage the health impacts that arise from FZDPCC. If public health officials fail to implement these initiatives, the incidence of FZDPCC will increase, along with associated socioeconomic consequences.

3. Blockchain technology-enabled agent-based modeling for CCFZDP

Multidimensional factors (variables) within the six subsystems are associated with CCFZDP as shown in Fig. 1. These factors differ from place to place as well as for each food item within the food systems.

In step 1 of the proposed conceptual model, the variables will be identified and collected from the six subsystems. In this stage, ecological degradation (ED), extreme weather event (EWE) and supply chain management subsystems can provide variables and data related to conditions that may promote the occurrence of CCFZDP. The food safety subsystem can then generate variables and data to identify appropriate interventions to prevent CCFZDP. The disaster management subsystem can add information on what is needed to respond to the CCFZDP, and the public health subsystem can add variables and data that are needed for laboratory analysis, forecasting, prediction and managing health impacts related to CCFZDP.

In step 2, data related to the subsystems' causal variables will be stored and managed by following procedures of the blockchain technology. Designated individuals or groups can upload information on pre-determined variables for each subsystem. The unique code or "hashing" feature in blockchain can secure the dataset from further tampering and enhance reliability at the modeling stage. The traceability function of blockchain is able to enhance governance and encourage data-ownership.

In step 3, the variables will be used for the agent (food item)-based modeling to track risk and vulnerability, surveillance, forecasting and scenario development of FZDPCC.

3. Conclusion

There is a crucial need to understand the impact of climate change on the health risks and vulnerabilities of food systems. Modeling CCFZDP by applying transdisciplinary perspectives is necessary to identify and implement better responses, early warning systems and appropriate strategies to control and prevent infectious diseases. Modeling is essential for understanding and identifying trends that otherwise may be difficult to detect and will help to illuminate the present and predict the future for appropriate planning.

The proposed modeling framework involves input from various stakeholders/actors of these six subsystems. For example, farms and the agricultural authorities manage ecological degradation variables and data, food companies govern supply chain management variables and data, meteorological departments control extreme weather event variables and data, disaster management agencies oversee food hazard management-related variables and data, and public health departments handle variables and data related to FZD.

Block-chain enabled systems potentially may improve the reliability and standardization of data through increased transparency, sense of ownership, better integration between different participants in the food supply chain in terms of data collection and management, and improved modes of communication and collaboration. Technologically, block-chain enabled systems may also improve agility and efficiency of existing systems for database functions, surveillance, monitoring, modeling, and mapping by reducing redundancies in information sharing between parties due to its decentralized multi-user functionality.

A cross-sectoral collaborative approach, as proposed in this article, may help formulate comprehensive policy approaches and interventions to prevent, respond to, and manage CCFZDP and CCFZDP-related emergencies. The model can contribute to the identification of emerging problems and food contamination trends, and improve risk assessments by sharing, monitoring and surveillance of information. The systems offer evidence-based context analyses that can result in actionable recommendations to augment or modify food systems to be more resilient to climate change impacts. The conceptual model also offers a scenario-planning toolbox for selecting, monitoring and evaluating CCFZDP of food systems and associated health risks as well as determining the appropriate interventions to prevent them. However, in order to utilize such fast-growing technologies efficiently and acquire standardized data in a decentralized manner, capacity-building and equitable access to the internet are critical.

Conflicts of Interest

The authors declare no conflict of interest.

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