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Food safety monitoring and surveillance in China: Past, present and future

Yong-ning Wu*, Jun-shi Chen

Key Laboratory of Food Safety Risk Assessment of Ministry of Health, China National Center for Food Safety Risk Assessment, Beijing, 100022, PR China

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ABSTRACT

As an integral component of the food safety risk analysis framework, monitoring and surveillance have developed rapidly in China after the promulgation of the Food Safety Law of the People's Republic of China in 2009. At present, a well-functioning national monitoring and surveillance system has been established, which is comprised of four networks and dietary exposure monitoring. The four networks include the foodborne disease surveillance network, the biological hazards (bacteria, virus and parasites) monitoring in foods network, chemical hazards monitoring in foods network and the microbial PFGE profile network. The system now covers all 31 provinces, major municipalities and autonomous regions in Mainland China and is carried out for the national food and exposure monitoring and foodborne disease surveillance and investigation. While the National Health and Family Planning Commission has been overall responsibly for food monitoring and disease surveillance work, the China National Center for Food Safety Risk Assessment has been assigned overall responsibility for foodborne disease surveillance and dietary exposure monitoring through periodic national Total Diet Studies. The Center also provides technical support and guidance to other agencies implementing parts of the national monitoring and surveillance plan. However, in order to provide more and better data for risk assessment and risk management, China needs to learn from more industrialized countries and further strengthen its capacities for food safety monitoring and surveillance.

Contents

* Corresponding author.
E-mail address: wuyongning@cfsa.net.cn (Y.-n. Wu).

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Acronyms and abbreviations

AMR	Antimicrobial Resistance
AQSIQ	General Administration of Quality Supervision, Inspection and Quarantine
FBD	Foodborne Disease
FSL	Food Safety Law
CDC	Center for Disease Control and Prevention
CFSA	China National Center for Food Safety Risk Assessment
CFDA	China Food and Drug Administration
dl-PCBs	Dioxin-Like Polychlorinated Biphenyls
EU	European Union, EURL European Union Reference Laboratories
FERA	Food Environment and Rural Agency, UK
FAO	Food and Agriculture Organization of the United Nations
GEMS/Food	Global Environmental Monitoring System/Food Contamination and Assessment Programme
HBCD	Hexabromocyclododecane
HFPD	Health and Family Planning Department
HCH	Hexachlorcyclohexane, IAEA International Atomic Energy Agency
ISAMR	Integrated Surveillance of Antimicrobial Resistance in Foodborne Bacteria
JECFA	Joint FAO/WHO Expert Committee on Food Additives
NNIH	Norwegian National Institute of Health
NHFPC	National Health and Family Planning Commission
NIP	National Implementation Plan
NRL	National reference laboratory
MOA	Ministry of Agriculture
3-MCPD	3-Monochloro-propan-1,2-diol
ML	Maximum Limit
MOH	Ministry of Health
PFOS	Perfluorooctane Sulphonate
POPs	Persistent Organic Pollutants
PBDE	Polybrominated Biphenyl Ether
PCB	Polychlorinated Biphenyl
PFGE	Pulsed-Field Gel Electrophoresis
PMQRG	Plasmid-Mediated Quinolone-Resistant Gene
SAG	State Administration of Grain
TDS	Total Diet Study
TraNet	National Foodborne Disease Molecular Tracing Network
UNEP	United Nations Environment Programme
WGS	Whole Genome Sequencing, WHO World Health Organization

1. Introduction

Food safety is not only an important public health and trade issue, but also one of the most challenging social issues in China (Wu & Chen, 2013). There have been two large-scale foodborne disease (FBD) outbreaks in China during the past three decades. The first was the FBD outbreak that occurred 30 years ago in Shanghai, which was caused by the consumption of raw clams contaminated with hepatitis A virus; it affected over 290,00 people both in Shanghai and along the coast. The second one was the food fraud incident in 2008 in which melamine was added to mask the quality of milk, which in turn was used to manufacture powdered infant formula. This contamination with melamine resulted in about 294,000 children suffering from urinary tract stones. Among these, about 52,000 infants were hospitalized, of which an estimated 6 to 11 infants died (Chen, 2009a, 2009b; Wu & Zhang, 2013). Consequently, in order to improve the food safety control system in China, in 2009 the Food Safety Law (2009 FSL) was promulgated, which replaced the existing Food Hygiene Law. One of the characteristics of 2009 FSL is its emphasis of the risk analysis framework, which is now considered the basis for modern food safety legislation (Chen & Zhang, 2017; Liu, Xie, Zhang, Cao, & Pei, 2013; Ni & Zeng, 2009). In order to strengthen the technical support for the implementation of risk analysis framework at national level, the China National Center for Food Safety Risk Assessment (CFSA) was established in October 2011 (Jia, 2011).

Chemical and microbial contamination monitoring and exposure data as well as FBD occurrence data are necessary for conducting risk assessments of foodborne hazards. Following the 2009 FSL, a national food safety monitoring and surveillance system was established in 2010 and covers all 31 provinces, major municipalities and autonomous regions in Mainland China. In addition to supporting risk assessment, the national monitoring and surveillance system is also a valuable tool in identifying potential food safety issues, assessing food contamination status and trends and supporting early detection, diagnosis and management of FBDs. This paper is intended to review the progress of the food safety monitoring and surveillance system in China before and since the 2009 FSL came into force.

2. Development of the national food safety monitoring and surveillance system in China

The 2009 FSL states “China shall establish a national system on food safety risk monitoring/surveillance to monitoring foodborne diseases, food contamination and harmful factors in foods”. During the past six years, the system has become the foundation for risk assessment and standard setting in China. The system aims to objectively and accurately reflect the food safety situation in China through the systematic and continuous collection of relevant food contamination and FBD data (Chen & Zhang, 2017). CFSA provides technical support, including assistance in quality control and assurance, for national food safety monitoring and surveillance system, assists the National Health and Family Planning Commission (NHFPC) to develop national food safety risk monitoring and surveillance plans, and helps to organize local institutions, such as provincial Centers for Disease Control and Prevention (CDCs), to implement the plans. CFSA is responsible for compiling and comprehensively analyzing national monitoring data, identifying food safety problems, timely reporting of outbreaks and other emergencies to NHFPC and proposing risk management measures and early warning suggestions as well as preparing final monitoring reports (China National Center for Food Safety Risk Assessment, 2013, 2014, 2015, 2017, 2018).

As practiced in China, food safety monitoring and surveillance are a process of systematically and continuously gathering data and information on FBDs, food contamination and dietary exposure to potential hazards in food. Its aim is to gain a picture of the overall situation of food safety in China to provide early detection and risk characterization of new and emerging food safety hazards and to serve as basis for food safety risk management of both routine, i.e., food standards, and non-routine matters, i.e., emergencies. As widely recognized, food safety risk monitoring is the one of the pillars for assuring food safety. Since the founding of the People's Republic of China, the national government has consistently given high priority to the establishment of the system for assuring food safety through monitoring. In the 2015 amendments to the 2009 FSL, the principle of risk prevention and the further improvement of the food safety monitoring and surveillance system were emphasized. According to revised 2009 FSL, the NHFPC in collaboration with China Food and Drug Administration (CFDA), Ministry of Agriculture (MOA) and the General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) are to jointly develop and implement the annual national food safety monitoring and surveillance plan. Based on the national plan, the provincial/municipal/autonomous regional Health and Family Planning Departments (HFPDs), jointly with their counterparts in the CFDA, MOA and the AQSIQ at the same level, are required to develop and implement local food safety monitoring and surveillance plans based on the national plan. A local technical institute (usually local CDCs) is assigned to carry out FBD surveillance in their jurisdictions. In the event that surveillance findings indicate a possible food safety risk, the county and above level HFPDs are required to notify the findings to the local FDA as well as to the local government of the same level and also to the higher level HFPC. The local FDA would then conduct a further investigation.

Presently, the monitoring and surveillance system covers all of mainland China in four tiers, namely, the national, provincial, county and village levels. A similar hierarchy exists for major municipalities. The system has carried out surveillance of FBDs and monitoring of biological and chemical hazards in food since 2010 (Fig. 1).

3. National foodborne disease surveillance network in China

The 2008 melamine crisis was a significant "watershed" event for FBD surveillance in China. The 2009 FSL clearly stipulates that FBD surveillance is an essential component of the national food safety monitoring/surveillance system. Prior to 2009, the only notifiable FBDs were *Salmonella typhi* and *paratyphi* infections, *Vibrio cholerae* infection, Shigellosis, botulism, and etc. In order to strengthen FBD surveillance, as soon as CFSA was established in 2011, NHFPC designated CFSA to be responsible for FBD surveillance at national level. Over the past six years (2012–2017) (China National Center for Food Safety Risk Assessment, 2013, 2014, 2015, 2017, 2018), three major milestones in China's FBD surveillance were achieved, namely, 1) all bacterial isolates are being sent to public health laboratories in local CDC departments for subtyping and further characterization; 2) FBD outbreaks are being promptly investigated and reporting is timely (also the rate of misreporting has decreased), and; 3) all provincial CDCs are performing molecular sub-typing using pulsed-field gel electrophoresis (PFGE) and providing that information to the TraNet surveillance network in order to identify isolated bacteria strains that cause FBDs (Guo, Wu, & Zhu, 2017; Li et al., 2018).

3.1. National reporting network on acute FBDs outbreaks caused by pathogens or toxins in food

During the period 1992–2010, reporting of acute foodborne infections and intoxications, including food poisoning incidents, was required only if the outbreaks affected 30 or more people according to previous China Food Hygiene Law. This resulted in only about 554 outbreaks on average being reported each year. In contrast, a pilot population-based, self-reporting survey of the burden of acute gastrointestinal illness in residents in Shanghai and the provinces of Jiangsu, Zhejiang, Jiangxi, Guangxi and Sichuan in 2010–2011 revealed that there was about one disease case annually for every 7 persons in the study area. If extrapolated to the whole Chinese population, an estimated 2–3 billion of cases of acute gastroenteritis occur every year. As in many countries, the official reporting network greatly underestimates the actual number of acute FBDs cases that occur in China (Chen et al., 2013). In terms of the types of the FBDs, among the 8869 investigations of FBDs outbreaks during the period 1992–2010 (with the exception of 2002, 2007 and 2009 where, data were not available), about 42%

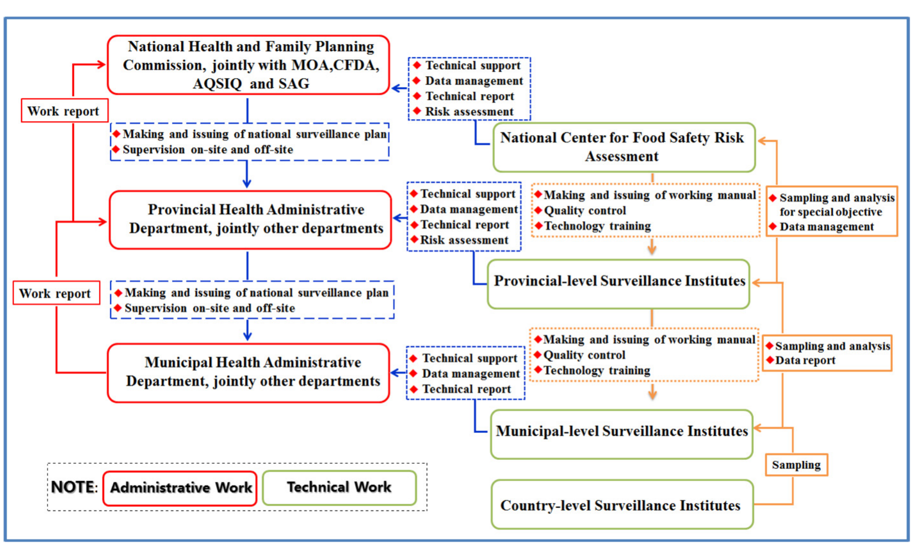


Fig. 1. The institutional structure of the food safety monitoring and surveillance system in China.

were caused by microorganism, 36% by toxic chemicals and 15% by natural toxicants in foods (animals, plants and mushrooms), and 6% with other unidentified cause (Guo et al., 2017). Up to 2015, the numbers of reported FBDs outbreaks as well as the numbers of cases have been declining, but reported deaths and overall mortality has remained constant (China National Center for Food Safety Risk Assessment, 2013, 2014, 2015, 2017). It was obvious that the data collected from the previous reporting system were not able to provide reliable and accurate estimates of the overall FBD burden, including the analysis of regional differences and time trends (Wu, Liu et al., 2018). In order to improve FBD surveillance, a new network comprised of national, provincial, municipal and county level CDCs was established to investigate, verify and report foodborne outbreaks with two or more cases (no longer 30 cases). Starting in June 2015, this new FBD surveillance and reporting network covered all the 31 provinces, major municipalities and autonomous regions across Mainland China, and will extend to Hong Kong and Macau information exchange system. With this new network in place, the timeliness and accuracy of outbreak investigations and reporting has greatly improved. The number of reported foodborne outbreaks increased from an average of 554 per year during 1992–2010 to an average of 1777 per year during 2011–2016. In addition to microbiological etiological data from acute FBD outbreaks, this system also provided information on other FBDs, e.g. outbreak of Haff Disease caused by consumption of crayfish (*Procambarus clarkii*) (Chen et al., 2016). Data from the new network showed that toxic foods originating from animals, plants and fungi were responsible for most deaths, and, in particular, poisonous mushrooms, which contributed to 55% of the deaths and which mostly occurred in remote southwest regions. Data also showed that 43% of the microbial cases were attributed to *V. parahaemolyticus*; in coastal area to China, this is leading cause of foodborne outbreaks and has resulted in detailed epidemiological investigations of this microorganism (Wu et al., 2015; Wu, Wen, Ma, Ma, & Chen, 2014).

3.2. National Laboratory-based foodborne disease surveillance network

In 2011 CFSA launched the National Laboratory-based FBD Surveillance Network with active sentinel surveillance as well as population surveys on foodborne infections to estimate baseline prevalence and burden of FBDs (Guo et al., 2017). Between 2011 and early 2012, the main task was to build the surveillance infrastructure and by late 2012 active surveillance was being carried out at 111 sentinel hospitals in seven provinces to detect *Salmonella*, *Shigella* and *V. parahaemolyticus* from outpatients. Later from 2013 to 2016, more sentinel hospital sites (n = 703 in 2016) were included in the network to identify an increased number of foodborne pathogens, which included *Salmonella*, *Shigella*, *V. parahaemolyticus*, diarrheagenic *Escherichia coli* (DEC) and norovirus from stools samples from diarrheal outpatients. The average positive rate of foodborne pathogens detected from diarrheal patients from 2013 to 2016 was 11% and the detection rates for specific pathogens were as follows: norovirus (6.8%), *Salmonella* spp. (2.9%), *V. parahaemolyticus* (2.1%), DEC (2.2%) and *Shigella* spp. (0.5%). Regional and age differences in patterns of pathogens were found. For example, *Salmonella* was a serious and widely distributed pathogen in most provinces; in coastal areas, *V. parahaemolyticus* was the leading causal pathogen of infectious diarrhea, especially in adults; *Shigella* was mostly identified in less developed regions among children under 5 years old, including northwest China and a few inland provinces, e.g. Henan.

3.3. National TraNet network for foodborne disease investigation

The In order to identify and track bacteria strains isolated from FBD investigations , national system so called the TraNet Network was established to conduct bacterial PFGE as a critical part of the Network what all provincial CDCs are currently able to do (Li et al., 2018). Samples from patient stools are provided by sentinel hospitals and PFGE profiles from isolated strains of pathogens are uploaded by provincial CDCs to the national database in CFSA for further analysis. Since 2013, the total number of PFGE profiles in the national TraNet database was over 20,000. TraNet has played a significant role in identifying the etiological causes and tracking contaminated casual foods in several foodborne outbreaks. With the rapid identification of outbreaks, public health and food safety authorities will have more time to trace, identify and stop the source of the outbreak. In addition, the earlier consumers can be informed of the nature and extent of the food contamination, the less people's health will be affected.

4. National monitoring network on chemical hazards in foods

4.1. Stage one before 2000

As early as 1970s, the former Ministry of Health (MOH) organized large surveys on some important food contaminants, e.g. aflatoxin B1 and certain heavy metals. Tens of thousands data across the country were obtained and used for the studies on the contamination of aflatoxin B1 in several food commodities. In conjunction with toxicological and epidemiological data, these contamination data played an important role in setting the Maximum Limits (MLs) for aflatoxin B1 in various foods that were consistent with to the Chinese conditions at the time, i.e., no risk assessments were undertaken. With these MLs in place, Chinese scientists and technologists studied methods for reducing aflatoxins during production, food processing and manufacturing and their practical application to avoid non-compliant end products. By the early 1980s, China joined the United Nations Environment Programme (UNEP), the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) Global Environmental Monitoring System/Food Contamination and Assessment Programme (GEMS/Food) and was designated as the WHO Collaborating Center for Food Contamination Monitoring (China) in 1981. The site of the WHO Collaborating Center was first located at the Chinese Academy of Medical Sciences, which then became the Chinese Academy of Preventive Medicine, and which in turn was succeeded by the China CDC. Since 2012, the WHO Collaborating Center has been located at the CFSA. Under the guidance of GEMS/Food, in China began to establish a food contamination-monitoring network. Due to constraints in funding and testing capabilities, early monitoring was limited to only a few contaminant-food combinations and only covered a few provinces. In 1992, contaminants included lead, cadmium, mercury, organochlorine pesticides, mainly α, β, γ and δ-hexachlorcyclohexane (HCH) and its total HCH, total dichlorodiphenyltrichloroethane isomers, several organophosphate pesticides and aflatoxin B1 in 8 food categories and 6 of the 31 provinces participated in the monitoring network (Wang, Wang, Bao, & Ran, 2002; Wu et al., 2015).

4.2. Stage two during 2000–2009

By continuing participation in the GEMS/Food, more key contaminants (e.g. additional heavy metals, residues of pesticides and veterinary drugs and certain mycotoxins) were included in the monitoring. Starting from 2000, a national network on food contamination monitoring in compliance with GEMS/Food was set up by the former MOH, with technical support from the MOH Food Hygiene Inspection Institute and CDC Institute of Nutrition and Food Safety as well as local CDC departments at provincial and municipal levels. In August 2003, the former MOH released the Food Safety Action Plan (Wei Fa Jian [2003] No. 219), which placed special attention on the need to set up a national network to carry out annual monitoring of food contaminants with adequate and sustainable funding support. With this policy emphasis, national food contamination monitoring became a regular activity of the MOH (now the NHFPC). During 2003–2009 the national network of food contamination monitoring developed rapidly as reflected by the continuous increase in monitoring areas, food categories and number of food samples analyzed. In addition, cause-targeted microbial and chemical substances were established and the monitoring capabilities of the technical institutions at both national and local levels were enhanced. For food additives and contaminants, the selected monitoring indicators were based on established MLs for food. In the case of pesticide and veterinary drug residues, cause-targeted chemical substances were based on national Maximum Residue Limits. Where national limits did not exist, those established by the Codex Alimentarius Commission were used.

The number of provinces included in the monitoring network increased from 9 in 2000 to 16 in 2009 and the number of cities covered increased from 45 to 178 during the same period (Jiang, Wang, Yang, Lu, & Yang, 2012). Basically, all of the more developed coastal provinces/municipalities were included in the monitoring system. Meanwhile, the food categories monitored increased from 15 subcategories under 10 categories in 2000 to more than 50 subcategories under 14 categories in 2009, covering basically all the daily consumed foods by Chinese people. The monitored contaminants increased from 14 in 2000 to 117 in 2009, including element contaminants, mycotoxins, agricultural chemicals, food additives, nutrients and specific food adulterants. The total data points obtained from the monitoring network increased from about 8000 per year in 2000 to over 350,000 in 2009.

4.3. Stage three from 2010 to the present

Since the implementation of the 2009 FSL, food safety monitoring entered a new era. Since 2010, the former MOH joined by the other related ministries developed an annual plan for national food safety risk monitoring, which was implemented by local governments (Jiang, Li et al., 2012). Today the governments at all levels value monitoring even more and have increased supporting funds producing a marked increase in the number of chemical indicators and the coverage of food types, which resulted in the doubling of data obtained. The monitored areas now cover all of the 31 provinces, major municipalities and autonomous regions in Mainland China, including both urban and rural sites. Furthermore, to meet the needs of risk assessment and food standard setting, specific monitoring projects are carried out from time to time, such as phthalates in 2011, aluminum in 2013–2014 (Chen & Zhang, 2017), and rare earth elements in 2012 (Jiang, Yang, Zhang, & Yang, 2012).

Of course, contamination monitoring is only as good as the analytical methodology used to measure the contaminant. Since the establishment of CFSA, its laboratory has participated in many international proficiency tests, which have included persistent organic pollutants (POPs), e.g., polychlorinated dioxins and furans (PCDD/PCDFs), polychlorinated biphenyls (PCBs) with both dioxin-like polychlorinated biphenyls (dl-PCBs) and marker PCBs, polybrominated biphenyl ethers (PBDEs), hexabromocyclododecane, tetrabromobisphenol A, organochlorine pesticides and perfluorinated organic compounds, such as perfluorooctanic acid and perfluorooctane sulphonate (PFOS) organized by UNEP, European Union Reference Laboratories (EURL) and the Norwegian National Institute of Health (NNIH); residues of pesticide and veterinary drugs as well as elements and their species organized by EURL, elements organized by the International Atomic Energy Agency (IAEA), aflatoxin B1 organized jointly by FAO and Texas A&M University in U.S., and chloropropanol and glycidyl esters in vegetable oil organized by Food Analysis Performance Assurance Schemas (Fera Limited, York, United Kingdom). Good analytic quality assurance were obtained in POPs analysis, including both actual food samples and standard solutions (Zhang, Li, Zhao, & Wu, 2013), as well as in complex matrices, such as serum and breast milk samples. As shown in Fig. 2, all Z scores were less than 2, most of the them were less than 1 in total toxic equivalents for PCDD/Fs and dl-PCBs in NNIH organized international inter-laboratory comparison tests from 2005 to 2016 (Fig. 2a). Additionally, in PFOS comparison organized by UNEP, excellent results have been shown in Fig. 2b with Z score ranging from −1 to 1. Up until 2016, the China NHFPC has set up 14 national reference laboratories (NRLs) for food safety risk monitoring of chemical substances, which include dioxins, heavy metals, harmful element species, mycotoxins, contaminants during food processing, i.e., 3-monochloro-propan-1,2-diol (3-MCPD), acrylamide, and polynuclear hydrocarbon, pesticide residues, veterinary drug residues, biological toxicants, food additives, exogenous hormones, food contact materials, intentional adulterants, and radionuclides. These NRLs has played important roles in implementing national monitoring plan and capacity building for the national monitoring system.

5. National monitoring network for microbial hazards in foods

Before 2000 no national system for monitoring microbial

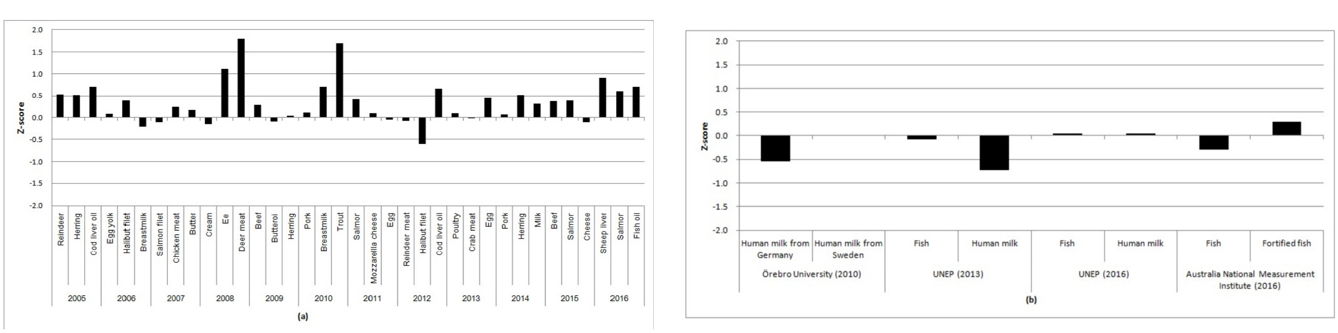


Fig. 2. Results of interlaboratory comparisons of persistent organic pollutants: (a) total Toxic Equivalent Quantity of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/Fs) and dioxin-like polychlorinated biphenyls (dl-PCBs) in 2005–2016; (b) Linear-perfluorooctane sulphonate (L-PFOS) in 2010–2016.

hazards in foods existed in China and only case studies on pathogens in food could be found in the literature. The development of monitoring network for microbial hazards in China started from 2000 and has undergone two stages (Pei et al., 2015).

5.1. Stage 1 from 2000 to 2009

The first stage was aimed to monitor the occurrence of bacterial pathogens in foods and the data obtained is used to identify major microbial risks, develop management policies and standards, and guide food inspection, production, and consumer education. The number of provinces covered gradually expanded from 32% (10/31) in 2000 to 71% (22/31) in 2009, and at cities within provinces from 10% (35/334) in 2000 to 51% (171/334) in 2009. Up until 2000, ad hoc studies only included *Listeria monocytogenes*, *Salmonella* spp. and *E coli* O157:H7, which were determined in around 1900 samples of various foods, including raw meat, cured meat, yoghourt, raw milk, ice cream, and aquatic products (for eating uncooked) (Wang et al., 2002). Along with the rapid development of the surveillance network, monitoring was extended to 9 foodborne bacterial pathogens with over 19,000 food samples taken, which covered all foods consumed daily by Chinese people, such as meat and meat products, eggs and egg products, milk and dairy products, aquatic products, and vegetables.

5.2. Stage 2 from 2010 to the present

A National Microbiological Monitoring Network was established in 2010 according to 2009 FSL, which covers all the 31 provinces, major municipalities and autonomous regions in Mainland China. All major foodborne pathogens were monitored, such as *Salmonella*, *Cronobacter* spp., *Bacillus cereus*, *Staphylococcus aureus*, *L. monocytogenes*, *V. parahaemolyticus*, *Campylobacter jejuni* and *Clostridium botulinum*, as well as hygiene indicator bacteria, such as *E. coli* and other Enterobacteriaceae. Parasites are relatively less monitored and only the nematodes *Angiostrongylus cantonensis* and *Trichina* spp. were included. Among viruses, only norovirus was monitored. In addition, sampling points were no longer limited to retail and catering establishments, but included farms and manufacturing and processing enterprises. In order to establish a national database of microbial contamination in food in China, the foodborne pathogens isolated from foods between 2010 and 2016 were compiled. *Salmonella* was mainly isolated from raw meat, raw poultry, egg and egg products. *S. aureus* strains were mainly isolated from cakes and pastries, raw and cooked meat products, cereal and cereal products, and egg and egg products. *L. monocytogenes* strains were mainly from cooked meat products, milk and milk products. *Enterobacter sakazakii* (*Cronobacter*) strains were mainly from infant formula and cereal-based complementary foods for infants and young children. *V. parahaemolyticus* and *V. vulnificus* strains were mainly from fish and fish products, and *B. cereus* strains were mainly from cereal and cereal products. The main foodborne pathogens vary not only by different food categories, but also by seasons, packaging materials and sampling sites in China. For example, prevalence and characteristics of *L. monocytogenes* isolated from retail food in Henan Province differed greatly from other provinces (Yu & Jiang, 2014). In 2014, the network covered 99% (331/334) of the cities and 87% (2484/2862) of the counties (Pei et al., 2015). Significant progress has been made in the type and number of pathogens as well as number of monitoring sites among 2010–2016.

The growing numbers of new pathogens with antimicrobial resistance (AMR) and even multi-drug resistance have become a worldwide concern (Bai et al., 2016; Hu et al., 2017; Li & Fanning, 2017; Yan et al., 2016). The AMR prevalence of isolated *B. cereus*, *S. aureus*, *V. parahaemolyticus*, *L. monocytogenes*, *Salmonella*, *E. sakazakii* (*Cronobacter*) from food have been characterized with prevalence of between 72.27% and 90.70% since 2013 in China (Fig. 3). The AMR for 16 antibiotics in *Salmonella* was tested and it was found that the resistant and sensitive ratio was quite different among the 16 different antibiotics. Resistance to one and up to seven and more antimicrobial classes for *Salmonella* is shown in Fig. 4. It was also revealed that there was potential transfer to agricultural lands by the plasmid-mediated quinolone-resistant genes (PMQRG) by antibiotic residues in wastewater and soil adjacent to swine feedlots (Li et al., 2012), which implied that PMQRG has entered food chain and human environment. After the discovery in China and worldwide that the novel colistin encoding-resistant gene, denoted as mcr-1, was carried out on the transmissible IncHI2 plasmid in isolates of *E. coli* cultured from food-producing animals and hospitalized patients, This was the first identified instance of transmissible resistance to this important drug, the finding got the attention of the world. Following this, institutes in numerous countries began to look for the *mcr-1* gene in their strain collections. China banned colistin as a feed additive for animals based on this finding (Walsh & Wu, 2016).

6. China total diet studies

A Total Diet Study (TDS) is recommended by WHO as an important part of national food safety monitoring/surveillance systems because it has been recognized internationally as the most cost-effective and reliable method to estimate dietary exposure to food chemicals and over/under intake of certain nutrients and to use such data to assess associated health risks for various cohorts of their population. In addition to monitoring chemicals in specific foods, GEMS/Food also assists countries in undertaking dietary exposure estimates, such as a TDS. As a WHO Collaborating Center for Food Contamination Monitoring, CFSA is responsible for carrying out the China TDS to provide scientific basis for assessing food safety risks and developing necessary management measures. The results of China TDS have provided important information and data for food safety risk assessment, standard setting, risk communication, trend analysis of exposure changes, and assisting risk managers to focus their limited resources on food chemicals and nutrients that pose the greatest risks to public health.

Since the first China TDS carried out in 1990 (Chen & Gao, 1993a, 1993b), four additional TDSs have been completed in 1992, 2000, 2007, and 2009–2013 (Wu, Li, & Zhao, 2018). The first China TDS was comprised of 4 market baskets from four regions of China (North 1 and 2 and South 1 and 2 regions), which covered 12 provinces. This TDS included the basic contaminants and nutrients recommended by GEMS/Food (Chen, 2013a, 2013b). The overall

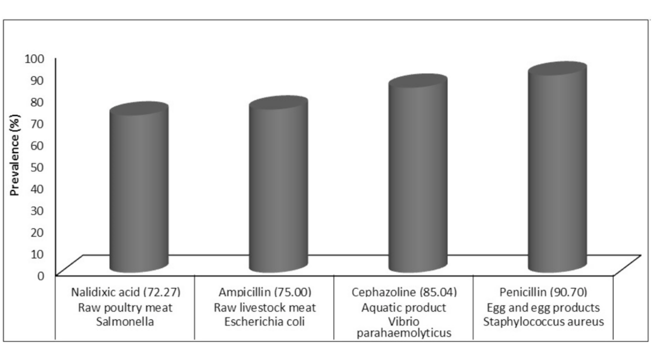


Fig. 3. Highest resistant rates for specific antibiotics of different foodborne pathogens in different foods.

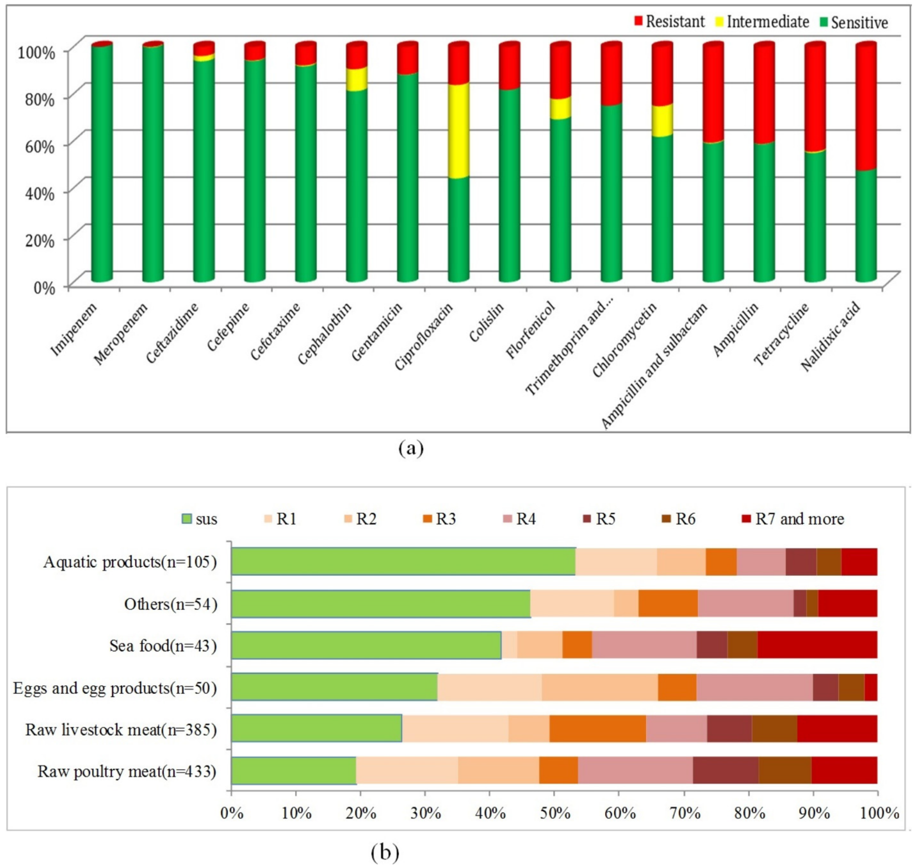


Fig. 4. Resistant sensitivity and multi-drug resistance to 16 antibiotics in isolated strains of *Salmonella* in 2016: (a) Resistant sensitivity; (b) Multi-drug resistance of *Salmonella* to 16 antibiotics (R1-R7 and more: resistance to one up to seven and more antimicrobial classes for *Salmonella*).

strategy and goals of the China TDS have remained constant since its inception in 1990, but the specific methodology has been revised periodically (Li, Wu, & Chen, 2011; Wu, Li, & Zhao, 2018; Wu & Li, 2015). For example, 48 composite samples by region-pooled market baskets in 1990 (12 food categories x 4 regional market baskets) has grown to 298 composite samples by provincial market baskets (12 food categories x 24 provincial baskets) plus about 3000 individual samples for a heavy metals study). The history of the China TDS has been published elsewhere (Li et al., 2011). The fourth China TDS report (2007) includes data on food consumption, food-processing factors, concentrations of various contaminants in foods and dietary exposure and intake data, and, importantly, risk assessments of hazards in the diets of various age and sex cohorts. This study has been published both in Chinese and English (Wu & Li, 2015), The fifth TDS (2009–2013) results have been published as same way (Wu, Li, & Zhao, 2018). The dietary exposure assessments included trace elements, heavy metal elements and their species (Shang, Li, Zhang, Zhao, & Wu, 2010), pesticide residues (Zhou et al., 2012), veterinary drug residues, POPs (Li, Wu, Zhang, & Zhao, 2007; Shi, Wu, Li, Zhao, & Feng, 2009; Zhang, Li, Liu, et al., 2013; Zhang, Li, Zhao, Li, et al., 2013; Zhang, Yin, et al., 2015) and other emerging contaminants, e.g., 3-MCPD (Wu et al., 2013), bisphenol A and nonylphenol (Niu, Zhang, Duan, Wu, & Shao, 2015), and acrylamide (Gao et al., 2016; Zhou et al., 2013).

CFSA uses the TDS results in various ways. For example, because dietary patterns and contamination situation may change over time, particularly with the rapid development of national economy, assessing the impact of these temporal and spatial changes are useful in updating the MLs of contaminants in China National Food Safety Standards. The results of exposure contribution from food categories have been the basis for selection of contaminant-food commodity combination MLs to be revised in the National Food Safety Standards. The MLs for cadmium, lead, arsenic, mercury, nickel, tin, chromium, nitrate and nitrite in a variety of food commodities were retained in the new general standard. MLs for zinc, copper, selenium and fluorine were discontinued on the basis that the potential health risks to the consumer from dietary exposure to these substances are low (Shao, Wang, Chen, & Wu, 2014). The China TDS has provided valuable data for national and international risk assessments carried out by the Joint FAO/WHO Expert Committee on Food Additives (JECFA). For example, Chinese individual food consumption data has been used by JECFA in acute dietary exposure assessment (1 of the 13 countries selected) and in chronic dietary exposure assessment (1 of 26 countries) (World Health Organization, 2011). The results of China TDS have been effectively used to identify the source of contamination when high levels of a certain chemical were found in a composite sample of food. For example, a cadmium concentration of 149 μg/kg was found in the aquatic food composite from the North 1 region that was much higher than other composite samples of aquatic food. The cadmium content was further analyzed in the aquatic food composite for 3 individual provinces that make up the North 1 region, and the results showed that the Liaoning provincial composite had a very high cadmium concentration (594 μg/kg) as compared to Heilongjiang and Hebei provincial composites. Finally, the sea crab sample (1498 μg/kg) was identified as the source of the high cadmium contamination from the analysis of all 7 individual aquatic foods from Liaoning (Chen, 2013a). Subsequently, the environmental source of the cadmium in the sea crab was studied to prevent future contamination. Regarding the use of TDS results in nutrition studies (Chen, 2013b), the results on sodium intake have been used in national salt reduction action programme and the dietary iodine intake data were used in assessing the universal salt iodization programme in China (Hipgrave, Chang, Li, & Wu, 2016; Wu et al., 2012).

As a signatory to the Stockholm Convention on POPs, China has issued its National Implementation Plan (NIP) to eliminate or restrict the production and use of the intentionally produced POPs. The Globe Monitoring Plan focuses on generating measurement data from core media: ambient air, human milk and blood for fat-soluble POPs, and surface water for water-soluble POPs (perfluorooctane sulfonic acid, its salts and perfluorooctanesulfonyl fluoride). Monitoring of human milk allows countries and regions to identify contamination problems and formulate measures to reduce and prevent human exposure to and environmental release of these chemicals. In the first human milk survey (Li et al., 2009), samples were collected from each of the 12 China TDS provinces. In the second survey (2011), another 4 TDS provinces were added so that the population included in the survey would represent about 50% of the total population of China (Zhang, Yin, Li, Zhao, & Wu, 2016). In each province, one urban site and two rural sites were selected for sampling. In each urban area, 50 donors were selected, and in each rural area, 30 donors were selected. The approach for donor selection and sampling human milk was based on the 'WHO Guidelines for Developing a National Protocol' for the Fourth WHO-Coordinated Survey of Human Milk for Persistent Organic Pollutants in Cooperation with UNEP Globe Monitoring Plan (United Nations Environment Programme). So far, the two national surveys of POPs in human milk in China have been conducted in 2007 (baseline (Li et al., 2009),) and 2011 (China NIP first effectiveness evaluation (Zhang et al., 2016),) respectively by CFSA (Liu et al., 2010; Zhang et al., 2011; Zhou et al., 2011). In order to link with data on dietary habits, contamination levels in foods and levels in human milk, the surveys were performed in the same regions and at the same time as the China TDS (Zhou et al., 2011). The results have shown that the increasing trend for dioxins and dl-PCBs and decreasing trend for PBDEs both in diet and human milk in China (Liu et al., 2010; Zhang et al., 2011; Zhang et al., 2016). Exposure monitoring has also been extended to biomonitoring of urinary excretion of cadmium and renal biomarkers (Zhang, Wang et al., 2015).

7. Challenges and future directions

Significant progress has been made in food safety monitoring and surveillance in China in the past 6 years (Fig. 5 and Fig. 6). In comparison with the past, China has upgraded a passive FDB surveillance model that was focused on mass outbreaks with little etiological information to an active comprehensive surveillance network with more rapid and detailed etiological information. However, FBDs still not considered as a high priority in the agenda of the Chinese food safety authorities. In China, effectiveness evaluation on food safety monitoring depends on the rate of qualification mainly (Fig. 6), then to set up the priorities for food inspection based on identifying main risk from the monitoring results. In US, the FDB burdens are the most important foundation to set up the priorities for food inspection. There are multiple reasons for this, but the most important one is the lack of comprehensive and convincing data on burden of FBDs compare to EU and US. Furthermore, the active FBD surveillance network is far from complete because the number of sentinel hospitals is insufficient and on-site epidemiological investigation of FBD incidents is usually not timely enough to collect leftover food samples. In the monitoring of biological agents in foods, the main bacteria species are mostly covered, but only a few virus and parasites species are included. Especially important parasites, such as liver fluke (*Clonorchis sinensis*) are missing from the monitoring plan. Despite several international recommendations during the last two decades, harmonized surveillance for antimicrobial resistance has still not been established in China. To be most effective, AMR surveillance requires an integrated approach using comparable methods. A programme of integrated surveillance of antimicrobial resistance in foodborne bacteria (ISAMR) must provide data for public health decision-making. Differences in production systems, sampling sites and procedures, as well as antimicrobial agents tested makes comparison between different departments from MOA, CFDA and CDC difficult and even at times, impossible in China. Today continuous ISAMR programmes, where data to some extent can be compared, only exist in advanced countries; some can be used as models, e.g., Danish Integrated Monitoring Programme and US National Antimicrobial Resistance Monitoring System. However, the design of comparable ISAMR programmes presents several challenges. Countries vary widely in their public health infrastructure, agricultural production systems and practices, food

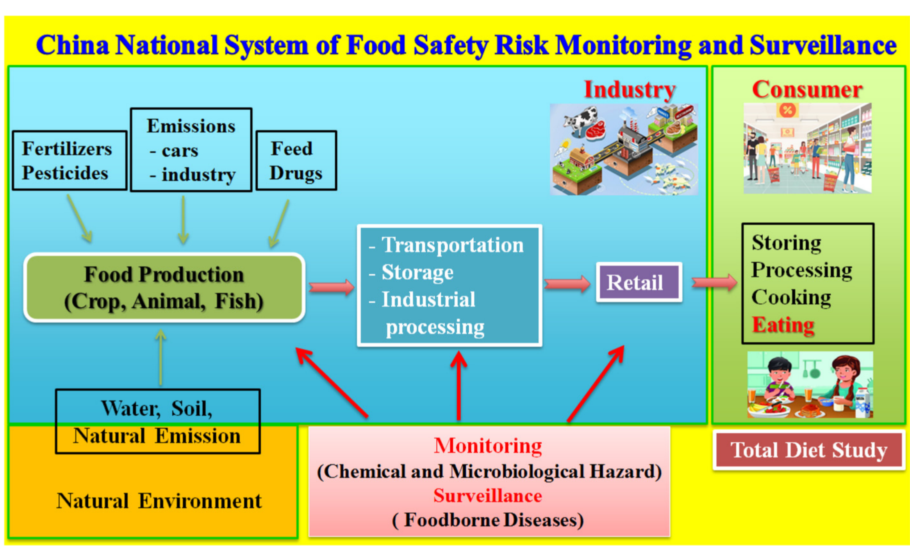
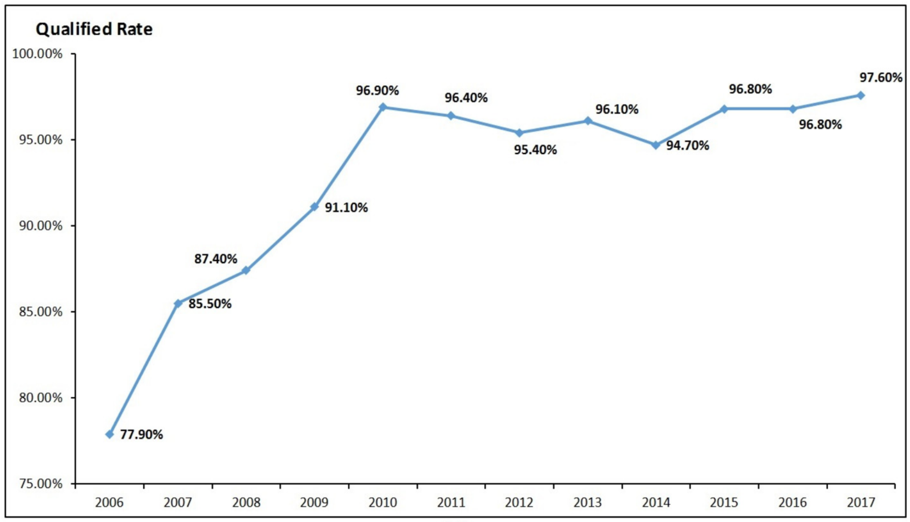
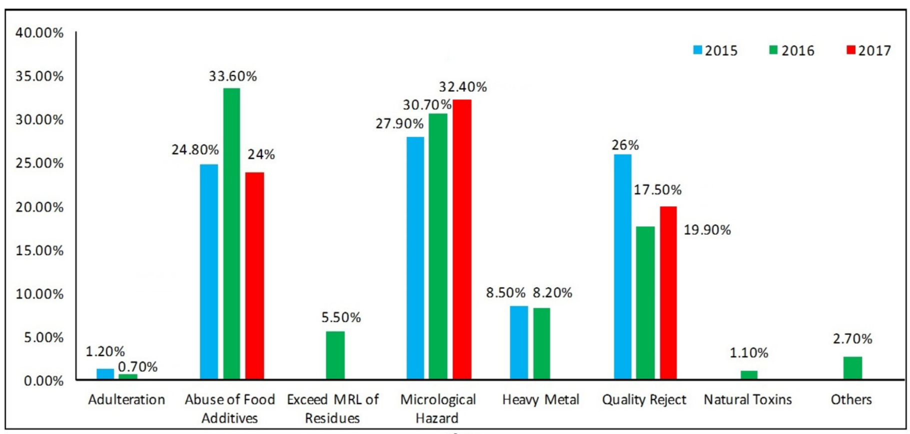


Fig. 5. The task of the food safety monitoring and surveillance system in China.



(a)



(b)

Fig. 6. The statues of food safety risk monitoring in China (a) trend of quality rate by monitoring over 2006 to 2017; (b) identifying the main risk during 2015–2017.

supply systems, and veterinary services. Therefore, to achieve comparability among those ISAMR programmes, it is necessary to establish a minimum set of criteria for every programme, which will require the coordinated sampling and testing of bacteria from food animals, foods, and clinically patients, and the subsequent evaluation of AMR trends throughout the food production and supply chain using harmonized methods in China. The One Health approach should be applied in building close collaboration between national animal, food and environment monitoring networks, so proper and efficient control and prevention measure and be developed. Whole Genome Sequencing (WGS) has become a fast and increasingly more affordable technology that is rapidly being adopted by surveillance and diagnostic laboratories around the world. WGS performs the same function as PFGE but has the power to differentiate virtually all strains of foodborne pathogens, no matter what the species. Along with the drop in reagent and instrument costs, bioinformatics tools are quickly evolving to simplify the analytical processes, making it possible to determine and evaluate the entire DNA sequence of a bacterium in a short time. In the USA and EU, WGS technology has been used to perform basic foodborne pathogen identification during FBD outbreaks and applying it in novel ways that have the potential to help reduce FBD and its deaths. These can then be compared to clinical isolates from patients. If the pathogens found in the food or food production environment match the pathogens from the sick patients, a reliable link between the two can be made, which helps define the scope of a foodborne illness outbreak. Its ability to differentiate between even closely related organisms allows outbreaks to be detected with fewer clinical cases and provides the opportunity to stop outbreaks sooner and avoid additional illnesses. However, the use of WGS in China FBD investigation has just started and there are few successful cases that showed the identity of causal bacteria strains isolated from patient's fecal sample and left-over food samples. Therefore, the etiology of most microbiological FBD incidents remains unknown in China.

In chemical hazards monitoring, the main challenge is the integration of food and environment monitoring, especially for heavy metals and POPs, because the environment is likely the source of most food contamination. Some outstanding examples include high levels of cadmium in rice due to soil contamination by mines or metallurgical industries and POPs in animal meat due to electronic wastes deposited in soil.

Capacity building is critical for further improvement of national food safety monitoring and surveillance system in China. Systematic training of professional teams from local CDCs should be strengthened because they are the work force that ensures the implementation of the national monitoring and surveillance plan. In regard to monitoring, dioxin laboratories are limited to few prosperous provinces. On the other hand, to use all means to learn from developed countries is also important, including training course, workshops, visits to foreign institutions and joint research projects. Finally, WGS needs to be expanded and integrated into the food safety monitoring and surveillance system to better identify pathogens for important foodborne diseases.

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