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One Health for Food Safety, Food Security, and Sustainable Food Production

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Globally, our society faces an enormous challenge to feed, house, and provide a healthy life for the growing human population while preserving the environment and natural resources for the benefit of future generations. In order to meet these challenges, sustainable food production and environmental stewardship is paramount and will require a One Health approach. One Health is the concept that the health of humans, animals, and the environment are inextricably linked. This approach can be applied to food safety, sustainable food production, and environmental stewardship by bringing together interdisciplinary teams to create a One Health network to address these challenges. In order to achieve food security for the global population, preserve natural resources, and improve health through safeguarding food safety, there is a need for increased awareness among academics, producers, consumers, and government agencies in the following topics: (1) One Health Initiatives for Sustainable Food Systems, Food Safety and Food Security, (2) Brief History of Food Safety in the United States, (3) Food Safety in the Twenty First Century: The Need for a New Perspective, (4) Food Security in the Twenty First Century: Disasters and Transboundary Disease. These topics cover the need for incorporating One Health education into curriculum for scientific, engineering, and humanities programs to build capacity in One Health competencies with the goal of established networks that will work toward improving public health, food safety, and sustainable agriculture by establishing new perspectives on interactions among plants, animals, and humans and recognizing the threat of disasters and transboundary diseases to food security.

Keywords: One Health, food safety, food security, food systems, education

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INTRODUCTION: THE INTERFACE OF SUSTAINABLE AGRICULTURE, FOOD SAFETY, AND FOOD SECURITY

The global human population is expected to reach 9.7 billion people by the year 2050. As the human population continues to grow, we face increasing challenges to ensure that people will have access to safe, nutritious, and healthy food. By the year 2050, food production will need to increase by more than 50% of 2012 production levels to meet demand. As incomes in developing countries continue to rise and living conditions improve, demand for meat, dairy, and specialty crops such as fruits, nuts, and vegetables has increased (FAO, 2017). Likewise, consumers in developed countries have developed preferences for specialized products that are marketed as organic, fair-trade, or locally grown (Bellows et al., 2010; Feldmann and Hamm, 2015; O'Connor et al., 2017). Increased demand for food has already strained natural resources resulting in soil erosion, loss of biodiverse landscapes, and pollution of the environment all around the world presenting new challenges in food safety and sustainable food production (Tilman et al., 2011).

Additionally, disasters and transboundary disease pose an enormous threat to food safety and security. Natural disasters such as fires and floods create routes in which pathogens, chemicals, heavy metals, and other pollutants can contaminate air, water, and the environment in which we live and grow food (Watson et al., 2007; Knorr et al., 2017; Wu et al., 2017; Andrade et al., 2018). Globalization and easy access to rapid travel has made transboundary diseases a top concern for food safety and food security. Transboundary diseases are highly contagious animal diseases that cause a high morbidity and mortality in animals. Outbreaks of transboundary disease are economically devastating for farmers and have significant impact on the cost and availability of food (Otte et al., 2004). Sometimes these diseases can be zoonotic and pose a public health risk.

There is a need for a holistic and systematic approach to solving these problems by assembling multidisciplinary teams composed of experts from academic, industry and government agencies. These teams must work to engage the public in outreach and education that will facilitate consumers in understanding the importance and complexity of ensuring animal health, food safety, food security, and sustainable food production. There are numerous challenges to addressing food safety and food security in the twenty first century and in this review we discuss the importance of a One Health approach in food safety and security and threats food safety and food security face in the twenty first century. The topics discussed are: (1) One Health Initiatives for Sustainable Food Systems, Food Safety, and Food Security, (2) A Brief History of Food Safety in the United States, (3) Food Safety in the Twenty First Century: The Need for a New Perspective, (3) Food Security in the Twenty First Century: The Threat of Disasters and Transboundary disease. These topics aim to highlight the diversity and complexity of the issues facing food safety, food security, and sustainable food production in the twenty first century for consideration by policy makers, academics, and industry experts.

ONE HEALTH INITIATIVES FOR SUSTAINABLE FOOD SYSTEMS, FOOD SAFETY, AND FOOD SECURITY

One Health is the concept that the health of humans, animals, and the environment are interconnected and a One Health approach consists of multidisciplinary teams working together to solve complex problems to improve health, society, and safeguard natural resources. This concept originates from "One Medicine," a term coined by Calvin Schwabe a Professor of Veterinary Medicine at the University of California, Davis. One Medicine is the idea that the course of disease and treatment in humans and animals is fundamentally the same and that human and animal health practitioners and scientists pursue the same general goals for medicine (Schwabe, 1984). In short, those goals are to control and combat disease, ensure food security, safeguard environmental quality, and uphold humane values in society. Failure to do so is a threat to public health.

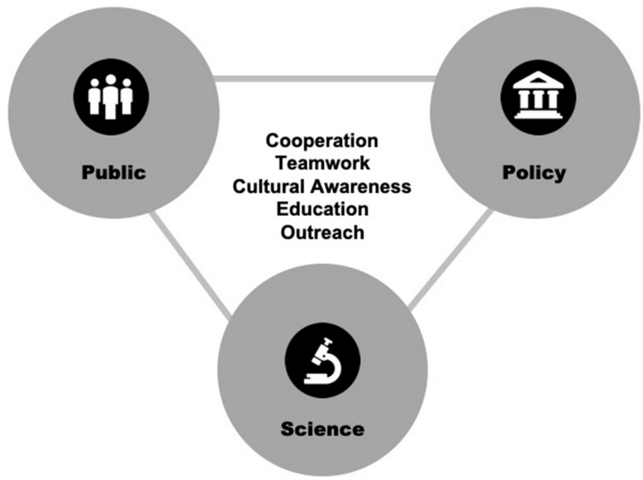

FIGURE 1 | Role of One Health practitioners. One Health practitioners in food safety and security bring together multidisciplinary teams consisting of experts from scientific, government, and public institutions to achieve meaningful change in public awareness, policies, and practices that support implementation of sustainable agricultural practices. It is the role of One Health practitioners to connect scientists, policy makers, and the public in dialog in order to realize meaningful change in agriculture practices and policies for the benefit of society.

One Health can be applied to establish a transformative approach to increasing sustainable practices in agriculture and improving the overall health and well-being of humans, animals, and the environment. As with any One Health program, a multidisciplinary team must work together to achieve these outcomes and we must bring together experts from academic, government, public, and private institutions to achieve meaningful change in public awareness, policies, and practices that support implementation of sustainable agricultural practices (**Figure 1**). Efforts to establish One Health initiatives have gained traction among important policy makers such as World Health Organization (WHO)[1], United Nations Food and Agriculture Organization (FAO), United States Center for Disease Control (CDC), and in the European Union with the One Health European Joint Programme (OHEJP)[2] (FAO, 2011)[3]. Furthermore, organizations such as the American Veterinary Medical Association (AVMA)[4], the Association of American

[1]WHO | One Health WHO. Available online at: http://www.who.int/features/qa/one-health/en/ (accessed April 15, 2019).
[2]One Health EJP. *One Health European Joint Programme*. Available online at: https://onehealthejp.eu/ (accessed September 22, 2019).
[3]CDC National Outbreak Reporting System (NORS). *National Outbreak Reporting System (NORS)*. Available online at: https://wwwn.cdc.gov/norsdashboard/ (accessed June 23, 2019).
[4]AVMA One Health. Available online at: https://www.avma.org/KB/Policies/Pages/One-Health.aspx (accessed September 22, 2019).

Veterinary Medical Colleges (AAVMC)[5], and the American Public Health Association have all embraced this initiative (APHA, 2017). The One Health strategic goal of many of these organizations is to prevent, detect and control disease that pose a major public health risk. Many focus on zoonotic disease, those that are transmitted from animals to humans and vice versa, because ~60% of known human pathogens originate from animals (Woolhouse, ME). Additionally, One Health approaches and curriculum has made its way into research and curriculum at universities in the most recent years (Togami et al., 2018). Many of these programs focus on animal and human health and there is a great need to disseminate the One Health model to other areas of study in science, engineering, and humanities in order to truly achieve collaborative and transdisciplinary approaches to solving complex problems at the intersection of soil, plants, animals, and humans.

Educational institutions around the world are working to implement educational frameworks that integrate One Health and transdisciplinary competencies to enhance the food safety, animal health, and public health workforce (Smulders et al., 2012; Angelos et al., 2016; Togami et al., 2018). In essence, these programs aim to produce graduates which are "One Health Practitioners" and incorporate new pedagogical approaches as scientific knowledge grows exponentially and changes with the advancement of technology and new discoveries in scientific fields (Leslie, 1998). These graduates are the next generation of researchers, which need to have an in depth understanding of topics and know how to effectively use technology to design research studies, collect data, analyze findings, and possess the skills to effectively communicate their work to a broad range of audiences. One health practitioners must work to facilitate collaboration across disciplines and establish a One Health mindset for the generation of scientists as previously outlined in the peer-reviewed article "One Health Curricular framework for food safety and security education" (Angelos et al., 2016). This framework is designed to assist in the development of curriculum that integrates One Health concepts to train the next generation of agriculture and food system workers and is needed to develop knowledge and skills for interdisciplinary teamwork to solve complex challenges.

One Health Practitioners have the knowledge, ability, and responsibility to actively participate in communicating One Health concepts and to increase awareness, outreach, and education of these ideas to society as a whole. Scientists must actively participate and advocate for data driven policies. Likewise, it falls upon One Health practitioners and researchers to ask meaningful research questions in order to improve the well-being and health for the communities in which we work. Establishing open lines of communication, cultural awareness, and understanding are the foundation to having a positive impact on society and policy. Raising general awareness of the goals and significance of One Health will assist in disseminating the One Health approach to decision makers and leaders in education, policy, and health. The responsibility of raising awareness falls to current "One Health Practitioners," who are scientists, academics, and others who have developed competencies in One Health (Togami et al., 2018).

Implementation and practice of the concept of One Health for food safety and security at this time is especially important as 63% of established farmers are over 55 years old and <2% of the population is directly employed directly in agriculture in the United States (Ahearn and Newton, 2009; Bureau of Labor Statistics, United States Department of Labor, 2017). These demographics along with the significant demands for safer foods and a sustainable environment are of utmost importance to consumers and environmentalist alike. The agricultural sector is facing a shortage of farmers and ranchers which may result in a negative impact on the food supply. Promoting One Health for food safety and security is a way to engage the next generation in entering employment and education in agriculture and the food system. Establishing a broader concept of One Health that incorporates the food system, cultural, and societal awareness is essential. Developing a holistic view of biomedical and agricultural sciences can help in transforming traditional academics and researchers into One Health practitioners who work in transdisciplinary teams to solve complex problems at the interface of human, animal, plant and environmental health.

BRIEF HISTORY OF FOOD SAFETY IN THE UNITED STATES: THE SANITARY REFORMATION TO THE TWENTY FIRST CENTURY

The concept of food hygiene and food inspection can be dated back to the age of the Romans in which inspectors would walk markets to inspect meat sales and remove rancid meat from the market. Only since the turn of the twentieth century has scientific research elucidated the role of zoonotic disease in foodborne pathogens (Schwabe, 1984). For example, in the late 1890's and early 1900's, Henry Koplik and Nathan Straus, who were part of the sanitary reform movement, recognized the connection of unpasteurized milk to childhood morbidity and mortality. Their work to provide sterilized milk to infants and children advanced public health and eventually led to regulations on the sale of pasteurized milk as well as the virtual eradication of tuberculosis and brucellosis transmission from ruminants to people in the United States. The Sanitary Reform movement resulted in "the Great Sanitary Awakening," which shifted the prevailing thought that health and transmission of disease was an individual matter to one in which health was a societal and public responsibility beyond the control of an individual. It was left to the "state" to implement social and economic interventions to safeguard public health (Sanitary reform a social movement, 2012).

The Sanitary Reformation laid the groundwork for scientific research of zoonotic, foodborne, and animal diseases which has resulted in advanced understanding of these diseases. Disciplines such as immunology, genetics, epidemiology, and pathology were essential tools in understanding the evolutionary and ecological basis of disease transmission across species and host-pathogen interactions. In the nineteenth century, modern botany found

[5] AAVMC One Health: Promoting a One Health Approach to Global Wellbeing. Available online at: https://www.aavmc.org/strategic-plan/one-health (accessed September 22, 2019).

its roots through the study of genetics, cellular division, and other physiological plant processes. In the twentieth century, plant pathology, the study of disease in plants, emerged from the field of horticulture. It served as a means to improve agricultural production through a concerted effort to safeguard the health of plants (Ainsworth, 1981). This distinction is important to note because it highlights the contrasting philosophical approaches of human and veterinary medicine with those of plant pathology and the gap in knowledge at the interface of plant, human, and animal pathogens. This interface is where produce food safety requires a closer look.

Foodborne illness places an undue burden on health and socioeconomics of society. According to the CDC, one in six Americans experience a bout with food borne illness each year with a total of 48 million new cases of illness, 128,000 hospitalizations, 3,000 deaths, and an economic loss of $77.7 billion annually (Scharff, 2012). Changes in consumer preferences, supported by nutritionists since the 1970's has resulted in a substantial increase in fresh produce consumption. Associated with this increased consumption of raw produce has resulted in exposing more consumers to pathogens found in fresh produce (Callejón et al., 2015). The CDC database National Outbreak Reporting System (NORS) identifies *Salmonella enterica*, Norovirus, and *Escherichia coli,* respectively, as the top 3 pathogens causing foodborne illnesses in fresh produce from 2008 to 2017[4]. In the Unites States, produce is defined under the Food Safety Modernization Act Produce Safety Rule (FSMA-PSR) as, "any fruit or vegetable, and includes mushrooms, sprouts, peanuts, tree nuts, and herbs" (U.S. Food Drug Administration, 2015). During the same period, the top three pathogens in leafy greens, which included lettuce, cabbage, arugula, and kale, were reported as Norovirus, which accounted for the largest cause of food borne illness, followed by *Escherichia coli* and *Salmonella enterica*. These statistics have remained high over the last two decades with no clear trend of increasing or decreasing (Callejón et al., 2015). The United States enacted the FSMA-PSR in 2011 in an effort to reduce foodborne outbreaks in produce by aiming to improve food safety practices throughout the food system. This legislation requires adherence to safe and hygienic food safety practices, training, and documentation of procedures and corrective actions for water quality, harvesting, animal intrusions, and soil amendments (U.S. Food Drug Administration, 2015). Implementation of FSMA-PSR has been difficult and it remains to be seen if these policies will improve food safety. What is clear is the need for further research into how food pathogens interact with water, soil, and plants and how humans and animals contribute to contamination of produce fields. These questions can be better answered through a holistic One Health approach.

FOOD SAFETY IN THE TWENTY FIRST CENTURY: THE NEED FOR A NEW PERSPECTIVE

Studies on Norovirus (NoV) offer an excellent example of the concept of One Health as it involves people, animals, plants and the environmental factors involved in transmitting this highly pathogenic disease. Human norovirus (HuNoV) is widely documented to be the number one cause of foodborne disease in leafy greens and is a highly infectious virus, resistant to common disinfectants. The virus is typically spread by person-to-person contact, aerosolized vomit, fecal material and contaminated food or water (Painter et al., 2013; Kotwal and Cannon, 2014). In agriculture production, it is widely thought that outbreaks occur through improper handling, poor hygiene, and contaminated surfaces. FSMA-PSR focuses heavily on employee health and hygienic practices needed to prevent contamination of produce. However, research suggests there may be other routes of contamination for norovirus.

During the last decade, new research has demonstrated that human pathogens such as Norovirus, *Salmonella enterica* serovar Typhimurium and *Escherichia coli* O157:H7, can be internalized in lettuce, cabbage, radishes, alfalfa, and green onions. Norovirus is the leading cause of food borne illness accounting for 45% of illnesses in produce (Gould et al., 2013). Numerous studies have established that human norovirus is able to attach and internalize in a variety of row vegetable crops (Hirneisen and Kniel, 2013; DiCaprio et al., 2015a,b; Markland et al., 2017; Yang et al., 2018). These studies suggest the multiple routes in which NoV can internalize and transport to various tissues of the plant and the potential immune response of plants to these pathogens. This research indicates internalization is dependent upon (1) production system, (2) initial inoculum, (3) pathogen type, (4) plant type, (5) route of entry, (6) microbial ecology factors (Shaw et al., 2008; Golberg et al., 2011; Ongeng et al., 2015). Furthermore, these works highlight the need for genomic sequencing of agriculturally important plants and further research on immunological interactions of plants with human and animal pathogens.

In 1999, Gibbs and Weiller report genetic evidence of a DNA plant virus that shifted hosts to a vertebrate and following the host shift the virus underwent a recombination event with a RNA virus. Their extensive phylogenetic analysis outlines evidence of a DNA nanovirus switching hosts from a plant host to a vertebrate host. They theorize that part of the nanovirus genome incorporated into the genome of the host vertebrate, which included the viral origin of replication. Their analysis supports that at a later unknown time, subsequent genetic recombination occurred with an RNA virus that was most likely from the Caliciviridae family (**Figure 2**). Upon aligning nanovirus and circovirus replication initiator protein (Rep) sequences, they found significant protein sequence homology. Additionally, when these sequences were aligned, the circoviruses aligned closely with the 2C-protein conserved region of calicivirus (Gibbs and Weiller, 1999). Twenty years has now passed since this analysis was originally conducted. In light of the significant advancements in genomics and the availability of DNA and protein sequencing data, it warrants new analysis to determine if new information can be obtained. Scientific knowledge of genetic recombination tells us it occurs quite regularly especially among RNA viruses and raises the question of viral interactions at the interface of produce, wildlife, and humans.

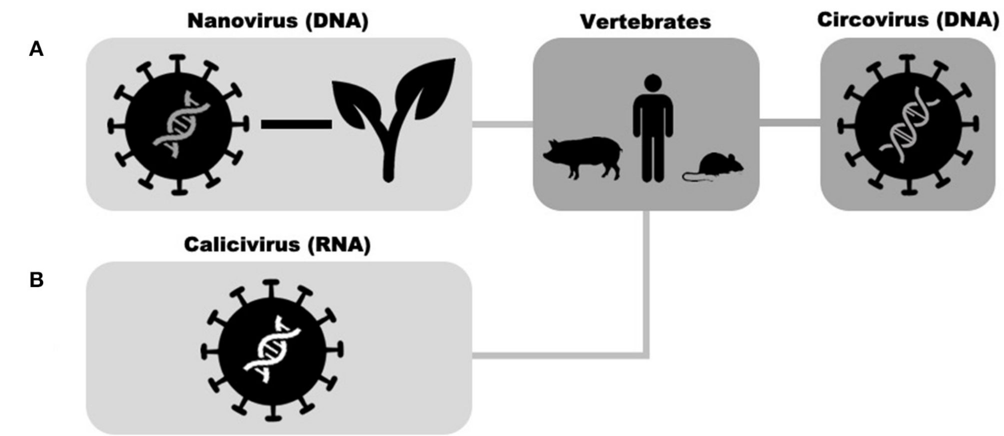

FIGURE 2 | Simplified model of circovirus evolution. Gibbs and Weiller (1999) report protein phylogeny analysis evidence for host switching of a virus from a plant to an unknown vertebrate. **(A)** A plant DNA virus, of the nanovirus family, host switches to a vertebrate, resulting in circovirus lineages. **(B)** Subsequently, a circovirus recombines with an RNA virus, of the calicivirus family, possibly via a reverse transcriptase from a retrotransposon or retrovirus.

Noroviruses belong to the family Caliciviridae and genus Norovirus, which are comprised of non-enveloped single stranded positive sense RNA. There are seven NoV genogroups, Norovirus GI, GII, and GIV infect humans, GIII infect bovine, GII infect swine, GV infect mice, and GVI infects canines. Swine NoV's are found in genogroup GII, which is the same genogroup that is most commonly found to infect humans (Scipioni et al., 2008). Porcine NoV has been found to be very similar to human strains and human NoV has the ability to replicate and induce an immune response in gnotobiotic swine. Studies by Tian et al. (2007) and Cheetham et al. (2006, 2007) found that human NoV and NoV like particles have the ability to bind to swine gastro-intestinal tissues. Mattison et al. (2007) conducted a study that surveyed 120 swine fecal samples and found 20 that were positive for NoV. Of those 20 positive fecal samples, 4 were confirmed to belong to GII.4, which is the most common occurring human genogroup of NoV (Mattison et al., 2007; Eden et al., 2013). Additionally, in 2018, Summa et al. reported finding HuNoV's in 31 out of 115 (27%) wild birds, 2 out of 100 (2%) rats, and 0 out of 85 (0%) mice from fecal samples collected from animals at a dump site in southern Finland. Of the wild bird samples, 25 were positive for NoV GII and the 2 rat samples were positive for NoV GII. The sequences of these genotypes were identical to previously publish HuNoV sequences (Summa et al., 2018). Summa poses the question, "But, how do birds become infected by Human NoVs and can these birds transmit NoVs to humans?" Produce food safety experts know that wildlife intrusions into produce fields are a threat to pre-harvest produce safety. Typically, the concern of animal intrusions is bacterial contamination by feces. However, one possible scenario to answer Summa's question, is that wildlife such as pigs, birds and rodents, can move from garbage sites to produce fields and even into urban areas before returning to their wild habitat, all the while eating, defecating, and spreading fecal pathogens in the environment. These studies clearly show the need for further research into the potential for zoonotic transmission of HuNoV either through mechanical transmission or through permissive carriers of HuNoV as it is well-documented that emerging zoonotic infectious diseases originate in wildlife (Taylor et al., 2001; Jones et al., 2008).

Clearly, further research is required and raises the question of genetic recombination. The generation of recombinant strains of NoV from co-infected animals is a potential public health risk and there are only a handful of studies that focus on this area of research. The use of new technologies is helping expand our knowledge of microbial causes of foodborne diseases. Applications of quantitative polymerase chain reaction (PCR) and Next Generation Sequencing (NGS) has proven to be valuable tools in elucidating the complex interactions of these pathogens (Ronholm et al., 2016). These tools allow a better understanding of the spatial and temporal niches pathogens occupy as well as their relatedness, and genetic factors that can be shared through horizontal gene transfer. All of these studies highlight the need for a new perspective and further research at the interface of wildlife, pathogens, and plants using new approaches. Specifically, investigation of pathogens that are not typically associated with zoonoses, plant responses to human pathogens, how these responses contribute to persistence of pathogens in plants and environment, and the role these interactions may play in the temporal-spatial dynamics of food safety. Understanding the complex nature of foodborne pathogens truly requires a One Health transdisciplinary approach involving microbiologists, pathologists, epidemiologists, veterinarians, animal, plant, and environmental scientists.

FOOD SECURITY IN THE TWENTY FIRST CENTURY: THE THREAT OF DISASTERS AND TRANSBOUNDARY DISEASE

Globally, 820 million people suffer food insecurity and experience chronic hunger and undernourishment. Most of these people live in extreme poverty, earning <$2 per day. Sustainable agricultural production must be the basis to achieve food security, reduce malnutrition, and alleviate poverty. The reduction of undernourishment has seen significant strides over the last 10 years. However, the Food and Agriculture Organization of the United Nations (FAO) recognizes extreme climate and climate variability as a "key driver" for recent increases in global hunger. Disasters, such as hurricanes, floods, tornadoes, wildfires, blizzards, emerging diseases, and earthquakes, have a huge impact on food security by disrupting agriculture production, food availability, access to food and utilization, and stability of food. Any one of these can contribute to outbreaks of disease in humans and animals (IFAD, UNICEF, WFP, WHO and FAO, 2018). Those living in poverty in both developed and developing countries are especially vulnerable to changes in food prices, climactic disasters, and transboundary animal disease, which are the largest threats to food security in the twenty first century (FAO, 2015).

Disasters devastate communities and severely impact society through death, injury, psychiatric trauma, and damage communities and infrastructure (Lindell and Prater, 2003). Additionally, these disasters can escalate biosecurity risks and epidemics in human health, animal health, and environmental health. For example, diarrheal disease outbreaks often occur after hurricanes, with increases of norovirus, *Escherichia coli*, *Salmonella*, and *V. cholerae* occurring in evacuees following Hurricane Katrina (Watson et al., 2007). Additionally, communities experience limited access to medical attention and shortages of medication. Those most vulnerable to these outcomes are poor, children and elderly people. While the focus after a disaster is to aid the communities in responding and recovering, little thought is given to agricultural impacts. Natural events and disasters impact agriculture in several ways (1) loss of animals and crops, (2) destruction of agricultural and rural infrastructure, (3) environmental contamination with pathogens, chemicals, and debris, (4) negative health outcomes of livestock and crops (Shields, 2015; EPA, 2018; MacLachlan et al., 2018). Livestock also are vulnerable to animal disease outbreaks and feed shortages and there is little scientific documentation regarding the incidence of disease following a natural disaster. For these reasons, highlighting the need for formal scientific inquiry of health impacts caused by these events needs further study (USDA, 2002).

Developing countries are most vulnerable to the economic and health impact of disasters. In a study conducted by FAO that surveyed natural disasters from 2003 to 2013, they found that agriculture sectors comprise 25% of disaster related losses and these losses have a negative impact on agricultural commerce and manufacturing. Additionally, employment and food security are also negatively impacted as there is a reduction in agriculture related employment and reduced food availability, resulting in lower family incomes and inflated food prices. Food insecurity can lead to purchasing less food that is of a lower quality resulting in undernourishment. Populations recovering from disasters are already more likely to be vulnerable to public health risks and this is exacerbated by negative impact on livelihood due to food insecurity following disasters FAO (Otte et al., 2004).

Transboundary diseases are another global threat to the health and well-being of humans, animals, and the ecosystem. Epidemics of highly contagious animal diseases can seriously impact society, economic trade, food security, and public health (FAO). Currently, African Swine Fever (ASF) is a transboundary disease affecting swine and wild boars and has nearly a 100% fatality rate (FAO, 2019). ASF is a DNA arbovirus that causes devastating hemorrhagic fever of domestic pigs and wild boar (Garigliany et al., 2019). ASF was first identified in sub-Saharan Africa at the turn of the twentieth century, where it is endemic and transmitted by *Ornithodoros* spp. soft ticks to warthogs. Warthogs are the natural reservoir of this virus in sub-Saharan Africa and they can have persistent infection without clinical symptoms (OIE, 2019). With no available vaccine or treatment for the disease and limited diagnostics available, prevention and control relies on early detection and biosecurity measures (Sánchez-Vizcaíno et al., 2015). However, these prevention and control methods remain difficult to achieve because ASF is persistent in the environment and is easily transmitted via fomites, swill, contaminated meat products as well as by direct contact and soft ticks (Sánchez-Vizcaíno et al., 2012). ASF has subsequently spread to Europe, Russia, and China, where wild boar, swill feeding, contaminated meat products, and biosecurity play a role in outbreaks and continued spread of the virus. ASF does not cause disease in humans and is not a direct public health threat however the spread of ASF has the potential for a major economic impact on the trade of swine globally due to production losses, eradication programs, and embargo on trade from infected countries.

The emergence of ASF in China in August of 2018 has raised concern over the impact of ASF on food security and availability and prices of pork in China and globally. China is the world's largest producer and consumer of pork, accounting for production of 500 million pigs per year, 50% of global pork production (Vergne et al., 2017). The outbreak has resulted in an estimated hog inventory reduction of 14%, 45 million pigs, and a sow inventory reduction of 13%, 4 million sows (Zhang et al., 2019). According to the Chinese General Administration of Customs, these losses have resulted in a 45% increase of meat importation into China from May 2018, at 252,000 tons to May 2019, at 374,600 tons, this includes pork, lamb, beef, and chicken (China Meat Imports Hit Record as Pork Prices Jump on Swine Fever, 2019). It remains to be seen what impact the ASF outbreak in China will have on global meat trade and prices, but ASF has the potential to disrupt global pork production, further complicating trade issues and impacting food insecurity for the lowest socioeconomic classes globally.

Disasters and transboundary diseases can result in agriculture crisis that jeopardize the stability of human, animal, and environmental health and well-being and have lasting implications on livelihoods and food security. Interruptions within the Food and Agriculture sector can have a devastating impact on the global economy. Safeguarding agriculture production and public health from natural disasters and transboundary diseases requires cooperation of multidisciplinary teams working together to prevent, respond, and recover from these events. Ultimately, people, animals, and the environment are all involved and follow the One Health concept.

CONCLUSION

Global food safety and security faces numerous challenges as the human population continues to grow. In the twenty first century, challenges will continue to center on increasing food security globally with food that is safe and nutritious. While there are a range of topics that are essential in this category, this review focuses on microbial contamination of produce, natural disasters, and transboundary disease as these challenges continue to be a threat to food safety and security and are in need of continued discussion and awareness. One Health has the potential to be a holistic and systematic approach to solving these problems. In order to accomplish this One Health education and outreach are necessary for the public as well as policy makers. One Health curriculum in agriculture and food systems education programs can be a way to engage the next generation in farming, agriculture and improving public health through food safety and security. The One Health approach will enable them to acquire the information and develop the skills needed in cooperation, teamwork, and communication that will be necessary to address these challenges.

Farmers, consumers, researchers, government agencies, and consumer advocacy groups play an important role in influencing food safety policies and sustainable food production practices. One Health practitioners need to bring awareness to these stakeholders and provide them with information that allows them to make data driven decisions about food and food practices, and to enact policy and guidelines that protect food safety and safeguard environmental sustainability. To make progress toward finding solutions to these challenges, we must continue to use foundational scientific research to inform regulations, practices and advance technological applications to increase food production, improve sustainable practices, and assess environmental impact. These activities must be supported through funding innovative research and collaborations which provide new information, approaches, and perspectives in food safety, food security and sustainable food production. Additionally, research, policy, and outreach efforts need to benefit the economic well-being of farmers so that they can continue to produce food required to feed 9.7 billion humans. The increased demand for safe foods and agricultural products has the potential to globally improve food security, nutrition, and economic well-being. Innovative agriculture practices and technologies are needed to ensure natural resources are available for future generations.

AUTHOR CONTRIBUTIONS

SG was responsible for writing the majority of the manuscript. BO and MJ-R edited and revised the manuscript text. All authors provided input for the literature review, manuscript preparation, proofreading, and critical analysis of the submitted review.

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