Climate change and food safety

Ariño A.

in

Sanchís V. (ed.), Líebana E. (ed.), Romagosa I. (ed.), López-Francos A. (ed.).
Food safety challenges for mediterranean products

Zaragoza : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 111

2015
pages 103-111

Climate change and food safety

A. Ariño

Veterinary Faculty of the University of Zaragoza
c/ Miguel Servet, 177, 50013 Zaragoza (Spain)

Abstract. Worldwide, climate change is already affecting the biology and ecology of some organisms because of changing patterns in crop production and livestock intensification, as well as altering the transport pathways of chemical contaminants. Consequently, climate change is expected to aggravate feed and food safety problems during all phases of food production and supply. Temperature increases and changes in rainfall patterns will have an impact on the persistence and patterns of occurrence of bacteria, viruses, parasites, fungi, and harmful algae and the patterns of their corresponding foodborne diseases and the risk of toxic contamination. Chemical residues of pesticides and veterinary medicines in plant and animal products will be affected by changes in pest pressure. The food risks of heavy metals and persistent organic pollutants (i.e. dioxins, polychlorinated biphenyls) could rise following changes in soils and long-range atmospheric transport, though quantitative estimates are scarce. This short review presents data on the effect of climate change on biological and chemical food safety hazards, as well as it discusses the need for scientific research and development of improved tools, techniques and practices to adapt the current risk management systems.

Keywords. Climate change – Food safety – Foodborne diseases – Contaminants – Risk assessment.

Le changement climatique et la sécurité alimentaire

Résumé. *Dans le monde, le changement climatique affecte déjà la biologie et l'écologie de certains organismes en raison de l'évolution des modes de production agricole et de l'intensification de l'élevage, ainsi que de la modification des voies de transport des contaminants chimiques. Par conséquent, le changement climatique devrait aggraver les problèmes d'alimentation animale et de sécurité alimentaire à toutes les étapes de la production alimentaire et de l'approvisionnement. Les hausses de température et les changements des précipitations auront un impact sur la persistance et les modes d'apparition des bactéries, virus, parasites, champignons et algues nuisibles et sur les configurations des maladies d'origine alimentaire correspondantes et le risque de contamination toxique. Les résidus chimiques de pesticides et de médicaments vétérinaires dans les produits végétaux et animaux seront affectés par les changements de la pression épidémique. Les risques alimentaires des métaux lourds et des polluants organiques persistants (c'est-à-dire les dioxines, les biphényles polychlorés) pourraient augmenter en raison des changements dans les sols et du transport atmosphérique sur grande distance, bien que les estimations quantitatives soient rares. Cette brève revue présente des données concernant les effets du changement climatique sur les risques biologiques et chimiques de sécurité sanitaire des aliments, et examine les besoins de recherche scientifique et de développement de meilleurs outils, techniques et pratiques pour adapter les systèmes de gestion des risques actuels.*

Mots-clés. *Changement climatique – Sécurité alimentaire – Maladie transmissible par l'aliment – Contaminant – Évaluation du risque.*

I – Introduction

There is widespread agreement that greenhouse gas emissions, among other driving forces, are leading to climate change and this will have a number of impacts, which will include changes in food security and food safety (Lake *et al.,* 2012). Anthropogenic activities have increased concentrations of carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons in the atmosphere, resulting in environmental warming. For instance, current atmospheric carbon dioxide concentrations (400 ppm) have increased by more than 40% from pre-industrial times (280 ppm), and they are expected to reach 550 ppm by the end of 2050 (Challinor *et al.,* 2014). Projections for Europe suggest that climate change will result in warming of 2.1-4.4°C by 2080, with Northern and Eastern Europe expected to become wetter, while the Mediterranean supposed to become drier. Predictions about extreme events are highly uncertain, but heat waves are expected to be more intense, frequent, and longer lasting, whereas extreme precipitation events will increase in northern and Western Europe (EEA, 2007).

In the literature, there is much focus on the effects of climate change on food security (Lobell *et al*., 2011), defined as when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life (WHO, 2014). Additionally, climate change and related disturbances are considered important factors that can cause changes in the nature and occurrence of food safety hazards at various stages of the food chain, from primary production to consumption (Tirado *et al.,* 2010). There are many pathways through which climate related factors may impact food safety including: changes in temperature and precipitation patterns, increased frequency and intensity of extreme weather events, ocean warming, and changes in the transport pathways of complex contaminants.

Temperature increases and changes in rainfall patterns have an impact on the persistence and patterns of occurrence of bacteria, viruses, parasites and fungi and the patterns of their corresponding foodborne diseases and the risk of toxic contamination (Tirado *et al.,* 2010). Climate change may alter the seasonal patterns and abundance of pests and diseases, which may affect pesticide use in plants (Boxall *et al.,* 2009). Elevated temperatures may also lead to the emergence and re-emergence of pathogens and vectors, resulting in greater use of biocides and veterinary medicines in livestock management (Kemper, 2008). Responses will differ between crops and animal production systems and between geographical locations, but changes in pest and disease control measures may have implications for the presence of chemical residues in the food chain. Consequently, an increase in the prevalence of antibiotic-resistant pathogens in animal and human populations is likely (FAO, 2008). The risk of emerging zoonosis may also increase due to climate related changes in the survival of zoonotic agents in the environment, changes in migration pathways, carriers and vectors and changes in the natural ecosystems.

Extreme weather events such as floods and droughts may lead to contamination of soil, agricultural lands, water and food and animal feed with pathogens, chemicals and other hazardous substances, originating from sewage, agriculture and industrial settings. Ocean warming and subsequent physico-chemical changes of marine water may also affect the persistence and patterns of occurrence of pathogenic bacteria, harmful algal blooms and chemical contaminants in fish and shellfish. Climate change may affect the transport of chemicals into food, including aerial inputs of volatile and dust-associated contamination, flooding, and increased bioavailability of heavy metals due to changing environments and soil properties (Boxall *et al*., 2009).

II – Climate change and biological hazards

Climate change could affect existing pathogens or lead to the emergence of new pathogens in food through effects on animal husbandry and animal-to-animal transmission, pathogen survival, and other mechanisms (Tirado *et al.,* 2010). The fact that most foodborne bacterial pathogens can grow at room temperature with faster growth favoured at elevated temperatures means that increases in ambient temperatures may also speed up the rate of pathogen proliferation along the food chain with the subsequent increase in the number of cases (FAO, 2008). Climate change may increase the demand for irrigation water, elevating pathogen risks by manure and sewage contamination. Particularly temperature increase and changes in precipitation pattern have a close relationship not only with the fate and transport of enteric bacteria, but also with their growth and survival. For instance, Liu *et al.* (2013), in a study of the impacts of climate change on the microbial safety of pre-harvest leafy green vegetables, predicted that the contamination risks by pathogenic *Escherichia coli* and *Salmonella* are likely to increase.

Some pathogens probably to be affected by climate change are those with low-infective doses (e.g. *Shigella*, *E coli* serovars) where small changes in distribution or abundance could lead to large outbreaks. Other certainly affected pathogens are those with significant persistence in the environment (e.g. enteric viruses and parasitic protozoa) (FAO 2008). Pathogens with good stress tolerance responses to temperature and pH (e.g. *Salmonella*) may also compete better against other pathogens under climate change. Another aspect to consider is that gene transfer between bacterial species is a common contributor to pathogenicity and antibiotic resistance and is likely to be impacted by changes in the environment caused by climate change.

Gastroenteritis and diarrhoeal disease are important causes of illness in the world and they are climate sensitive, showing strong seasonal variations (Kovats and Tirado, 2006). Higher temperature has been found to be strongly associated with increased episodes of diarrhoeal disease in adults and children worldwide. For instance, diarrhoeal reports in Peru increased 8% for each degree of temperature increase (Checkley *et al.*, 2000). Increased rates of water-borne diarrhoeal diseases such as cholera, cryptosporidiosis and typhoid fever have been reported after flood events (Tirado *et al.*, 2010).

As reviewed by Van der Spiegel *et al.* (2012), there are several ways in which climate change may affect infectious diseases (Fig. 1). First, hot and humid conditions can cause heat stress in livestock, which will induce a higher vulnerability to diseases. Climate change may bring about substantial shifts in disease distribution, and outbreaks of severe disease could occur in previously unexposed animal populations. Second, higher temperatures may increase the rate of development of pathogens or parasites, which may lead to larger populations. Changes to winds could affect the spread of certain pathogens and vectors. In turn, other pathogens that are sensitive to high temperatures and moist or dry conditions may have their survival compromised and decrease with climate warming. Also, there may be several impacts of climate change on the distribution and the abundance of disease vectors (e.g. flies, ticks, mosquitoes). Finally, farming and husbandry practices (including the use of veterinary drugs) will be affected due to climate related changes.

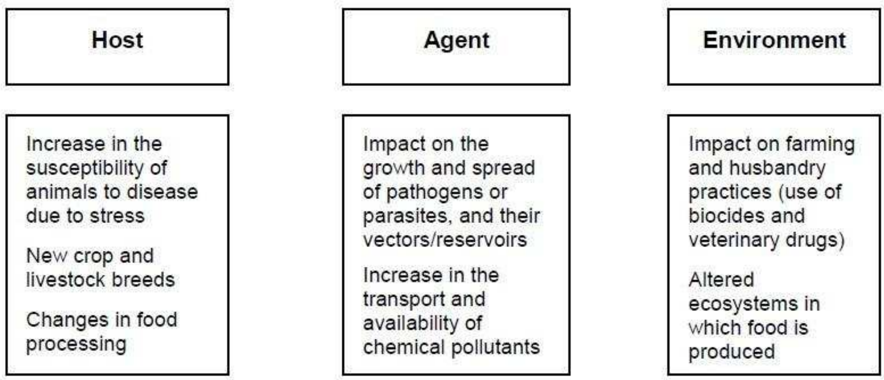


Fig. 1. Some pathways through which climate related changes and variability may impact all three elements of the epidemiologic triad: host, agent, and environment. Adapted from Tirado *et al.*, 2010.

Foodborne diseases that have been identified as a priority because of changing climate conditions include salmonellosis, campylobacteriosis, vibriosis, other bacterial infections, viral diseases, and parasitic infections (ECDC, 2007).

1. Salmonellosis

Previous research has demonstrated that *Salmonella* infections in humans are positively associated with temperature. A time series analysis study on human salmonellosis in several European countries showed that, in general, cases of salmonellosis increased by 5–10% for each one-degree increase in weekly ambient temperature (Kovats *et al.,* 2004). Infection with *Salmonella* Enteritidis appeared to be more sensitive to the effects of environmental temperature, at least as compared with infections caused by *Salmonella* Typhimurium.

2. Campylobacteriosis

The role of climate related parameters such as short-term increases in ambient temperature on human campylobacteriosis is unclear (Kovats *et al.*, 2005). Although associations between human cases and weather exist, the seasonality is less pronounced and the biological mechanisms underpinning these associations are not fully understood, which makes it difficult to predict the effects of climate change on campylobacteriosis infection.

3. Vibriosis

Higher temperatures, flooding and changes in water salinity may all have an impact on water microbiota including aquatic human pathogens such as the pathogenic *Vibrio* spp. (FAO, 2008). Large outbreaks attributed to the consumption of oysters contaminated with *Vibrio parahaemolyticus* have been linked to higher mean water temperatures in the Gulf Coast of the US. Additionally, changes in epidemiology have been noted since new serovars of *V. parahaemolyticus* such as O3:K6 have emerged and spread, even though a definitive relationship to global climate change has yet to be made (Tirado *et al.*, 2010). The global epidemiology of foodborne *V. vulnificus* infection revealed a statistically significant increase in the number of cases when summer temperatures peaked. Infection by the enteric pathogen *Vibrio cholera,* which is usually transmitted to humans through contaminated water, is endemic in certain tropical and subtropical regions of the world. In these areas, there are characteristic epidemic peaks which are frequently seasonal (Marques *et al.*, 2010).

4. Viral foodborne diseases

Viruses do not grow in foods and many of the viruses which cause gastroenteritis in human do not have a readily demonstrated relationship to ambient temperature. Three major routes of viral contamination of foods have been identified: human sewage and faeces; infected food handlers; and animals for zoonotic viruses (FAO/WHO, 2008). All these routes may be influenced by climate-induced changes. For example flooding can result in the overflow of untreated human sewage, resulting in increased likelihood of enteric virus contamination during the production of fresh produce and molluscan shellfish.

5. Parasitical agents and foodborne diseases

There is a causal relationship between climate change and emerging parasitic diseases (Poulin and Mouritsen, 2006). Several studies in different geographical regions of the US and Europe show that climate related variability, such as changes in precipitation affect the incidence of parasitical foodborne and water-borne diseases transmitted by protozoan parasites such as cryptosporidiosis and giardiasis (ECDC, 2007). Likewise, global warming and increased temperature may affect the transmission cycle of foodborne trematodes of public health significance such as *Fasciola*, *Clonorchis, Schistosoma* and *Paragonimus* (Poulin and Mouritsen, 2006), which are transmitted by the consumption of raw or undercooked freshwater fish, crabs, crayfish and plants. All trematodes use molluscs (generally snails) as first intermediate hosts for the production of infective cercariae, and an increase in temperature is almost invariably coupled with a larger cercarial output.

III – Climate change and chemical hazards

The chemical safety of food (toxins, contaminants, residues) varies by food type and where it is produced, making it difficult to assess associated changes in food safety when consuming different types of food produced in different geographical areas. Mycotoxins, an important public health concern, are formed through complex interactions between fungi and crops and are affected by weather conditions such as temperature, humidity and precipitation. A recent review indicated increasing problems of aflatoxins in parts of temperate Europe and the United States as climate change-associated temperature rises approach the optimal level for production of aflatoxins, one of the most important mycotoxins from a public health point of view (Paterson and Lima, 2010).

Freshwater and coastal environments are likely to be especially vulnerable to climate change because aquatic ecosystems are fragile (FAO, 2008). A number of human illnesses are caused by consuming seafood (especially shellfish) containing natural toxins produced by algal blooms, which are predicted to be more common and more widely distributed in coming decades (FAO, 2008).

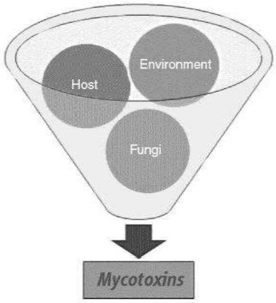
It is generally accepted that climate change may lead to altered chemical inputs to food. Greater use of biocides, pesticides and veterinary medicines is likely in some areas, increasing the presence of chemical residues as well as the prevalence of antibiotic-resistant pathogens Changes in transport pathways may also affect contaminant inputs to agricultural systems and food (Miraglia *et al.,* 2009). Flooding is one mechanism for transporting chemical contaminants onto agricultural land and may increase due to climate change (Boxall *et al.*, 2009). In addition altered contaminant inputs to surface waters may have impacts upon aquatic species that are subsequently consumed. Increases in the aerial inputs of volatile and dust-associated contamination may also occur, posing increased risks for human health and the environment.

1. Mycotoxins

Environmental factors such as favourable temperature and water activity are crucial for mycotoxigenic fungi and mycotoxin production both in pre-harvest and post-harvest scenarios (Fig. 2). In general, if the temperature increases in cool or temperate climates, the relevant countries may become more liable to mycotoxins such as aflatoxins during harvest and storage. Aflatoxins mycotoxins represent a serious health hazard as aflatoxin B1 is classified as IARC Group 1 carcinogenic to humans (Iqbal *et al.*, 2013). This imposes an additional threat to human health since this toxin is transferred to milk when lactating dairy cattle are fed with aflatoxin B1 contaminated feedstuffs (van der Spiegel *et al.*, 2012).

Environmental conditions such as temperature, humidity, gas composition and sunlight, affect the growth of mycotoxigenic fungi. The major toxins that contaminate maize and small grain cereals (wheat, triticale, barley) are deoxynivalenol and zearalenone, as well as fumonisins and aflatoxins on maize; type-A trichothecene mycotoxins T2 and HT2 affect mainly oats and barley. Recent studies by van der Fels-Klerx et al. (2012a; 2013) indicated that climate change could increases deoxynivalenol contamination of wheat in north-western Europe by up to 3 times, while for maize, an overall decrease in deoxynivalenol contamination was projected. However, variability between regions and crop years was large, illustrating the need of carefully considering both direct and indirect effects when assessing climate change impacts on crops and related food safety hazards. An important indirect factor is that the feeding rate of many arthropod vectors (i.e. corn borers) increases at higher temperatures, thus increasing exposure of crops to mycotoxigenic fungi (i.e. *Fusarium* spp.), and hence the spread of mycotoxins.

Thermotolerant fungal species are adapted to warmer climate, and, for example, *Aspergillus flavus* (i.e. aflatoxins) may become more problematic than *Penicillium verrucosum* (i.e. ochratoxin A) in temperate Europe (Paterson and Lima, 2010). As another example of the effect of climate on fungal disease, increasing atmospheric CO_2 concentration will directly increase the amounts of *Fusarium* Head Blight and the subsequent risk of trichothecene mycotoxins (Chakraborty and Newton, 2011).This increased susceptibility is probably due to changes in the host physiology and morphology rather than a more infective pathogen.



Aflatoxins	Peanuts, oilseeds, nuts (pistachios), dried fruits, cereals (corn), spices; milk (for aflatoxin M1)
Ochratoxin A	Cereals, grapes, coffee, cocoa, spices, liquorice
Trichotecenes	Cereals, pasta, bread, breakfast cereals
Zearalenone	Cereals, bread, corn oil
Fumonisins	Corn, breakfast cereals
Patulin	Fruit juices, apple products, baby foods
Citrinin	Cereals (rice)
Ergot alkaloids	Cereals

Fig. 2. The system of fungi, host and environmental conditions must be all functioning for mycotoxin production in susceptible commodities. Adapted from Iqbal *et al.*, 2013 and Patterson and Lima, 2010.

2. Algal toxins

Some algal species (mainly dinoflagellates and diatoms) produce toxins usually when they bloom, and these marine biotoxins can accumulate in filter-feeding shellfish and some fish species and cause food poisonings in humans, which can be very serious. The most common illnesses associated with algal toxins are ciguatera fish poisoning (CFP), paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), azaspiracid shellfish poisoning (AZP), diarrhetic shellfish poisoning (DSP), and neurotoxic shellfish poisoning (NSP). Global increase of harmful algal blooms in recent decades has been linked to eutrophication of water bodies, the transport of harmful algae species in ships' ballast water, and climate changes (Marques et al., 2010). The observed increase in frequency, duration, and geographic scope of algal blooms has been associated with warmer than usual conditions, so projected warming is likely to result in even greater problems in the future. A study of climate change projections for the years 2030-2050 (van der Fels-Klerx *et al.,* 2012b) reported that the frequency of harmful algal blooms of *Dinophysis* spp. may increase, but consequences for contamination of shellfish with diarrhetic shellfish toxins are uncertain.

3. Chemical contaminants

Human activities have resulted in the release of several chemical contaminants into the environment in the last decades. These include toxic metals (e.g. mercury, cadmium, lead) and persistent organic chemicals, like dioxins and polychlorinated biphenyls (PCBs), among others (Marques *et al.,* 2010). For instance, chemical contaminants enter marine ecosystems via direct discharges from land-based sources (e.g. industrial and municipal wastes), atmospheric deposition from local and distant sources, and ships (Schiedek *et al.,* 2007). Many contaminants accumulate in sediments, where they can remain for very long periods, and in the food-web where they can reach high concentrations in top-level predators and ultimately affect human health. Climate change impacts on hydrographic conditions are expected to directly influence the availability and toxicological effects of chemical and biological contaminants. Warmer water temperatures and changes to precipitation and stream flow patterns may exacerbate many forms of water pollution with toxic metals and persistent organic chemicals.

The salinity of coastal and estuarine systems will experience fluctuations arising from changes to precipitation and stream flow patterns. Salinity may affect the toxicity of various classes of toxic metals due to either bioavailability or physiological factors. In particular, metals like cadmium and mercury are taken up more rapidly by molluscs and crustaceans at reduced salinities (Hall and Anderson, 1995). Likewise, temperature-related increases in the uptake, bioaccumulation and toxicity of metals have been reported for crustaceans, echinoderms and molluscs (Wang *et al.,* 2005). Warmer water temperatures facilitates mercury methylation, and the subsequent uptake of methyl mercury by fish and mammals has been found to increase by 3–5% for each 1ºC rise in water temperature (Booth and Zeller, 2005). Similarly, cadmium bioaccumulation by blue mussel *Mytilus edulis* was higher at 12ºC than at 2ºC, as well as lead uptake increased at 26ºC as compared to 6ºC.

IV – Conclusions

In the future, food systems are likely to change for a number of reasons, including climate change as a very important factor. An altered climate will mean that food will be produced under different environmental conditions and, coupled with adaptations to and mitigations against climate change, food production will be very different in the future. These changes will result in emerging pathogens, altered use of pesticides and veterinary medicines and will likely affect the main transfer mechanisms through which contaminants move from the environment to food, with implications for food safety.

Some pathogens and chemicals are transferred from animals to humans, so monitoring of animal health may enable us to detect threats before human infection occurs. Development of rapid detection methods for pathogens and chemicals in food, and surveillance systems to report these quickly, may enable action to be taken in a timely manner. Furthermore, it is recommended to closely monitor levels of mycotoxins and marine biotoxins, in particular related to risky situations associated with favourable climatic conditions for toxin producing organisms.

The common theme arising for food safety is altered risks and increasing unpredictability and change (Jacxsens *et al.,* 2010). Greater unpredictability suggests the need for increased surveillance to identify potential hazards before they occur, and greater speed in addressing emerging threats. Risk managers are encouraged to pay attention to the continuity of collecting the right data, and the availability and accessibility of databases, as well as the harmonisation of terminology and data collection. The situation demonstrates the need for scientific research and development of improved tools, techniques and practices to adapt the current risk management systems.

Acknowledgments

This review was supported by the Spanish MICINN (Project AGL2011-26808), the Government of Aragón (Grupo de Investigación Consolidado A01), and the European Social Fund.

References

Booth S. and Zeller D., 2005. Mercury, food webs, and marine mammals: Implications of diet and climate change for human health. In: *Environmental Health Perspectives*, 113(5), p. 521-526.

Boxall A., Hardy A., Beulke S., Boucard T., Burgin L., Falloon P., Haygarth P., Hutchinson T., Kovats S., Leonardi G., Levy L., Nichols G., Parsons S., Potts L., Stone D., Topp E., Turley D., Walsh K., Wellington E. and Williams R., 2009. Impacts of climate change on indirect human exposure to pathogens and chemicals from agriculture. In: *Environmental Health Perspectives,* 117(4), p. 508-514.

Chakraborty S. and Newton A.C., 2011. Climate change, plant diseases and food security: an Overview. In: *Plant Pathology,* 60, p. 2-14.

Challinor A.J., Watson J., Lobell D.B., Howden S.M., Smith D.R. and Chhetri, N., 2014. A meta-analysis of crop yield under climate change and adaptation. In: *Nature Climate Change,* 4, p. 287-291.

Checkley W., Epstein L.D., Gilman R.H., Figueroa D., Cama R.I., Patz J.A. and Black R.E., 2000. Effects of El Niño and ambient temperature on hospital admissions for diarrhoeal diseases in Peruvian children. In: *Lancet*, 355, p. 442-450.

ECDC, 2007. Environmental change and infectious disease workshop. European Centre for Disease Prevention and Control. Meeting report. Stockholm (Sweden), 29-30 March 2007.

EEA, 2007. Europe's environment – The fourth assessment. Copenhagen, European Environment Agency.

FAO, 2008. Climate change: Implications for food safety. Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/010/i0195e/i0195e00.htm

FAO/WHO, 2008. Viruses in food: Scientific advice to support risk management activities. Food and Agriculture Organization of the United Nations/World Health Organization: Meeting report. Microbiological risk assessment series 13. Rome. 74 pp.

Hall L.W. and Anderson, R.D., 1995. The influence of salinity on the toxicity of various classes of chemicals to aquatic biota. In: *Critical Reviews in Toxicology*, 25(4), p. 281-346.

Iqbal S.Z., Asi, M.R. and Ariño A., 2013. Aflatoxins. *Brenner's Encyclopedia of Genetics* (Second Edition), Elsevier. pp. 43-47.

Jacxsens L., Luning P.A., van der Vorst J.G.A.J., Devlieghere F., Leemans R. and Uyttendaele M., 2010. Simulation modelling and risk assessment as tools to identify the impact of climate change on microbiological food safety – The case study of fresh produce supply chain. In: *Food Research International*, 43, p. 1925-1935.

Kemper N., 2008. Veterinary antibiotics in the aquatic and terrestrial environment. In: *Ecological Indicators*, 8, p. 1-13.

Kovats R.S., Edwards S.J., Charron D., Cowden J., D'Souza R.M., Ebi K.L., Gauci C., Gerner-Smidt P., Hajat S., Hales S., Hernández Pezzi G., Kriz B., Kutsar K., McKeown P., Mellou K., Menne B., O'Brien S., van Pelt W. and Schmid H., 2005. Climate variability and campylobacter infection: An international study. In: *International Journal of Biometeorology*, 49, p. 207-214.

Kovats S. and Tirado M.C., 2006. Climate, weather and enteric disease. In: B. Menne and K. L. Ebi (Eds.), *Climate change and adaptation: Strategies for human health*, pp. 269-290. Darmstadt: WHO, Steinkopff Verlag.

Kovats S., Edwards S., Hajat S., Armstrong B., Ebi K. and Menne, B., 2004. The effect of temperature on food poisoning: Time series analysis in 10 European countries. In: *Epidemiology Infection*, 132(3), p. 443.

Lake I.R., Hooper L., Abdelhamid A., Bentham G., Boxall A.B.A., Draper A., Fairweather-Tait S., Hulme M., Hunter P.R., Nichols G. and Waldron K.W., 2012. Climate Change and Food Security: Health Impacts in Developed Countries. In: *Environmental Health Perspectives*, 120(11), p. 1520-1526.

Liu C., Hofstra N. and Franz E., 2013. Impacts of climate change on the microbial safety of pre-harvest leafy green vegetables as indicated by *Escherichia coli* O157 and *Salmonella* spp. In: *International Journal of Food Microbiology*, 163, p. 119-128.

Lobell D.B., Schlenker W. and Costa-Roberts J., 2011. Climate trends and global crop production since 1980. In: *Science*, 333, p. 616-620.

Marques A., Nunes M.L., Moore S.K. and Strom M.S., 2010. Climate change and seafood safety: Human health implications. In: *Food Research International*, 43, p. 1766-1779.

Miraglia M., Marvin H.J., Kleter G.A., Battilani P., Brera C., Coni E., Cubadda F., Croci L., De Santis B., Dekkers S., Filippi L., Hutjes R.W., Noordam M.Y., Pisante M., Piva G., Prandini A., Toti L., van den Born G.J. and Vespermann A., 2009. Climate change and food safety: An emerging issue with special focus on Europe. In: *Food and Chemical Toxicology*, 47(5), p. 1009-1021.

Paterson R.R.M. and Lima N., 2010. How will climate change affect mycotoxins in food? In: *Food Research International*, 43, p. 1902-1914.

Poulin R. and Mouritsen K. N., 2006. Climate change, parasitism and the structure of intertidal ecosystems. In: *Journal of Helminthology*, 80, p. 183-191.

Schiedek D., Sundelin B., Readman J.W. and Macdonald, R.W., 2007. Interactions between climate change and contaminants. In: *Marine Pollution Bulletin*, 54, p. 1845-1856.

Tirado M.C., Clarke R., Jaykus L.A., McQuatters-Gollop A. and Frank J.M., 2010. Climate change and food safety: A review. In: *Food Research International*, 43, p. 1745-1765.

Van der Fels-Klerx H.J., Olesen J.E., Madsen M.S. and Goedhart P.W., 2012a. Climate change increases deoxynivalenol contamination of wheat in north-western Europe. In: *Food Additives & Contaminants: Part A*, 29 (10), p. 1593-1604.

Van der Fels-Klerx H.J., Olesen J.E., Naustvoll L.J., Friocourt Y., Mengelers M.J.B. and Christensen J.H., 2012b. Climate change impacts on natural toxins in food production systems, exemplified by deoxynivalenol in wheat and diarrhetic shellfish toxins. In: *Food Additives & Contaminants: Part A*, 29 (10), p. 1647-1659.

Van der Fels-Klerx H.J., van Asselt E.D., Madsen M.S., and Olesen J.E., 2013. Impact of Climate Change Effects on Contamination of Cereal Grains with Deoxynivalenol. In: *PLOS ONE*, 8 (9), p. 1-10.

Van der Spiegel M., Van der Fels-Klerx H.J. and Marvin H.J.P., 2012. Effects of climate change on food safety hazards in the dairy production chain. In: *Food Research International*, 46, p. 201-208.

Wang J., Chuang C.-Y. and Wang W.-X., 2005. Metal and oxygen uptake in the green mussel *Perna viridis* under different metabolic conditions. In: *Environmental Toxicology and Chemistry*, 24(10), p. 2657-2664.

WHO, 2014. Trade, Foreign Policy, Diplomacy and Health. Food Security. World Health Organization. http://www.who.int/trade/glossary/story028/en/