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Original citation & hyperlink:
Alsanius, BW, Von Essen, E, Hartmann, R, Vagsholm, I, Doyle, O, Schmutz, U, Stützel, H, Fricke, A & Dorais, M 2019, 'The “one health”-concept and organic production of vegetables and fruits', Acta Horticulturae, vol. 1242, pp. 1-14.
https://dx.doi.org/10.17660/ActaHortic.2019.1242.1

DOI 10.17660/ActaHortic.2019.1242.1
ISSN 0567-7572

Publisher: International Society for Horticultural Science (ISHS)

The original publication is available at:
https://www.actahort.org/members/showpdf?booknrarnr=1242_1.

The "one health"- concept and organic production of vegetables and fruits

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Abstract

Although the organic production concept is characterised by an efficient and environmentally sound production that is based on a few off-farm inputs as well as recycling organically grown products. Organic products are often perceived as safer and more promotive to consumers' health as compared to products from conventional or integrated production systems. However, from a hygienic point of view, animal husbandry and plant crop production can share a larger contact interface in organic farming than in conventional or integrated production systems due to a higher usage of animal waste products and composts which are mainly used for soil health and fertility purposes. Furthermore, animals may also play an integral part in crop rotation/management (i.e., pasture) in organic horticulture. However, there are also organic systems which exclude any livestock inputs (vegan organic). This paper assesses the organic production of fruits and vegetables in light of the "one health"- concept. The "one health"-concept encompasses human medicine, veterinary medicine and husbandry science with zoonoses as the linking element. However, this concept does not consider plant foods as a potential health hazard. In light of the "one health"- concept, the organic production of fruits and vegetables, in particular for products that are consumed raw or after minimal processing, is a hotspot for the transmission of fecal pathogens and completes the pathogens' transmission cycle between animals and humans and/or humans and humans. This review focuses on four critical routes of transmission (i) soil and soil fertility management, ii) irrigation water, iii) presence of livestock and wildlife, iv) humans) and discusses the measures (risk assessment, hurdle concept, guidelines and risk based inspection regimes) to be taken for the organic (and conventional with livestock inputs) production of safe fruits and vegetables. We concluded that a mixture of measures is available to manage risks within the "one health"- concept and this includes a choice for consumers to source more vegan organic products that are produced without any animal inputs.

Keywords: foodborne illnesses, guidelines, intervention strategies, irrigation water, microbial activity, *Listeria* spp., organic manure, *Salmonella* spp., shigatoxigenic *E. coli* (STEC), soil management, stock-free, vegan organic, workers' health and hygiene

INTRODUCTION

To meet the global grand challenges of food security, sustainable approaches for crop production are important tools. The wise use of resources and crop inputs are key elements of organic production systems. According to the International Association of Organic Farm Movements (IFOAM), organic agriculture is based on the four principles of:

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i) health (“should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible”);
ii) ecology (“should be based on living ecological systems and cycles, work with them, emulate them and help sustain them”);
iii) fairness (“should build on relationships that ensure fairness with regard to the common environment and life opportunities”); and
iv) care (“should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment”) (IFOAM, 2016).

From a European perspective, organic farming is the only production system that is defined in European legislation (European Commission, 2014, 2008; European Union, 2007). According to council regulation (EC) no 834/2007 (2007), organic production pursues:

i) to “establish a sustainable management system for agriculture”;
ii) to “aim at producing products of high quality”; and
iii) to “aim at producing a wide variety of foods and other agricultural products that respond to consumers’ demand for goods produced by the use of processes that do not harm the environment, human health, plant health, or animal health and welfare”.

Hence, based on the European legislative framework, the primary objective of organic farming considers the environment. Within the framework of a visionary paper, Alsanius et al. (2017b) recently presented a concept for forthcoming developments within organic greenhouse (OGH) production. They advocated for an expansion of the OGH concept based on scientific insights with the objective of bringing about a paradigm shift towards a system based approach integrating the different levels of the domains of “environment” and “people”.

Despite its environmentally based concept and lack of medical insights to support enhanced health benefits (Smith-Spangler et al., 2012) or evidence of critical pesticide concentrations in non-organic produce (EFSA, 2014), organically produced plant foods are often assumed to have stronger health promoting properties than others that are produced in conventional or integrated production systems. This perception may have been enhanced not only by the recent numerous outbreaks of food illnesses associated with conventionally produced fruits and vegetables as reviewed by Mandrell (2009) and others, but also by the concerns related to pesticide residues, genetically modified organisms as well as food additives (Stolz et al., 2011). The wide availability of less healthy foods is judged today to be one of the largest risk factors for the poor human health of the populace (WHO, 2002). The reasons for consumers choosing organic food are complex and based mostly on egoistic and altruistic motives. They are more of an expression of a reflexive, responsible lifestyle encompassing political, ethical as well as health and wellbeing considerations (Hjelmar, 2011; Magnusson et al., 2003; Stolz et al., 2011; von Essen and Englander, 2013). Among young organic consumers, conventionally produced plant foods and meat are increasingly recognized as risk factors in terms of both safety and quality. Particularly, pesticides in foods are perceived to be threatening to their mental and physical health (von Essen and Englander, 2013). The preference for organic food has become a strategy to achieve sustainability and resilience and is described as an awakening when combined with the exchange of meat for vegetables. Organic food appears as a vehicle for achieving health, well-being and good lifestyle. Also young vegetarian consumers have a conviction that it is possible to eat and cook food in a way that is more sustainable both for the individual and for the society (von Essen and Mårtensson, 2014).

However, the narrow margin between animal husbandry and the use of recycled animal waste materials in organic plant production poses a potential risk to human health in terms of zoonoses. This is of a special interest in respects to fruits, berries, vegetables and herbs that are consumed raw or after minimal processing without any steps being taken to eliminate potential food borne pathogens.

The “one health”-(OH)-concept is defined as “…an integrated approach to health that focuses on the interactions between animals, humans and their diverse environments. It encourages collaborations, synergies and cross-fertilisation of all professional sectors and actors in general whose activities may have an impact on health" (European Union, 2016). It links human medicine with veterinary medicine and environmental and husbandry sciences through zoonoses. However, this concept has not considered plant foods as a vehicle for health hazards. In light of the "one health" concept, organically grown fruits and vegetables, in particular products that are consumed raw or after minimal processing, can be hot spots for the transmission of fecal pathogens adding another transmission cycle for zoonoses and biological hazards linking animals and humans and/or humans and humans. This was illustrated by the tragic outbreak caused by the shigatoxigenic *E. coli* strain O104:H4 that originated from organically produced sprouts in Germany and France in 2011. This paper focuses on the perceptions, beliefs and food hazards related to organically grown fruits and vegetables in light of the OH-concept.

BACKGROUND

Definitions

- Food safety: "biological, chemical or physical agent in, or condition of food with the potential to cause an adverse health effect" (FAO/WHO, 2003).
- Hurdle: …"a factor, a condition, or a processing step that limits, retards or prevents microbial growth, and/or reduces the microbial load, but which by itself cannot keep microbiological hazards under control. A microbiocidal hurdle is a hurdle that, by various means, reduces the concentration of microorganisms in the product while a microbiostatic hurdle is a hurdle that, by various means, limits, retards or prevents microbial growth in the product" (CAC/RCP, 2004).
- "One health": …"an integrated approach to health that focuses on the interactions between animals, humans and their diverse environments. It encourages collaborations, synergies and cross-fertilisation of all professional sectors and actors in general whose activities may have an impact on health" (European Union, 2016).
- Zoonosis: disease "transmitted from vertebrate animals to man" (Pan American Health Organization, 2001).

Food safety aspects

Food safety hazards are comprised of three distinct groups of hazards: biological, chemical and physical. In context of this paper, our focus is mainly on biological hazards. Statistics of the various disease outbreaks related to fruits and vegetables indicate that organic produce are frequently implicated. Examples for such outbreaks that are explicitly linked to organic produce are the 1995-outbreak of verocytotoxigenic *Citrobacter freundii* associated with organically grown parsley in north-west Germany (Tschäpe et al., 1995), the 2011-outbreak of the shigatoxigenic *Escherichia coli* O104:H4 associated with sprouted fenugreek seeds in Germany/France with 3842 registered cases (of these 855 with haemolytic-uremic syndrome (HUS) and 53 deaths) (Beutin and Martin, 2012) and the 2012- outbreak of *E. coli* O157:H7 associated with spinach and spring seeds in the USA with 33 registered cases.

The costs of such outbreaks, in addition to the deaths of individuals, are substantial and include societal costs and economical losses due to health care costs and sick leave (Sundströmm, 2007; Toljander et al., 2012), as well as losses sustained by primary producers and food business operators as well as other trade implications. They do not only concern the commodity responsible for the outbreak but also spin off to affect other produce as well, which was demonstrated especially during and after the German fenugreek outbreak. The multistate outbreak caused by *E. coli* O104:H4 related to fenugreek sprouts, European horticultural producers suffered a loss of more than 800 million Euros during the first two weeks of the outbreak (Bitsch et al., 2015). For example Spanish cucumbers were erroneously implicated initially as being the source of the outbreak, which resulted in large implications for Spanish farmers. In addition, consumers may change their purchasing habits due to such news and this may endure over a long time which is reflected in the drop in market prices (Bitsch et al., 2015). Also additional safety management procedures during primary production is an additional cost that is mostly not acknowledged in terms of wholesalers, retailers or consumers' willingness to pay a higher price.

Prominent microbial agents involved in food borne illnesses in fruits, berries and vegetables are enterotoxigenic; as well as shigatoxigenic *E. coli*, *Salmonella* spp., *Yersinia enterocolitica*, *Listeria monocytogenes*, *Shigella* spp., *Bacillus cereus*, *Cyclospora cayetanensis*, *Cryptosporidium parvum*, as well as *Norwalk virus* (Norovirus) and *Hepatovirus A* (Hepatitis A). Many of these microorganisms follow the fecal-oral direct or indirect route of transmission and are closely related to the animal-human contact interface where animals may act as their asymptomatic reservoir. On the other hand, organisms such as *Listeria monocytogenes* and *Bacillus cereus* are ubiquitous in the environment and pose a constant risk.

Plant colonization

Seeds and plants are epi- and endophytically colonized by microorganisms (Golberg et al., 2011; Hartmann et al., 2017a; Hirneisen et al., 2012; Hora et al., 2005; Wright et al., 2013) and the individual plants appear to influence their associated microbial community structure, they select specific microorganisms to colonize their tissues (Rosberg et al., 2014), a feature that may not be influenced by management practices. An ongoing argument of whether microorganisms like human enteric pathogens which are not commonly grouped as plant colonizers, end up on plants by accident or if the different plant cultivars might actually be more or less conducive to supporting growth of human pathogens (Teplitski et al., 2009). In general, the factors for a successful plant colonization by these human pathogens include nutrients availability, water availability, temperature, electromagnetic radiation, atmospheric composition, pH, redox potential as well as surface potential for colonization, spatial relationships, microbial community composition and microbial interactions. As a habitat, the phyllosphere is often described as harsh, due to the considerable variations in nutrients availability, temperature, humidity and UV-irradiation (Brandl, 2006; Brandl and Mandrell, 2002; Leveau, 2006; Lindow and Brandl, 2003; Lindow and Leveau, 2002). However, few studies have delved into the interactions between environmental factors, plant species and microbial community structure (Alsanius et al., 2017a; Alsanius et al., submitted; Kadivar and Stapleton, 2003; Rastogi et al., 2012).

Favourable microbial colonization sites in the phyllosphere are in the proximity of stomata, trichoma, leaf veins as well as injuries or open wounds on plant tissues. Thus, the colonization is variable. Unless human pathogens were already present on the seeds and colonized the developing plants as they grew, human pathogens spreading on a crop stand could be considered immigrants. This means that they compete for space and nutrients with other epiphytes. To be a successful intruder, human pathogens either need to outcompete the microbes already present in the microbial aggregates or be protected by other colonizers. Such interactions with the resident microbial aggregates could either enhance or inhibit the survival of the immigrant microbes in a strain-dependent manner. For example, *Salmonella enterica* integrated into the existing microbial aggregates on the leaves of edible plants was less prone to acute death upon desiccation due to them being coincident with several strains of *P. syringae* and *E. herbicola* (Poza-Carrion et al., 2013).

Leaf properties, such as leaf age (Brandl and Amundson, 2008) as well as injuries have been listed as important factors for leaf colonization (Brandl, 2008). Injuries act as both leakage sites for organic nutrients beneficial to microbial growth and entrances for passive and active invasions of the plant endosphere. This highlights the connection between plant health, in the context of organic farming, food safety and OH concept.

Routes of transmission within primary organic production of fruits and vegetables

Routes of transmission are displayed in Figure 1. Water resources (groundwater, rainwater, municipal water, standing or running surface water, treated or non-treated waste water) and their quality, soil management and soil fertility maintenance together with the use of organic manures, as well as the participation of farm animals in the production chain are fundamental routes of transmission in primary fresh produce production. Crop harvesting, in particular manual harvesting, poses a risk of cross contamination of the harvested produce with not only the pathogens carried by workers, but also from soil via improperly cleaned containers or directly from contaminated soil.

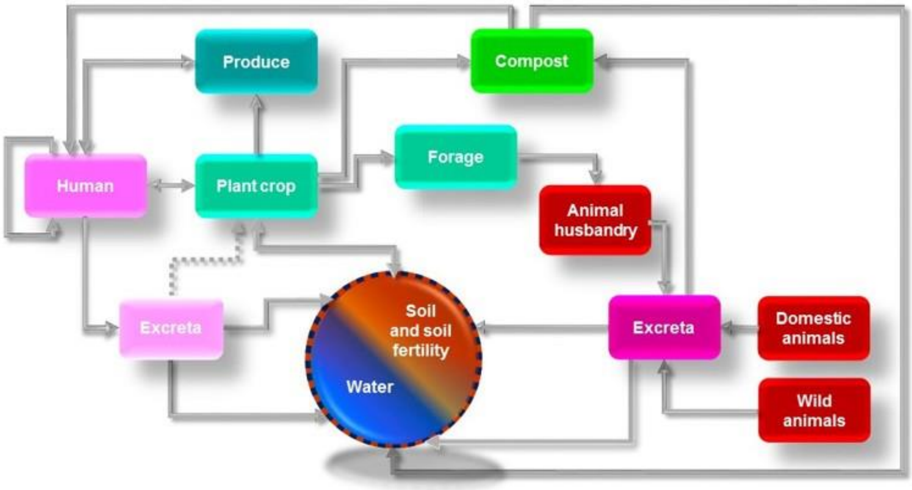

Figure 1. Food safety issues in organically grown fruits and vegetables in light of the "one-health"-concept (Illustration: B. Alsanius).

Furthermore, wildlife carrying zoonoses may cross-contaminate crops in the field, such as deer (Handeland et al., 2002; Hellström et al., 2008; Jay et al., 2007; Kruse et al., 2004; Millán et al., 2004; Palmgren et al., 1997; Renter et al., 2006; Wacheck et al., 2010), rodents, birds (LeJeune et al., 2008; Makino et al., 2000; Morabito et al., 2001; Nielsen et al., 2004; Scaife et al., 2006; Wallace et al., 1997), insects (Wasala et al., 2013), also domesticated animals (cattle, pig, sheep, goat, fowl, dogs) (see Dorais and Alsanius (2015) and references therein). Thus, controlled climate cropping systems (organic greenhouse production, in glasshouse and polytunnels) may be less prone to zoonotic challenges (Holvoet et al., 2014a). However, controlled climate cropping sites are characterised by stable environmental conditions with elevated temperatures and relative humidity, also greenhouses' covers may filter UV-irradiation, which may enhance the survival of food pathogens.

Humans working or visiting the cropping site may disseminate zoonoses which emphasises the need for effective leadership commitment and management of food safety issues in the primary organic production of fruits and vegetables. Workers' health and hygiene are important in general but especially in connection with a crop management that involves manual work, such as hand harvesting. Although workers are using gloves when picking e.g., strawberries or raspberries for the fresh market, they may not always wear them all day because of the high temperature in the plastic tunnels during the day. In addition, enough toilets and hygiene facilities for large working groups may not be provided to cope with the increasing number of workers in one field. These are obviously issues which can be equally applied to large-scale conventional productions, but the organic inspection scheme with regular and spot inspections could be helpful in eliminating such critical risks with group labour during harvest season early and regularly.

Critical control points from a "One health"-perspective

Identification of critical control points is fundamental in reducing hazards. The production environment, the plant/crop and the harvested produce are not sterile and they are not meant to be so. Contamination of the crop and/or produce may occur anytime during the entire production and supply process, from farm to fork (or colon). In addition, similar challenges were observed within the production systems for other foods, such as milk or chicken produce. The hurdle concept is a widely recognised concept in food technology and has successfully been implemented for dairy and poultry production.

1. Soil and soil fertility management.

Organic fertilizers of animal origin are the critical point when connecting the OH concept to the organic production of fruits and vegetables. As enteric pathogens have been shown to endure in soil over a long time, health-challenging organisms may be transferred from contaminated manure via soil, soil splash or run-off water to the crop or applied as compost extracts or teas to control soil and foliar plant pathogens (Scheuerell and Mahaffee, 2006). Thus, the use of hygienically inferior organic fertilizers of animal origin can lead to a cluster of hazards. In this context, it needs to be underlined that the presence of an enteric pathogen in the soil may not imply crop contamination per se. However, it shows that there is a potential for adverse safety implications and the need for a stronger commitment for leadership for a healthy fruits and vegetables production. A large number of studies have indicated the survival of various human pathogens such as shigatoxigenic *E. coli*, *Salmonella* spp. and *Listeria monocytogenes* in different types of organic manure, as recently reviewed by Dorais and Alsanius (2015). The most interesting finding in the context of OH is that the quality of animal feed, i.e., roughage, affects the survival and pathogenicity of shigatoxigenic *E. coli*, as presented by Franz et al. (2005). Fibres content and pH in the cattle farm yard manure explained the more rapid decline of *E. coli* O157:H7 when straw based feedstock was compared with low-digestible grass silage and high digestible grass silage supplemented with corn silage (Franz et al., 2005). This is good news when applying organic farm yard manure from organic livestock; however, the national guidelines in some countries allow the use of farm yard manure retrieved from conventional husbandry (Termorhuizen and Alsanius, 2016). These facts demonstrate the intricate and narrow link between animal husbandry and human health.

Conditions for approved sources of animal based manure are listed by the European Union. The indicator organism *Salmonella* spp. shall be absent in all samples and the mean viable count (CFU) of *E. coli* as well as *Enterococcaceae* from five samples may not exceed 1000 CFU. In addition, only one of these five samples may contain 1000-5000 CFU. Composting is often used to decontaminate organisms adventuring food safety. Composting is accompanied by a temperature rise up to>60°C, impairing the survival of non-thermophilic microorganisms. Improper composting and storage jeopardise the hygienic status of composts (Termorhuizen and Alsanius, 2016).

FiBL (2011) presented a simple risk assessment for the use of organic manures of animal origin. Proper hygienisation, for example using thermophilic composting or anaerobic digestion, is recommended before the application of such materials in the organic production cycle (van der Wurff et al., 2016). The choice of a hygienisation technique ought to be based on the biology of the target pathogen/s (Franke-Whittle and Insam, 2013). Also, non-excreta based organic manures should be considered as less contaminated alternatives (Möller and Schultheiss, 2014).

Within the IFOAM organic movements there have always been some critical voices against the use of manure from any conventional (extensive and intensive) farming systems (Schmutz and Foresi, 2017). This has been heightened in recent years as many conventional feeds contain genetically modified crops, which can then be found in e.g., horse manure. Although organic certification excludes those GM-manure inputs in certified organic lands, conventional manure without GM feed is still considered acceptable within the organic standards.

A similar issue is appearing with horn-meal and blood and bone meal, both are by-products from slaughterhouses. Although currently up to 20% of slaughtered animals might be of organic origin, the majority will be from intensive conventional systems. It was this dependency on conventional animal by-products for the organic fertility management that can be seen as one of the triggers for the development of a livestock-free input (stock-free) in organic systems. Considerations for contamination are seen as a secondary risk, but only from conventional manure. Proponents of stock-free organic agriculture and horticulture (Hall and Tolhurst, 2010) do not see organic animal manures as a potential contamination risk, they just do not want to depend on external sources for their soil fertility.

There is a second group – vegan organic – which have developed organic standards to exclude animals as a matter of principle (Vegan Organic Network, 2007) and this includes marketing produce as vegan organic to achieve a potentially premium price over the normal organic prices, for the efforts made to exclude all animal inputs from the production process. In both cases it is clear that the potential for animal contamination is widely excluded (there could still be wild animals eating crops). Especially vegan organic for a potential premium price (Schmutz and Foresi, 2017) could develop soil fertility systems based on plant fertilisers which could eventually replace animal based fertilisers in "normal" organic production and this can include vegan anaerobic digestion (Schmutz, 2012). In fact, since vegan organic has not yet used the potentially lower contamination risk in its marketing plan it could be worth emphasizing in order to convince more consumers to integrate a vegan day or some vegan organic food items into their current diet regime (note: we do not discuss a 100% vegan diet as this has wider and complex implications on health and the environment).

2. Water.

In relation to the OH concept, water, organic manure, wildlife, farm animals occurring in organic cropping systems as well as the staff working in such systems are the most crucial hazard points and deserve special attention.

Aspects of irrigation water hygiene have recently been reviewed by Pachepsky et al. (2011) and Dorais et al. (2016). Deep well groundwater, rainwater and municipal water are regarded as relatively safe water sources, however, risks may occur when rainwater is not appropriately stored (Evans et al., 2006). The hygienic status of irrigation water distribution systems is not comparable to municipal systems used for potable water as they are not constantly exposed to higher pressures, allowing reflux as well as microbial growth and biofilm formation within the pipeline (Pachepsky et al., 2011; Shelton et al., 2012). Also aboveground irrigation pipelines, which are only used on demand, are moved from location to location in the field and are commonly stored in close contact with soil, providing shelter for small animals such as rodents. Running and standing surface water is influenced by the weather and climatic conditions (Holvoet et al., 2014b; Pachepsky et al., 2012) as well as the presence of animals close to the water reservoirs (grazing animals at river banks, dual use of water reservoirs for aquaculture and irrigation, run-off of liquid effluent from stored manure or effluent of reclaimed water to the reservoir).

Irrigation water guidelines, that were established for ensuring food safety, have been developed in different areas and for different types of production (British Columbia Ministry of Environment, 2001; Canadian Council of Minsters of Environment, 1999; CSFSGLLGSC, 2013; DIN 19650, 1999). However, a consensus on the choice of indicator organisms, the method to determine safe irrigation water, safe threshold values or prognosis models for determining hygienic irrigation water quality are needed. As fruits and vegetables are globally traded, such consensus should also take place on an international level. Such a model also needs to include the crop, weather conditions and the die-off/survival rate of human pathogens on crop plants and in water resources. Such an equation might be difficult to achieve in running surface waters. Water scarcity needs to be taken into account as well when setting up such guidelines, as an inferior water source might not be able to be replaced by a satisfactory one at any given site.

3. Farm animals and wildlife in the organic production area.

The close proximity of animal farms' production to the organic fruits and vegetable crops production could be considered as questionable measures from the OH perspective. For example free range chickens that are used for weed control, or sheep and goats that are used for grazing on crop residues. Likewise, despite their contribution to the ecosystem by increasing the biodiversity in the organic production sites, the encouragement of wildlife does not sit well with the efforts that are being made to ensure safe and healthy fruits and vegetables. Wildlife can neither be avoided nor excluded in open fields nor in many covered cropping sites, but the presence of these vectors of human pathogens should not be encouraged.

Risk scenarios

To determine the best practice, risk scenario approaches have been conducted. Using high and low risk scenarios for water reservoirs, irrigation techniques, mulching and fertilization. Hartmann et al. (2017a) concluded that season, plant species and age rather than cultural management decide the natural colonization of human pathogens in organically grown leafy vegetables. Their results were also confirmed in a greenhouse experiment using untreated chicken manure and pig hair pellets where a *gfp*-tagged strain of *E. coli* O157:H7 was supplemented. The relative risk was higher for pig-hair pellet than raw chicken manure, treated Swiss chard and rocket (Hartmann et al., 2017b).

This leads to the raised hypothesis that biodiversity might affect the survival of human pathogens in organic production systems of fruits and vegetables. Indeed, Gu et al. (2013) found a correlation between the bacterial diversities of endophytic *Salmonella enterica* that was inoculated on tomato plants and the soil management type, where lower endophytic diversity was observed for tomatoes grown in conventionally as opposed to organically managed soil. In contrast, epiphytic bacterial diversities were governed by the crop rather than the treatment (Alsanius et al., submitted). Among others, leaf nutrient composition was a decisive factor in relation to the abundance of different bacterial families and genera.

To find an answer to the impact of biodiversity on the survival of zoonotic organisms in organic cropping systems, further attention should be given to the crop stand, to the inner quality properties of the produce (i.e., pH, composition of bioactive compounds) and the biological and environmental conditions of the crop. Biodiversity in the soil, within a greenhouse or in the field is a complex web of fauna and flora interactions and more evidence is needed to conclude if it has a positive, negative or neutral effect on the OH concept, and under which conditions it could provide a potential risk or reward to the "one-health"-concept.

CONCLUSIONS

Conventional/integrated and organic horticulture provide fresh commodities rich in minerals, fibres and bioactive compounds, thereby contributing to healthy diets worldwide. Fruits and vegetables are associated and consumed with a living biota. However, despite health claims and expectations for organic produce, potential hazards need to be acknowledged, particularly under organic farming practices. Therefore, a critical analysis of different production systems is necessary. To date, few procedures or hurdles to mitigate or prevent health risks have been included in organic fruit and vegetable production protocols. In the light of the recently presented vision paper for organic greenhouse horticulture, research on the interactivities between the environment and people domains needs to be intensified.

The majority of studies on human pathogens in organic production of fruit and vegetables embrace the prevalence and survival of human pathogens on the crop. Difficulties in translating experimental conditions to natural situations occur as space and number of plants in experimental manipulations is limited and thus high pathogen concentrations must be introduced. Furthermore, the use of non-pathogenic mutants of the target pathogens does not always mimic reality. Few studies have used a holistic approach, although monitoring of the crop and external factors including hurdles prevailing at the cropping site as well as the microbial community structure are necessary to explain these interactive mechanisms. However, the hurdle concept would be interesting to implement in fruits and vegetables to avoid risking consumers' health. For example, a log-reduction in *E. coli* of log 1 to log 2 was observed during the washing step of field grown leafy green vegetables in a commercial setting (Rosberg, pers. commun.).

However, the presence of a zoonotic organism in a crop-microbiome-environment-context does not per se present a health risk. Dose-response relationships as well as consumer exposures (i.e., the number of pathogens ingested) must be considered before the risks are fully characterized. Very few studies have involved risk assessments. This is a necessity to understand the ecology of zoonotic organisms in plant production settings, to optimize organic cropping systems for fruits and vegetables and to transform these insights into thresholds, guidelines and crop protocols. In an appendix to the global GAP guidelines released in 2014 food safety is highlighted. However, not only the existence of such guidelines, but also the actual use of guidelines is required. Safe organic (and conventional) production of fruits and vegetables with livestock inputs demand healthy animals, intelligent control of pathogens and a healthy environment. A compromised, dysfunctional human colon will not be able to make full use of the potential health benefits of organic fruits and vegetables. Consumers worried about risks today have also the option to switch to vegan organic products for part of their diet. Thus, we conclude that choice, safe food and access to food are preconditions to ensure that human populations can become nutritionally secure.

ACKNOWLEDGEMENTS

The study was informed by Tvärlivs project "Hazards of invading food borne pathogens in vegetables and prospects for preharvest prevention" and "Safe ready to eat vegetables from farm to fork: The plant as a key for risk assessment and prevention of EHEC infections (acronym: Safe Salad)" both funded by Formas, Stockholm, Sweden, the EU-COST Action 1105 "BioGreenhouse" and the project "Qualität und Sicherheit in der Produktionskette biologisch produzierter Fertigsalate" (German Federal Ministry of Agriculture and Nutrition, BLE; project no. 2811OE097).

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