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Review:

Fresh fruit and vegetables as vehicles of bacterial foodborne disease: A review and analysis of outbreaks registered by proMED-mail associated with fresh produce

Übersichtsarbeit:

Früchte und Gemüse als Ursache lebensmittelbedingter Erkrankungen: Übersicht und Analyse der von proMEDmail registrierten Fälle rohkost-assoziierter Ausbrüche

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Summary

Raw food-containing diets have grown in popularity over the last decades since they correspond with the perception of a healthy lifestyle. However, infections from fruit and vegetables also represent an important food safety issue. Produce-borne outbreaks are of concern because of their potentially serious health consequences and the high socioeconomic costs. This review summarizes outbreaks of bacterial disease associated with sprouts, salads, vegetables, fruit, fresh herbs, raw nuts and raw edible seeds registered by proMED-mail during the period between 2011 and mid-2015. The possible pathways of contamination are examined and discussed, with special attention to the role of *E. coli* and *Salmonella* as cross-domain pathogens. Various multidisciplinary approaches aimed at reducing the occurrence of pathogenic bacteria in fresh produce are discussed, including the enhancement of surveillance and consumer awareness, improvement of agricultural and trading practices and the development of novel materials and sanitizing methods in the food industry.

Thirty-five outbreaks, each associated with a single raw produce were reviewed. Sprouts and lettuce were the most common produce associated with disease. *E. coli,* especially EHEC O157:H7, and *Salmonella* spp. were the most common pathogens, causing 42.9 % and 34.3 % of the outbreaks, respectively, while *Listeria monocytogenes* accounted for 14.3 %. Novel vehicles of disease were noted, including watercress, strawberries and stone fruit.

Keywords: fresh produce, foodborne diseases, outbreaks, proMEDmail

Zusammenfassung

Rohkost (rohes Obst und Gemüse) gilt allgemein als wichtiger Bestandteil gesunder, ausgewogener Ernährung. Aus lebensmittelhygienischer Sicht ist der Verzehr roher oder minimal verarbeiteter Lebensmittel mitunter mit der Gefahr einer Infektion mit pathogenen Bakterien verbunden. Rohkostbedingte Gruppenerkrankungen (Ausbrüche) haben gesundheitspolitisch und ökonomisch erhebliche Auswirkungen und sind deshalb von grosser Bedeutung. Die vorliegende Übersichtsarbeit beleuchtet Ausbrüche bakteriellen Ursprungs, welche mit dem Verzehr von Sprossen, Salaten, Gemüsen, Früchten, frischen Gewürzen, rohen Nüssen und rohen essbaren Samen in Zusammenhang stehen und zwischen 2011 und Mitte 2015 von proMEDmail registriert wurden. Kontaminationswege dieser Nahrungsmittel (v. a. von pathogenen *E. coli* und *Salmonella*) werden aufgezeigt und diskutiert. Verschiedene multidisziplinäre lösungsorientierte Ansätze zur Reduktion von pathogenen Bakterien in Rohkost werden dargelegt, wie verstärkte Überwachung, Sensibilisierung der Konsumenten, Verbesserungen der landwirtschaftlichen Produktions- und Handelsmethoden sowie die Entwicklung neuer Materialien und Reinigungsverfahren für die Lebensmittelindustrie.

Es werden insgesamt 35 Ausbrüche diskutiert, wobei jeder Ausbruch auf die Kontamination eines einzelnen Rohkostproduktes zurückgeführt werden konnte. Am Häufigsten verursachten Sprossen und Kopfsalat Krankheitsausbrüche. Die Mehrheit der Ausbrüche wurde auf *E. coli,* vorwiegend EHEC O157:H7, (42.9%) und *Salmonella* spp (34.3 %) zurückgeführt. *Listeria monocytogenes* wurde in 14.3 % der Fälle nachgewiesen. Erstmalig wurden Brunnenkresse, Erdbeeren und Steinfrüchte mit lebensmittelbedingten Erkrankungen in Zusammenhang gebracht.

Schlüsselwörter: Früchte, Gemüse, lebensmittelbedingte Erkrankungen, Ausbrüche, proMEDmail

Introduction

It is a concept commonly accepted that diets that include fruit and vegetables contribute to a healthy lifestyle, since they contain fibre, minerals, vitamins and other phytochemicals that are beneficial to the consumer's health. Many health organizations as well as governments (Anonymus, 2002; Anonymus, 2009; Anonymus, 2010) successfully promote the consumption of fresh produce, which may be home grown, purchased from local providers or obtained via national and global trade. In developed countries, the propagation of the consumption of raw produce additionally aims to decrease the burden of chronic diseases, mainly obesity, and obesity-associated diseases such as type 2 diabetes, cardiovascular diseases (including hypertension and stroke), cancer, dental diseases and osteoporosis (Buijsse et al., 2009; Griep et al., 2010; Mozaffarian et al., 2011), all of which are health problems that affect the population of nutrient affluent, post-industrialized nations. As a result, raw food-including diets have grown in popularity over the last decades.

In addition, changes in socioeconomic factors such as increased labour market participation of women and demographic shifts (ageing) are accompanied by changes in food preparation and eating habits (Fine et al., 1997; Chenhall, 2010). Food is to a large extent purchased as preprocessed convenience products for the home as well as for food service establishments. One important aspect is the increase of consumption of cold raw produce, combining modern needs for convenience with the concept of a healthy diet. Consequently, the last decades have seen a dramatic increase in year-round demand of a high variety of fresh products and a globalization of their production and distribution.

Notwithstanding the health benefits, the consumption of raw produce is also an important risk factor in the transmission of bacterial diseases. This is reflected in the number and dimensions of reported gastroenteritis outbreaks related to fresh produce over the last years in many parts of the world (Lynch et al., 2009). An outbreak is defined as the occurrence of two or more cases of similar illness resulting from the consumption of a common food (Anonymus, 2008). Outbreaks of infections caused by *E. coli* O157:H7 linked to fresh spinach (Wendel et al., 2009), of *E. coli* O157:H7, *Salmonella enterica,* and *Campylobacter jejuni* associated with cantaloupe melons, tomatoes and peppers (Bowen et al. 2006) and *Listeria monocytogenes* linked to cantaloupe (McCollum et al., 2013), as well as the German outbreak of Shiga-toxin producing *E. coli* O104:H4 traced to fenugreek sprouts (Buchholz et al., 2011) illustrate the vast public health and socioeconomic impact of produce borne disease. The latter outbreak represents a climax in a trend registered for Europe between 2008 and 2011, which consists of an increase in the numbers of reported outbreaks, cases, hospitalizations and deaths associated with food of non-animal origin. This trend coincided with a decrease in the numbers of corresponding reported outbreaks associated with food of animal origin (Anonymous, 2013d).

Despite increased awareness within the food processing industry and health care systems, there is so far no evidence of a decline in the number of annual outbreaks (Callejón et al., 2015) This indicates that there is still much unknown about the possibilities to prevent produce-associated disease.

One key element for successful prevention is a public health infrastructure that conducts continuing surveillance, detection and reporting of pathogens in the food chain. A second key element is improvements of production and distribution line quality. A third factor is consumer behaviour, which ultimately determines the extent of produce related infections.

This article provides a review of reported bacterial foodborne outbreaks linked to fresh produce that have been reported since 2011, and discusses the wider implications of these findings on research, the production industry and consumer health.

Methods

Search strategy

For this study, the internet-based biosurveillance system maintained by the International Society for Infectious Diseases (ISID) as ProMed-mail (Madoff, 2004) was selected (www.promedmail.org). This database was recently positively assessed for its system performance with regard to sources, languages, geographical coverage and especially its human moderation (Barboza et al., 2014). Further advantages consist of daily updates, cross-references and access to archived data.

Additionally, governmental, food safety and public health sites were searched for information on outbreaks, including US Centers for Disease Control and Prevention, CDC (http://www.cdc.gov), the European Centre for Disease Prevention and Control, ECDC (http://www.ecdc.europa.eu) the Australian, New Zealand and Japanese reporting systems (http://www.ozfoodnet.gov.au, http://foodsafety.govt.nz and http://idsc.nih.go.jp, respectively). PubMed and Google Scholar were searched for publications relating to the outbreaks registered by proMED-mail.org. Cases or outbreaks reported by the press or social media and similar nontraditional data sources were not included. Reports of food recalls were not included, if they did not involve diseased persons. Reports were read to ensure that they constituted outbreaks and that there was no duplication of outbreak information. Details of the food vehicle, the causal agent, outbreak date, and geographic location were noted.

Selection of fruit and vegetables

A variety of salads, vegetables and fruit were selected to search for. These included produce recommended for raw or cooked consumption by governmental health guidelines (Anonymus, 2009). The keywords included in the searches contained the names of approx. 170 fruit and vegetables as indexed by the electronic data information source of the University of Florida (https://edis.ifas.ufl.edu/features/fruitvegindex.html), and the bacterial pathogens *E. coli, Salmonella, Shigella, Listeria, Yersinia, Campylobacter* and *Staphylococcus.*

Nuts, fresh herbs and edible seeds that are consumed raw were included in the search, as were sprouts. Mixed commodities such as French salads or potato salads were not included, as were vegetable or fruit juices.

Results and Discussion

Reported outbreaks

Identified reports of outbreaks of gastrointestinal infections associated with sprouts, salads, vegetables, fruit, fresh

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herbs, raw nuts and edible seeds that occurred between 2011 and mid-2015 are listed in Table 1. A total of 35 outbreaks were reported in the ISID database. This number probably represents only a fraction of all illnesses caused by produce-borne bacterial pathogens, since gastrointestinal infections in general are prone to underestimation, due to characteristics such as self-limitation, mild etiopathology or lack of access to health care systems (Gibbons et al., 2014). At the healthcare level, many cases remain unreported and are never subjected to investigation (Anonymus, 2008).

Reports were distributed unequally among the world regions. Data was retrieved from the USA (21 outbreaks), Canada (6 outbreaks), European countries (8 outbreaks) and New Zealand (one outbreak). No raw produce-related outbreaks were detected for other countries, including African, Mediterranean, and Asian regions. Epidemiological intelligence data from African countries, from where the majority of reports on gastrointestinal infections worldwide are reported, show that for the most part, reported outbreaks are linked to water rather than food and that food as a vehicle goes largely unspecified (Dewaal et al., 2010). Data on foodborne pathogens communicated by various governmental health authorities show that, for example, the Japanese infectious disease surveillance center (http://idsc.nih.go.jp) lists bacterial pathogens detected in food from 2013–2015 without further identification of the food category. Australia and New Zealand assign implicated food to categories as described by Painter at al. (2009). Thereby, raw produce is allotted to the subcategories "leafy, root, sprout or vine-stalk".

By contrast the US governmental health authorities (http://www.cdc.gov/ecoli/outbreaks.html) and European Food Safety Authority (http://www.efsa.europa.eu/en/zoonosesscdocs/zoonosescomsumrep.htm) report in more detail the precise produce implicated in an outbreak.

While these differences may be explained in part by the varying degree of sophistication regarding surveillance tools available to different countries, they also reflect different perceptions of threats to public health from fresh produce (Anonymus, 2000). Ultimately, this awareness could be seen as a characteristic of countries in which highly propagated raw food-based diets have grown in popularity over the last decades. Hence, the reported and investigated cases are not only unrepresentative of the actual rate of contamination but also of the afflicted countries and regions.

Notwithstanding this obvious bias, the data obtained give an indication of which produce appears to be prone to bacterial contamination and which pathogens are likely to be involved.

Produce associated with outbreaks

Sprouts

Between 2011 and mid-2015, seven outbreaks resulting in 3686 illnesses were associated with the consumption of sprouts (Tab. 1). The majority of illnesses (3469 cases, 94.1 %) were due to the very large outbreak in Germany in 2011 (Bielaszewska et al., 2011). Successive outbreaks all occurred in the USA (5 outbreaks, 71.4 %) or Canada (1 outbreak, 14.3 %). Outbreaks were most often caused by enterohemorrhagic *E. coli* (4 outbreaks, 57 %), followed by *S. Enteriditis* (two outbreaks, 28.5 %) and one (14.5 %) *L. monocytogenes.* The latter represents the only outbreak whose sprout contamination was attributed to unsanitary conditions in the production line (Anonymus, 2015d).

Lettuce

Between 2011 and 2014, at least one outbreak per annum occurred due to consumption of contaminated lettuce (Tab. 1), with none reported by mid-2015. The six reported outbreaks resulted in a total of 347 illnesses, including four with hemolytic uremic syndrome (HUS). Four of the outbreaks (66.7 %) occurred in the USA and Canada and were caused by *E. coli* O157:H7. The outbreak in 2011 affected 60 people, two of which developed HUS. Traceback analysis indicated pre-harvest contamination (Anonymus, 2011a). Further outbreaks in Canada in 2012 and 2013 (Anonymus, 2013c; ProMED-mail, 2012) were associated with restaurants where food such as hamburgers and tacos were garnished with romaine lettuce. The latter affected 94 people, whereof two children developed HUS. According to the ISDS database, the lettuce implicated in the 2013 outbreak in Canada was traced to California and had been provided by a large North America-based fresh produce distributor that acquires fresh produce nationwide.

By comparison, outbreaks caused by contaminated lettuce were rare in Europe and elsewhere, and were not linked to enterohemorrhagic *E. coli.* Radicchio rosso lettuce (Italian chicory) contaminated with *Yersinia enterocolitica* caused an outbreak affecting 21 patients in Norway in 2011 (MacDonald et al, 2011). This represents the first and so far only outbreak of yersiniosis in Norway linked to raw produce. Finally, a total of 124 cases of infections due to *Yersinia pseudotuberculosis* were registered in in New Zealand in 2014. This outbreak was linked to bagged lettuce.

Cucumber

Cucumber was involved in three outbreaks and a total of 367 illnesses during the period reviewed (Tab. 1). They all occurred in the USA, however two (66.6 %) involved cucumber imported from Mexico. Outbreaks involving imported cucumbers were associated with *Salmonella* Saintpaul and *E. coli* O157:H7. The latter outbreak represents the first to specify cucumber as a vehicle for *E. coli* O157:H7 (Anonymus, 2013b). A recent outbreak affected 275 patients infected with *Salmonella* Newport (Tab. 1). Genetic analysis by polyamide gel electrophoresis (PFGE) and epidemiological investigations (Angelo et al., 2015) revealed that this particular strain had been involved in previous outbreaks in 2002, 2005 and 2006 linked to tomatoes grown in the Delmarva region of Maryland and Virginia (Anonymus, 2007); Bennettet al., 2015). Since the implicated cucumber originated from the same farming region, this suggests an environmental reservoir of *S.* Newport and its shift to a novel food vehicle (Angelo et al., 2015).

Spinach

Two outbreaks amounting to 46 cases of disease were attributed to the consumption of spinach, which included one produce defined as "leafy green" (Tab. 1). In 2012, thirty-three patients were infected with *E. coli* O157:H7 after consuming pre-packaged organic spinach. Thereof, two developed HUS (Anonymus, 2012a). This outbreak is the first since the large U.S. multistate outbreak in 2006, that involved 205 confirmed illnesses and 3 deaths caused by *E. coli* O157:H7 infection (Wendel et al., 2009). Further, 13 cases of *E. coli* O157:H7 infection attributed to ingestion of leafy greens were registered by the Canadian health authorities in 2015.

TABLE 1: *Summary of outbreaks registered by ProMEDmail associated with sprouts, salads, vegetables, fruit, fresh herbs, raw nuts and raw edible seeds.*

Year	Region	No. of cases	Implicated produce	Bacterial pathogen	Point of contamination/origin	References
2011	EU (D)	3842	Fenugreek	EHEC O104:H4	Seeds	Bielaszewska et al. 2011
	USA	25	Alfalfa and spicy sprouts	*S.* Enteriditis	–	Anonymus, 2011b
	USA	60	Lettuce	EHEC O157:H7	Pre-harvest	Anonymus, 2011a
	EU (N)	21	Lettuce	*Y. enterocolitica*	–	MacDonald et al., 2011
	EU (DK)	43	Tomatoes	*S.* Strathcona	Italy	Anonymus, 2012c
	USA	147	Cantaloupe	*L. monocytogenes*	Production	McCollum et al., 2013
	USA	20	Cantaloupe	*S.* Panama	Guatemala	Anonymus, 2011d
	USA	15	Strawberries	EHEC O157:H7	Deer feces	Laidler et al., 2013
	EU (DK)	46	Basil	Shigella	–	Guzman et al., 2013
	USA	42	Pine	*S.* Enteritidis	Turkey	Anonymus, 2011c
2012	USA	29	Clover sprouts	EHEC O26	–	Anonymus, 2012b
	CA	18	Lettuce	EHEC O157:H7	–	ProMED-mail, 2012
	USA	33	Spinach	EHEC O157:H7	–	Anonymus, 2012a
	EU (UK, D)	63	Watermelon	*S.* Newport	Brazil	Byrne et al., 2014
2013	USA	94	Lettuce	EHEC O157:H7	–	ProMED-mail, 2013
	CA	30	Lettuce	EHEC O157:H7	California	Anonymus, 2013c
	USA	84	Cucumber	*S.* Saintpaul	Mexico	Anonymus, 2013b
	EU (UK)	19	Watercress	EHEC O157:H7	–	Launders et al., 2013
	EU (UK)	592	Curry leaves	*S.* Agona	Pakistan	Foster, 2013
	USA	16	Sesame	*S.* Montevideo, Mbandaka	–	Anonymus, 2013a
2014	USA	115	Mung bean sprouts	*S.* Enteriditis	–	Anonymus, 2015b
	USA	19	Clover sprouts	EHEC O121	–	Anonymus, 2014e
	USA	5	Mung bean sprouts	*L. monocytogenes*	Production	Anonymus, 2015d
	CA	24	Bean sprouts	EHEC O157:H7	–	ProMED-mail, 2014a
	NZ	124	Lettuce	*Y. pseudotuberculosis*	–	Anonymus, 2014a
	USA	8	Cucumber	EHEC O157:H7	Mexico	ProMED-mail, 2014b
	USA	15	Cabbage	EHEC O111	–	ProMED-mail, 2014c
	USA	57	Celery	EHEC O157:H7	–	ProMED-mail, 2014d
	EU (DK)	5	Asparagus	*L. monocytogenes*	Undercooking	ProMED-mail, 2014e
	USA & CA	37	Apples	*L. monocytogenes*	Production	Anonymus, 2015a
	USA	4	Stone fruit	*L. monocytogenes*	Production	Jackson et al., 2015
	USA	17	Cashew	*S.* Stanley	–	Anonymus, 2014d
	USA & CA	83	Chia	*S.* Hartford, Newport, Oranienburg and Saintpaul	–	Anonymus, 2014c Anonymus, 2014f
2015	USA	275	Cucumber	*S.* Newport	Pre-harvest	Angelo et al., 2014
	CA	13	Leafy green	EHEC O157:H7	–	Anonymus, 2015c

Abbreviation: EHEC; enterohemorrhagic *Escherichia coli*. –: unknown

Other vegetables

Outbreaks associated with vegetables not included in the preceding categories accounted for five outbreaks (13.9 %) and a total of 139 illnesses. The majority (3 outbreaks, 60 %) was caused by enterohemorrhagic *E. coli* (Tab. 1). Watercress contaminated with *E. coli* O157:H7 was responsible for 19 cases in the U.K. (EU) in 2013. Although watercress as a semi-aquatic plant is vulnerable to ingress by nearby livestock and surface waters, extensive outbreak investigations could not pinpoint the source of contamination in the environment and the possibility of contamination of the seeds could not be excluded. Notably, this produce represents a novel vehicle of infection with *E. coli* O157:H7 (Launders et al., 2013).

The outbreak involving tomatoes contaminated with a rare serotype, *Salmonella* Strathcona (Tab. 1) represents the first related to this particular salmonella serovar. According to the investigating Staten Serum Institute (SSI), the produce was imported from southern Italy (Anonymus (2012c).

Fruit

Melons

One of the largest foodborne outbreaks in the USA was related to cantaloupe melons contaminated with *Listeria monocytogenes* (Tab. 1). Extensive multistate epidemiologic, trace-back, and environmental investigations identified a production farm with contaminated processing equipment as well as insufficient sanitizing and cooling steps, as the source (McCollum et al., 2013). Further, cantaloupe melons imported from Guatemala to the USA were implicated in an outbreak involving 20 persons infected with *Salmonella* Panama in 2011 (Anonymus, 2011d). Watermelons contaminated with *S.* Newport caused a further outbreak involving 63 cases in UK, Ireland and Germany. This is the first melon-associated outbreak in Europe (Byrne et al., 2014).

Strawberries

In 2011, strawberries emerged as a novel vehicle for *E. coli* O157:H7 infection, affecting 15 cases, whereof four developed HUS. Investigations showed that the strawberries originating from a small-scale farm in Oregon, USA, were contaminated with deer feces that contained the outbreak strain (Laidler et al., 2013).

Apples and stone fruit

In 2014, an outbreak of listeriosis involving 35 diseased persons in the USA and two cases in Canada was linked to commercially produced, prepackaged caramel apples. According to the CDC final report, the outbreak resulted in seven deaths, three cases of meningitis and one fetal loss (Anonymus, 2015a). A further outbreak of 4 cases in 2014 involved prepackaged nectarines and peaches contaminated with *Listeria monocytogenes,* representing the emergence of stone fruit as a newly reported vehicle of human listeriosis (Jackson et al., 2015).

Fresh herbs

Basil

Fresh basil imported from Israel to Norway was held responsible for an outbreak of *Shigella sonnei* infections in 2011 (Tab. 1). In total, 46 people fell sick after the consumption of pesto sauce made from the raw leaves (Guzman-Herrador et al., 2013).

Curry

A large outbreak of 592 cases of salmonellosis occurred among attendees of a Spice Festival held in Newcastle

(U.K.) in 2013 (Tab. 1). Extensive outbreak investigations identified fresh curry leaves that had been consumed uncooked as the vehicle of infection. *Salmonella* Agona phage type 40 was isolated from curry leaves and fecal specimens from patients. In addition, several fecal specimens yielded *S.* Hadar, *S.* Cero, *S.* Typhimurium, Shiga-toxin producing *E. coli* (STEC) and several serotypes of enteroaggregative *E. coli* (EAEC) (Foster, 2013). A retrospective investigation detected several EAEC serotypes, including O104:H4 strains with close phylogenetic relationship to the EAEC O104:H4 strain associated with the German outbreak in 2011 (Dallman et al., 2014).

Nuts and seeds

Although commonly referred to as nuts, both cashew and pine nuts are seeds in the botanical sense. Hence, the outbreaks described in this category are essentially all associated with seeds. All outbreaks occurred or originated in the USA, affecting a total of 158 diseased persons (Tab. 1). In all cases, infection was caused by *Salmonella.* Of the seven serotypes reported, *S.* Enteriditis was linked to pine nuts imported from Turkey to the USA (Anonymus, 2011c), *S.* Stanley was associated with fresh raw cashew nuts (Anonymus, 2014d) and *S.* Montevideo and *S.* Mbandaka were detected in a tahini paste made from ground sesame seeds (Anonymus, 2013a). Finally, ground chia seeds causing an outbreak in 2014 involving 31 persons in USA and 52 in Canada were found to contain *Salmonella* serotypes Newport and Hartford, Oranienburg and Saintpaul (Anonymus, 2014c; Anonymus, 2014f).

Pathogens involved in produce-borne outbreaks

Pathogenic E. coli

Between 2011 and mid-2015, enterohemorraghic *E. coli* was the etiological agent of 15 outbreaks (42.9 %) and 3903 reported illnesses. In total, EHEC O157:H7 caused 11 (31.4 %) of all reported outbreaks during the period under review (Tab. 1). Although for most of the 11 outbreaks, the point of contamination could not be established with absolute certainty, it is well recognized that the primary reservoir of pathogenic *E. coli,* in particular EHEC O157:H7 appears to be cattle, and to a lesser extent, pigs and deer (Ferens and Hovde, 2011). Pre-harvest contamination of crops due to ingress from nearby livestock farms or cattle ranches via surface waters and invasion of crops by wildlife is thought to contribute to the risk of contaminating produce with EHEC O157:H7 (Cooley et al., 2007; Ferens and Hovde, 2011). It has been suggested that contamination of plants by human pathogens is promoted by the diminished competition from the endemic non-pathogenic plant-specific microflora (van Overbeek et al., 2014). Hence, agricultural practices that include fertilization methods that establish a healthy plant microflora may prove to be a viable method for reducing the risk of ingress by pathogens.

Notwithstanding these plausible pathways of passive contamination, studies outlined by Brandl (2006), Deering et al. (2012), and van Overbeek et al. (2014) provide evidence that enteropathogenic *E. coli* (as well as *S. enterica*) are able to actively assume an epi- and/or endophytic lifestyle which enables these pathogens to long-term survival on and in plants, including their leaves, roots, flowers and seeds. Studies reviewed by Barak and Schroeder (2012) and Melotto et al. (2014) suggest that human pathogens colonize plants and activate defense signaling pathways in the plant cell. Type three secretion system (T3SS), which are used by human pathogens to invade mammalian human cells (Coburn et al., 2007) appear to play an important but hitherto insufficiently understood role in plant immune response. The role of EHEC O157:H7 as a cross-domain pathogen is further demonstrated by its ability to trigger stomatal closure in the leaf epidermis of *Arabidopsis thaliana* (Roy et al., 2013). Clearly, the molecular mechanisms of plant responses to human bacterial pathogens represent a field of research that merits further attention. Identifying plant species and cultivars with high innate immune response to human pathogens may provide a step towards reducing the risk of bacterial produce contamination.

A further important pathogenic *E. coli,* EAEC O104:H4 is well documented as the etiological agent of the German outbreak in 2011. Its co-detection with *S.* Agona in the outbreak associated with fresh curry leaves in 2013 (Tab. 1) gives further evidence to its pathogenic potential and to its association with fresh produce.

Salmonella enterica

Salmonella was involved in 12 (34.3 %) produce-related outbreaks between 2011 and 2015, ranking it the second most common pathogen after *E. coli.* In general, *Salmonella* continues to be a very frequently reported gastrointestinal pathogen. The threat to public health from fresh produce contaminated with *Salmonella* is illustrated by the high number of 1375 diseased persons during the time span under scrutiny. Currently, *S.* Enteriditis is responsible for 18 % and 39.5 % of all salmonellosis cases in the USA and in Europe, respectively (Anonymus, 2014b; Anonymous, 2015e). Accordingly, three outbreaks (25 %) of produce-associated salmonellosis were due to this serovar. The data collected during the period under review show that *Salmonella* detected in fresh produce is characterized by a wide variety of serovars, including rare ones. In total, 14 different *Salmonella* serovars were reported for 12 outbreaks (excluding one large outbreak involving *S.* Newport that went unreported by proMEDmail (Bayer et al., 2014)). Additionally, several commodities, notably herbs and seeds were contaminated with up to four different *Salmonella* serovars, or combinations of *Salmonella* and *E. coli* (Tab. 1). Fresh herbs and spices are classified into the ready-to-eat (RTE) category (Regulation EC No. 2073/2005). Hence, consumer awareness of the risks for *Salmonella* (and other) infections associated with theses commodities may be lower than with poultry meat and eggs. Therefore, adequate handling and food preparation are food safety issues that currently need to be addressed, especially in the context of fresh produce imported from agricultural regions with lower agricultural standards.

Listeria monocytogenes

Produce-associated listeriosis has increased remarkably during the last few years. A recent review focusing the 12 years between 2004–2012 noted 3 outbreaks caused by *L. monocytogenes* in the USA. This corresponded to 2.3 % of the bacteria-associated outbreaks (Callejón et al., 2015). By contrast, during the 4.5 years under scrutiny in this review, five outbreaks occurred (14.3 %). With the exception of one outbreak that was due to improper handling, all outbreaks were production related (Tab. 1). This illustrates the growing importance of *L. monocytogenes* in the food production industry. *L. monocytogenes* is widely distributed throughout the environment and essentially, contamination of produce can occur during pre- peri- or post harvest periods. Internalization studies performed by Chitarra et al. (2014) state that *L. monocytogenes,* similar to EHEC O157:H7 is capable of internalization and endophytic persistence in lettuce, particularly at temperatures around 24 °C. This internalization phenomenon may contribute to its introduction to the processing environment, since it cannot be readily eliminated by washing. A most important characteristic of *L. monocytogenes* in the context of food safety is the ability to attach to working surfaces in industrial, commercial and domestic environments (e. g. stainless steel machinery), to form biofilms and to persist at refrigeration temperatures (4–5 °C). Poimenidou et al. (2009) show that *L. monocytogenes* cells attached to equipment surfaces are able to detach and subsequently multiply in food products at 5 °C, constituting a significant risk of cross-contamination in the production lines of food processing plants. Thus, novel approaches addressing the development of new materials merit attention. Wilks et al. (2006) argue that compared to stainless steel, the use of copper-base alloys in surfaces and equipment greatly reduces survival of *Listeria* and *E. coli* O157. A recent study by Feng and collaborators (2014) demonstrate that anodized aluminum surfaces with 15 nm pore diameters significantly inhibit attachment and biofilm formation of *Listeria* spp. and *E. coli,* and suggest the use of such material for food processing equipment and biomedical applications. Such approaches may prove beneficial to production hygiene.

Other pathogens

Three (8.6 %) of the outbreaks reviewed were due to pathogens other than those mentioned above and concerned *Yersinia enterocolitica, Yersinia pseudotuberculosis* and *Shigella sonnei.* Yersiniosis associated with produce is rare and is suggestive of cross-contamination or environmental contamination, while the presence of *Shigella* is indicative of fecal contamination. No outbreaks associated with either *Campylobacter* or *Staphylococcus* were reported during the period under review.

Future prospects

Food-borne outbreaks have to be investigated jointly by food and public health authorities. Public health will continue to be dependent on continuing surveillance and monitoring of produce. In addition to traditional surveillance systems which function mostly at regional or national levels, nontraditional approaches may gain importance as social media usage continues to grow worldwide. Recent studies propose that automated data mining processes can be developed to identify clusters of disease suggesting outbreaks (Newkirk et al., 2012; Nsoesie et al., 2014). Thus, data obtained from online restaurant reports or micro-blogs such as Twitter have the potential to enhance traditional surveillance. Furthermore, governmental and health organizations propagating of raw food as a healthy diet need to improve consumer safety by means of additional food-handling guidelines and by enhancing consumer awareness.

Although the increase of global trade and the removal of trade barriers may be beneficial from an economic point of view, the impact on food safety cannot be ignored and measures to control the dissemination of contaminated produce are of utmost importance. Nations importing produce from developing countries need to implement a system of strict preventive controls as well as to provide sustainable technical and financial assistance to such countries in the areas of agricultural practices and water hygiene.

Food irradiation by gamma or X-rays is established in the USA for the non-thermal treatment of a variety of foods including meat, shellfish, fruit, vegetables and sprouts. The development of new technologies to supplement conventional postharvest washing and sanitizing include so-called cold plasma decontamination which consists of ionized gas that effectively reduces bacterial populations on food (Niemira, 2012), including fresh produce (Ziuzina et al., 2014). Further, the application of bacteriophages in pre-and postharvest produce has the potential means to control and eradicate pathogenic bacteria (Endersen et al., 2014).

Combining the efforts of traditional and innovative approaches is necessary to develop strategies to improve produce food safety.

Conclusions

Raw food-based diets have grown in popularity over the last decades and infections associated with fresh fruit and vegetables represent a major food safety issue and a challenge to the producing industry. Reviewing outbreaks may be conductive to identifying novel vehicles of disease and to detecting trends in the occurrence of specific pathogens causing outbreaks. Thirty-five outbreaks, each associated with a single raw produce were examined for this review. While sprouts and lettuce remain the most common produce associated with bacterial disease, novel vehicles have emerged, including watercress, strawberries and stone fruit. *E. coli,* especially EHEC O157:H7 and *Salmonella* spp. remain the most common pathogens, but *L. monocytogenes* infections are increasing. Addressing the threat to human health linked to the contamination of produce necessitates a holistic, multidisciplinary approach.

Conflict of interest

The authors have no conflict of interest.

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