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RESEARCH ARTICLES

Changing epidemiology of *Salmonella* outbreaks associated with cucumbers and other fruits and vegetables

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Abstract
Background: Salmonella is one of the leading causes of foodborne outbreaks globally, with chicken and eggs the most common food vehicles associated. Fruit and vegetables have increasingly been reported as vehicles for salmonella.

Aims: We aimed to determine the trends in salmonella outbreaks associated with cucumbers, as well as other fruit and vegetables from 2009-2017.

Methods: Data from the published and grey literature were searched to investigate outbreaks of *Salmonella* globally caused by fruit and vegetables and specifically cucumbers. An open source epidemic database, Epi-Watch, was also searched for salmonella outbreaks.

Results: We identified and described 39 *Salmonella* outbreaks due to fruit and vegetables between 2009 and 2017 from Northern America, Europe and Australia, including 6 multi-state and 1 state-based outbreaks due to cucumbers, the first being documented in 2013. The proportion of *Salmonella* outbreaks cause by fruit and vegetables have been increasing, as observed in both the United States of America (USA) and Australia.

Conclusions: There has been a shift in the epidemiology of foodborne *Salmonella* outbreaks, with a higher number and proportion now associated with fruit and vegetables. This includes novel vehicles such as cucumbers, only reported as a vehicle for *Salmonella* since 2013. Emergence of less common serotypes has been observed in outbreaks from 2017-2019. Prevention at the production stage is important with limited options for consumers to reduce their risk of vegetable-associated *Salmonella*. Globalisation, changes in farming practices and importation of produce remains a challenge in monitoring and ensuring safety in the food supply chain.

Introduction

Salmonella is of significant public health concern, causing a large amount of morbidity and mortality globally (1). *Salmonella* is a common foodborne disease caused by bacteria, of which there are many different serotypes. The global burden of *Salmonella* has been estimated at 93.8 million infections of gastroenteritis each year leading to 155,000 deaths (2). It is estimated that most of these cases are caused by contaminated food. This highlights the importance of prevention and control efforts for foodborne *Salmonella* (3). The symptoms of *Salmonella* infection usually begin 12 to 72 hours after infection and include diarrhoea, fever and cramps. It is generally a self-limiting illness lasting from 4 to 7 days. More serious complications can arise including severe dehydration (2). Young children, people aged ≥65 years and those with weakened immune systems are at higher risk of infection (2).

In 2000, the World Health Organisation (WHO), the US Centres for Disease Control (CDC) and the Danish Veterinary founded WHO Global Salm-Surv, which is now the Global Foodborne Infections Network (GFIN), in order to promote global laboratory-based surveillance of *Salmonella* outbreaks among member countries (4,5). Every year, GFIN pooled surveillance data from its 142 country members, notably a list of 15 most common serotypes from each country. An analysis of data from WHO Global Salm-Surv country databank from 2000-2002 found that *Salmonella* Enteritidis and Typhimurium were the most common human serotypes globally, whereas the top 3 serotypes for non-human serotypes are *Salmonella* Typhimurium, Heidelberg and Enteritidis respectively. The trends become more heterogeneous at regional level, with serotypes Newport, Heidelberg and Javiana in high ranking among isolates from North America. Many serotypes, such as *Salmonella* Marina, Tilene or Weltevreden were restricted to certain regions of the world (6).

Historically *Salmonella* outbreaks have been commonly associated with chicken and eggs (7-11). From 1995 to 2000, meat (30%) was identified as the most common foodborne vehicle causing Salmonella outbreaks in Australia, with chicken the most commonly implicated meat (12). Trends remained similar in Australia from 2010 to 2011 with eggs and chicken identified as the sources responsible for the highest proportion of *Salmonella* outbreaks (9,10). In the USA, chicken and egg products have been identified as two of the primary sources responsible for outbreaks in the time period from 1998 to 2008 (13). Whilst chicken and eggs continue to contribute to the spread of *Salmonella* infections globally, in recent years the number and proportion of outbreaks linked to fresh vegetables, including recent outbreaks associated with cucumbers, have been increasing (14). In this review we aimed to summarise the trends in Salmonella infection caused by fruit and vegetables globally, comparing the USA and Australia, and particularly outbreaks caused by the novel vehicle, cucumbers.

Methods

A review of the literature was conducted using search engines MEDLINE and EMBASE, to identify relevant articles from 1 Jan 1990 to 30 April 2017. The search terms used were as follows: "Salmonella" AND "cucumber" OR "fruit and vegetables" OR "vegetables". A grey literature search, using a Google and Google Scholar, was also conducted to identify other relevant sources of information such as health department websites and reports. The same search terms were used for this search.

All references from the articles included in the final report were then reviewed and experts in the field were consulted, to identify any further relevant publications. There were no age or geographical restrictions.

Studies were included if they described outbreaks of *Salmonella* caused by cucumbers in any population from January 1990 to April 2017. Additional literature regarding *Salmonella* outbreaks involving other types of fruit and vegetables were also included to allow for comparisons only, this was not a complete review of the literature to document all fruit and vegetables-related outbreaks. Foodborne disease outbreaks in Australia were identified from OzFoodNet Quarterly Reports (15). Foodborne disease outbreaks in the US were identified from the Centres for Disease Control and Prevention, National Outbreak Reporting System (NORS) (16). Other portals that were consulted include WHO (17) and the European Centre for Disease Prevention and Control (ECDC) (1819). We adapted the classification scheme proposed by Painter et al. to categorize reported foods associated with *Salmonella* outbreaks (19). Vehicles where only one food was identified, or all foods fell into the same category, were classified into specific groups. Where more than one item, or a mixed ingredient (e.g. chicken/salad sandwich, mixed salad), was identified, the vehicles were classified as "Others".

In addition, surveillance data from an open source epidemic observatory, Epi-Watch (20), was scanned for media articles relating to outbreaks. Only *Salmonella* outbreaks that occurred from 2017 to 2019 were included in this review.

Data retrieved from searches were analysed using descriptive epidemiology, and multistate outbreaks were further analysed. Foodborne outbreak data in the US and Australia were summarised and compared to identify any changing trends in the epidemiology of salmonellosis.

Results

Salmonella in cucumbers

There have been a growing number of foodborne outbreaks associated with fruit and vegetables in recent years. Specifically, there have been several recent *Salmonella* outbreaks associated with a novel food vehicle, cucumbers.

The first multi-state outbreaks of *Salmonella* caused by cucumbers was identified in the USA in 2013. An outbreak of *Salmonella* Saintpaul occurred from 12 January 2013 to 28 April 2013 with 84 cases identified. Of 60 people for whom information was available, 17 required hospitalisation. This outbreak was found to be linked to imported cucumbers from Mexico. Importing restrictions were placed on two implicated suppliers, who were then required to prove imported cucumbers were *Salmonella* free before they could be imported in to the USA (21).

The second outbreak of *Salmonella*, in which the Newport serotype was implicated, occurred from 20 May to 30 September 2014 across 29 states in the USA. There were 275 cases reported linked to the outbreak with 48 of those requiring hospitalisation, and one case resulting in death. The outbreak was traced back to production in Maryland. The investigation involved environmental sampling from the supplier, including areas in which the cucumbers were grown and processed, as well as samples of sediment and manure. No samples were positive for *Salmonella*, although the testing was conducted several months after harvest. A definitive contamination source was not identified. Laboratory typing showed that *Salmonella* with a similar pulsed-field gel electrophoresis (PFGE) pattern had been previously associated with contaminated tomatoes from eastern Virginia (22).

The third and the largest outbreak, occurred from 3 July 2015 to 29 February 2016 in the USA. The outbreak was cause by *Salmonella* Poona. A total of 907 cases across 40 states were identified. Six people died and 204 people were hospitalised as a result of the outbreak (23). Epidemiological and environmental investigation identified cucumbers from one particular company, who imported the produce from Mexico, as the source. The company responsible voluntarily recalled the product (24). The peak of cases occurred in August and September 2015, after the number of cases declined. However, it took several months to return to the baseline level of *Salmonella* infections, with cases continuing until February 2016. The cause of the ongoing cases is unclear, as cucumbers have a short shelf life and the infected produce was no longer available for purchase during this time. Trace-back and laboratory investigations isolated the outbreak serotype from cucumbers in stores, as well as from the distributing facility (23).

The fourth outbreak, caused by *Salmonella* Oslo, was discovered in April 2016 in the United States of America (USA). A total of 14 people from 8 states, three of who were hospitalised, became ill between March 21 and April 9, 2016. The outbreak spread across three states and Persian cucumbers were identified as the source. A traceback investigation identified two common suppliers from Canada, linked to three different growers in Mexico, Canada and the Dominican Republic. No one grower was identified as the source. Laboratory testing of samples conducted one month after the outbreak found no traces of *Salmonella*. As this was the fourth outbreak since 2013 in the USA, the Food and Drug Administration has initiated enhanced surveillance of cucumbers (25).

The most recent outbreak occurred in five provinces in Canada, with the onset date from mid-June to late-October 2018. A total of 56 laboratory-confirmed cases of *Salmonella* Infantis were reported, the majority centred on British Columbia. 11 individuals were hospitalised. Although English cucumbers were the primary suspected vehicle, laboratory testing of samples found no positive trace of *Salmonella* (26). This outbreak was possibly related to another outbreak in the Washington state of the USA, which shares a border with British Columbia, in which six Salmonella infections were also linked to English cucumbers (27).

Outside the North American continent, a multi-country outbreak of *Salmonella* Agona was described in a joint report by the ECDC and the European Food Safety Authority. 147 cases were reported from five EU countries (the United Kingdoms (UK), Finland, Denmark, Ireland and Germany), with 122 cases since 2017 and 25 historical cases between 2014 and 2016. The UK had the most cases (129), followed by Finland (15). Human samples were analysed using the core genome multilocus sequence typing scheme and were found to be genetically close (with a maximum difference of 2 alleles), suggesting a common source. Although *Salmonella* food isolates from cucumbers (17 isolates) were found to be genetically linked to the human serotype, pointing to cucumbers as a possible vehicle of contamination, there was inefficient epidemiological information to definitively prove this hypothesis. These isolates were found in both cucumbers during processing (before and after washing) and ready-to-eat products, but all contaminated samples were from separate production chains, and thus there was no concrete evidence of where contamination might have taken place. This report highlights the challenges of traceback investigations, especially in navigating complex production chains where multiple processing stages take place in different countries (28).

The association found between *Salmonella* outbreaks and cucumbers is new. To the best of our knowledge, there are no outbreaks of Salmonella associated with cucumbers in the literature prior to the first USA multistate outbreak in 2013.

Salmonella in other fruit and vegetables

Whilst cucumbers are a novel vehicle, outbreaks of *Salmonella* are also associated with other types of fruit and vegetables have previously been identified as the cause of *Salmonella* outbreaks globally, including leafy vegetables, papayas, tomatoes, melons, sprouts, shredded coconut, peas and hazelnuts (29-61). Major identified outbreaks are summarised in Table 1 below.

Changing trends in Salmonella outbreaks

Whilst there have been no *Salmonella* outbreaks associated with cucumbers reported in Australia to date, outbreaks of *Salmonella* associated with fruit and vegetables appear to be increasing in recent years. In Australia from 2001 to 2005, 4% (n=16) of foodborne outbreaks where a vehicle was identified were linked to fruit and vegetables (62). In annual reports from OzFoodNet, Australia's foodborne disease surveillance network, it was reported that in 2007, 7/56 (8%) of outbreaks were a vehicle was identified were caused by fruit and vegetables (63). In 2008, 6/75 (8%), of food borne outbreaks where a vehicle were caused by salad and/or sandwiches (64). Data from 2009 is similar, with a total of 69 foodborne outbreaks had a vehicle identified, of which eight (12%) were caused by fruit and vegetables or sandwiches (65). Data from 2010 and 2011 was reported for outbreaks in which a single food source was identified as the cause of an outbreak. In 2010, 3/43 (7%) were caused by fruits or nuts (9) and in 2011, 3/49 (6%) were caused by fruits, nuts, grains or beans (10). More recent annual national data in relation to foodborne outbreaks does not appear to be published.

The increase in fruit and vegetable-related *Salmonella* outbreaks has also been shown in the USA. Outbreaks which were caused by fruit and vegetables rose from less than 1% in the 1970's to approximately 6% in the 1990s (66). A review of data from the USA showed that from 1973 to 1997 showed the proportion of foodborne outbreaks occurring linked to fruit and vegetables had increased in this time from 0.7% to 6%. The most commonly identified bacteria associated with these outbreaks was *Salmonella*. A number of different food vehicles were identified, but of these the most common identified were lettuce, sprouts, melon, and berries (67). More recent US data, from 1990-2005 showed that fruit and vegetables is responsible for 13% of foodborne outbreaks (68). An additional review from 1973 to 2012, 5% (n=606) of foodborne outbreaks in the USA were caused by leafy greens. Of those with a cause identified, 11% were identified as *Salmonella* (69). It has been shown that some serotypes of *Salmonella* are more common to plant-derived foods, with data from 1998–2008 showing that serotypes Javiana, Litchfield, Mbandaka, Muenchen, Poona, and Senftenberg were responsible for greater than 50% of outbreaks caused by foods that come from plants (13). A review of melon associated outbreaks in the USA showed that from 1973 to 2011 showed that the rate of melon associated outbreaks was found to increase over this time period from 0.5 to 1.3 outbreaks per year. For outbreaks in which the source had been identified, the majority were imported from Mexico (9/13). The majority of contamination was also identified to occur during the production process at different stages including during the growing, harvesting, processing and packaging stages (70).

Incidence of Salmonella in cucumbers

Salmonella contamination has been identified in cucumbers globally. In April 2011, the U.S. Food & Drug Administration (FDA) found cucumbers positive for *Salmonella* during routine testing. The company was informed and a recall was put in place. There was no associated illness reported with these contaminated cucumbers (71). *Salmonella* has also been found in cucumbers in Japan as a result of its National Food Surveillance System, which was initiated in 1998 following three major outbreaks in 1996-1997 linked to radish sprouts from school lunches. Data from 1998 to 2009 shows that *Salmonella* was detected in approximately 0.1-0.2% of cucumber samples tested for food safety surveillance (72).

Emergence of new serotypes

Traditionally, global epidemiology of salmonellosis tends to be dominated by a few *Salmonella* serotypes. For example, in 1995, more than 76% of global isolates were caused by *Salmonella* Enteritidis, Typhimurium and Typhi (4). These serotypes, especially Enteritidis, were associated with eggs and poultry, thus making these food groups the target of food surveillance programmes and control measures by public health authorities (73).

Among outbreaks caused by fruits and vegetables in 2017-2019, some were caused by typical serotypes, such as *Salmonella* Newport (22,38,45,58), Infantis (26,38) and Typhimurium (31,43,59,60). However, many other outbreaks were associated with less common serotypes. For example, *Salmonella* Anatum, which was implicated in 2016 multistate outbreak in Australia (29) and 2017 multi-state outbreaks in the US (39), had been previously popular in Asia, Africa and South America, but had not been reported in North America from 2001-2007 (74). Similarly, serotypes St Paul, Poona, Oslo and Agona were behind major outbreaks associated with cucumbers in the USA and Europe (21,23,25,28), although they have not been featured in the top 5 common serotypes in these regions from 2001-2007 (74). Most significantly, serotype Enteritidis – the world's leading *Salmonella* serotype (6) – was notably absent in these outbreaks.

Modes of contamination

There is growing evidence which shows the ways in which *Salmonella* can contaminate produce during growing, process, transport and storage. The rising number of *Salmonella* infections caused by fruit and vegetables has led to investigations into the mechanisms by which produce can become contaminated with *Salmonella*. These include produce grown close to water sources which have been contaminated by excretion from cattle and wildlife, exposure in fields to wild animals and their waste materials, sewage, and the use of contaminated fertiliser (69). In addition, a review of the literature investigated associations between contaminated fruit and vegetables, predominantly leafy greens and tomatoes, and growing practices. The study identified risks that increase the likelihood of contamination include growing produce in clay-type soil, the use of contaminated water and untreated manure, and the use of contaminated irrigation water (72). Contamination can also occur during storage and distribution if storage facilities and transport vehicles are not using appropriate hygiene and disinfectant procedures (75-76).

Reina, et al., found that several factors contribute to *Salmonella* surviving specifically on the surface of cucumbers. The most important of these are higher temperatures, higher concentration and longer length of exposure to contaminated water. The study also highlighted the importance of using appropriately treated water (77). One popular theory of contamination of fruit and vegetables currently being explored in the internalisation theory. This suggests that *Salmonella* may be able to enter and replicate within produce. To date experiments regarding internalisation have focused on leafy vegetables/greens and herbs (78). A recent study found that *Salmonella* can internalise in cucumbers when introduced in the early stages of growth via the flowers of the plant. When *Salmonella* was introduced via the flower, 83% (n=58) of cucumbers were contaminated with *Salmonella* and 67% (n=39) had internalised *Salmonella*. This was much lower for cucumbers which had *Salmonella* introduced into the soil (8%). The most common *Salmonella* identified in the contamination experiment was *Salmonella* Poona (70%) (79).

Other studies have investigated the length of time *Salmonella* can survive on the outside of fruit and vegetables. Evidence shows that once introduced on the surface of tomatoes, *Salmonella* can grow and live for up to 18 days depending on temperature. Higher concentration of the *Salmonella* was shown in the first seven days (80). Tomatoes have also been shown to internalise *Salmonella*. This can occur when tomatoes are washed in water that is contaminated and a lower temperature than the tomatoes, which causes the produce to draw in water, along with the contaminants (67).

Table 1. Summary of outbreaks linked to other fruits and vegetables beside cucumbers (29-61).

Date	Location	Serotype	No. of identified cases	Implicated fruit/vegetable	Other details	Reference
Feb 2016	Victoria, Australia	Anatum	>200	Pre-packed salad	No details of environmental trace-back was provided.	29, 30
Aug-Sep 2000	England and Wales	Typhimurium DT104	361	Lettuce	Trace-back investigation did not identify a common source.	31
Oct-Nov 2004	Norway	Thompson	21	Rucola lettuce (salad rocket)	Environmental investigation suggested the most likely source of contamination was poor quality irrigation water close to the time of harvest.	32
Oct-Nov 2008	Finland	Newport, Reading	131	Iceberg lettuce	Trace-back investigation did not identify a common source.	33
Sep-Oct 2004	Northern Ireland	Newport	130	Lettuce	Trace-back investigation did not identify a common source.	34
Apr-May 2019	Multistate, US	Infantis	5	Vegetable trays containing broccoli, cauliflower, carrots and dill dip	A particular brand was identified as a common source. No details of environmental trace-back was provided.	35-36
Jul-Aug 2017	Multistate, US	Urbana	7	Yellow Maradol papayas	*Salmonella* detected in samples. Trace-back investigation identified papayas from a particular farm in Mexico as the common source.	37
Jul-Aug 2017	Multistate, US	Newport, Infantis	4	Yellow Maradol papayas	*Salmonella* detected in samples. Trace-back investigation identified papayas from a particular farm in Mexico as the common source.	38
Dec 2016-Aug 2017	Multistate, US	Anatum	20	Yellow Maradol papayas	*Salmonella* detected in samples. Trace-back investigation identified papayas imported from Mexico by a particular importer as the common source.	39
May-Oct 2017	Multistate, US	Thompson, Kiambu, Agona, Gaminara, Senftenberg	220	Yellow Maradol papayas	*Salmonella* detected in samples. Trace-back investigation identified papayas from a particular farm in Mexico as the common source.	40
Jan-Jun 2019	Multistate, US	Uganda	71	Cavi brand papayas	*Salmonella* detected in samples. Trace-back investigation identified a particular brand of papayas as the common source.	41
July 2004	Multistate, US	Braenderup	23	Tomatoes	Traceback investigation points to one producer but no source for the contamination could be identified.	42
2006	Multistate, US	Typhimurium	190	Tomatoes	Traceback investigation points to one packer. The mechanism for contamination was not reported.	43
2011	Denmark, Germany, Italy, Austria & Belgium	Strathcona	71	Tomatoes	Traceback investigation points to one producer but no source for the contamination could be identified.	44

2018	Kansas, US	Newport	14	Tomatoes	The outbreak was confined to a dinner event, in which samples of tomatoes tested positive for the same strain of Salmonella. Multiple providers were involved and no source for the contamination could be identified.	45
Jun-Aug 2016	Multistate, Australia	hvittingfoss	86	Rock melons	The contaminated produce was linked back to one producer and a recall was implemented.	46
2006	Multistate, Australia	Saintpaul	115	Rock melons	A number of food safety issues were identified that could have led to the contamination including washing ready-to-eat rock melons in inadequately treated water, incorrect disinfectant techniques, differences in temperature between the fruit and water used, and including damaged fruit in processing.	47
Dec 2017	Multistate, US	Unidentified	18	Pre-cut watermelons & cantaloupes	No details of environmental trace-back was provided.	48
Apr-Jul 2018	Multistate, US	Adelaide	77	Pre-cut watermelons & cantaloupes	Traceback investigation points to one producer but no source for the contamination could be identified.	49
Mar-May 2019	Multistate, US	Carrau	137	Pre-cut watermelons, honeydew melons & cantaloupe	Traceback investigation points to one producer. Cutting the melons might have exposed the internal surfaces of the fruits to bacterial contamination.	50
2006	Victoria, Australia	Oranienburg	15	Alfafa sprouts	Traceback investigation led to one brand of sprouts which was tested positive and subsequently recalled from the market.	51
Jun 2018	South Australia, Australia	Havana	21	Alfafa sprouts	Several brands of sprouts were tested positive and subsequently recalled from the market.	52
Sep 2018	South Australia, Australia	Oranienburg	8	Alfafa sprouts	Several brands of sprouts were tested positive and subsequently recalled from the market.	53
Nov 2015-Apr 2016	Multistate, US	Muenchen & Kentucky	26	Alfafa sprouts	Environmental traceback points to a single source of alfafa seeds used to produce the sprouts, which were possibly contaminated by irrigation water.	54
May-Sep 2016	Multistate, US	Reading & Abony	36	Alfafa sprouts	Traceback investigation points to one producer but no source for the contamination could be identified.	55
Dec 2017	Multistate, US	Montevideo	10	Raw sprouts	All but one case reported consumption of raw sprouts served at a common restaurant chain, marking the seventh time since 2008 that raw sprouts at the same franchise were implicated in Salmonella outbreaks. No contamination source has been identified.	56, 57
2017	Multistate, US	*I 4,(5),12:b:-* & Newport	27	Shredded coconut	Traceback investigation points to a particular brand of frozen shredded coconut, as well as coconut milk and Asian-style dessert using coconut milk.	58
Sep 2017-Feb 2018	Multistate, US	Typhimurium	14	Dried coconut	Traceback investigation points to a particular brand of frozen shredded coconut.	59
Nov-Dec 2017	Oregon, US	Typhimurium	5	Hazelnuts	Although the implicated farm distributes the bulk of its hazelnuts through wholesalers, the risk of contamination was restricted to partially-shelled hazelnuts sold directly to consumers at the farm's roadside stand	60
Jul 2017	Wisconsin, US	Typhimurium	7	Shelled peas	Three separate farmers' markets were involved. No details of environmental trace-back was provided. Public health warning only applied to shelled peas, not whole peas that are still in their pods.	61

Data from 21 farms growing produce in New York State show that *Salmonella* can be found in irrigation and non-irrigation water, 6.1% of fields and 11% of water samples. Although only 4% of water positive samples were from water used for irrigation purposes, the study found that the use of manure to fertilise a field within the last year and cultivation of the field within the previous 7 days were associated with a higher risk of *Salmonella* contamination. A buffer zone of 5 metres or more from potential risks such as animals or contaminated water was associated with a decreased risk of *Salmonella* contamination (81).

Changes in cucumber production and consumption

The increase in outbreaks associated with fruit and vegetables may be due to several factors including changes in the diet of populations. The US population have increased their per capita consumption of fruits and vegetables from 95kg per capita in 1970 to 114kg per capita in 2013, according to statistics from the Food and Agriculture Organisation (82). Australia's per capita intake of fruits and vegetables has increased over time. The Australian Bureau of Statistics report that Australians ate 162kg per capita of vegetables in 1998-1999, which increased from 117kg per capita in the late 1950's. A similar trend is seen with fruit; reported consumption was 135 kg per capita in 1998-1999, increasing from approximately 85kg per capita in the late 1960's (83).

There are also different issues which need to be considered with fruit and vegetables such as cucumbers. These include the facts that the typical shelf life of cucumbers is 16-25 days (84), and fruit and vegetables are often eaten raw, with no heating method to eliminate possible contamination. In addition, cucumbers specifically, may often be eaten with the skin on. Other factors which may contribute to the increase in produce-related outbreaks are changes in methods of food production, and an increase in the distance in which produce is transported (85).

Prevention

With the number of outbreaks associated with fruit and vegetables, and cucumbers specifically, prevention is key to limiting the spread. Methods of sanitising fruit and vegetables for consumers is limited. This is because a lot of fruit and vegetables, such as cucumbers, are eaten raw so bacteria can't be killed with heat as with chicken. Additionally, washing vegetables with water alone under commercial conditions is not particularly effective to reduce *Salmonella* risk to consumers (86), and in some cases can even introduce risks of cross-contamination (87).

Table 2. Identified sources of *Salmonella* outbreaks with known sources in Australia, 2001-2014 (9-10, 15, 62-65)

	Dessert		Eggs		Fish/ shellfish		Poultry		Meat		Fruit/ vegetables		Others		Unknown		**Total**	
2001	4	(14.8%)	3	(11.1%)	1	(3.7%)	4	(14.8%)	4	(14.8%)	0	(0.0%)	3	(11.1%)	8	(29.6%)	**27**	**(100%)**
2002	4	(15.4%)	5	(19.2%)	0	(0.0%)	3	(11.5%)	1	(3.8%)	0	(0.0%)	8	(30.8%)	5	(19.2%)	**26**	**(100%)**
2003	1	(3.2%)	4	(12.9%)	0	(0.0%)	2	(6.5%)	7	(22.6%)	1	(3.2%)	7	(22.6%)	9	(29.0%)	**31**	**(100%)**
2004	4	(11.1%)	3	(8.3%)	3	(8.3%)	3	(8.3%)	1	(2.8%)	0	(0.0%)	7	(19.4%)	15	(41.7%)	**36**	**(100%)**
2005	2	(6.1%)	5	(15.2%)	1	(3.0%)	1	(3.0%)	1	(3.0%)	1	(3.0%)	16	(48.5%)	6	(18.2%)	**33**	**(100%)**
2006	2	(4.9%)	12	(29.3%)	0	(0.0%)	0	(0.0%)	2	(4.9%)	4	(9.8%)	11	(26.8%)	10	(24.4%)	**41**	**(100%)**
2007	7	(14.0%)	12	(24.0%)	0	(0.0%)	1	(2.0%)	2	(4.0%)	2	(4.0%)	10	(20.0%)	16	(32.0%)	**50**	**(100%)**
2008	0	(0.0%)	17	(48.6%)	0	(0.0%)	3	(8.6%)	3	(8.6%)	0	(0.0%)	6	(17.1%)	6	(17.1%)	**35**	**(100%)**
2009	1	(1.7%)	16	(27.1%)	0	(0.0%)	2	(3.4%)	2	(3.4%)	1	(1.7%)	6	(10.2%)	31	(52.5%)	**59**	**(100%)**
2010	0	(0.0%)	21	(36.2%)	0	(0.0%)	3	(5.2%)	1	(1.7%)	0	(0.0%)	10	(17.2%)	23	(39.7%)	**58**	**(100%)**
2011	2	(3.3%)	26	(42.6%)	0	(0.0%)	5	(8.2%)	4	(6.6%)	1	(1.6%)	7	(11.5%)	16	(26.2%)	**61**	**(100%)**
2012	0	(0.0%)	25	(38.5%)	0	(0.0%)	2	(3.1%)	2	(3.1%)	0	(0.0%)	14	(21.5%)	22	(33.8%)	**65**	**(100%)**
2013	1	(2.0%)	19	(37.3%)	0	(0.0%)	1	(2.0%)	1	(2.0%)	0	(0.0%)	9	(17.6%)	20	(39.2%)	**51**	**(100%)**
2014	4	(4.3%)	38	(40.9%)	0	(0.0%)	2	(2.2%)	2	(2.2%)	0	(0.0%)	13	(14.0%)	34	(36.6%)	**93**	**(100%)**
2015	0	(0.0%)	45	(47.9%)	0	(0.0%)	4	(4.3%)	5	(5.3%)	0	(0.0%)	16	(17.0%)	24	(25.5%)	**94**	**(100%)**
Total	**32**	**(4.8%)**	**206**	**(30.9%)**	**5**	**(0.8%)**	**32**	**(4.8%)**	**33**	**(5.0%)**	**10**	**(1.5%)**	**127**	**(19.1%)**	**221**	**(33.2%)**	**666**	**(100%)**

**Data sourced and compiled from OzFoodNet quarterly reports*
**Note: Quarterly reports were only published for outbreaks occurring up to 2015. Outbreak data was thus incomplete for accurate comparison from 2016-2019.*

Table 3. Identified sources of multistate *Salmonella* outbreaks in the USA, 2006 – 2016 (14)

	Fish / shellfish		Dairy		Eggs		Meat/ poultry		Grains / beans		Fruit and vegetables		Other		**Total**	
2001	2	(2.2%)	3	(3.2%)	11	(11.8%)	25	(26.9%)	1	(1.1%)	10	(10.8%)	41	(44.1%)	**93**	**(100%)**
2002	0	(0.0%)	3	(3.0%)	4	(4.0%)	28	(28.3%)	0	(0.0%)	9	(9.1%)	55	(55.6%)	**99**	**(100%)**
2003	2	(2.2%)	1	(1.1%)	7	(7.6%)	23	(25.0%)	1	(1.1%)	10	(10.9%)	48	(52.2%)	**92**	**(100%)**
2004	3	(3.7%)	2	(2.4%)	9	(11.0%)	31	(37.8%)	0	(0.0%)	5	(6.1%)	32	(39.0%)	**82**	**(100%)**
2005	1	(1.2%)	3	(3.7%)	5	(6.1%)	21	(25.6%)	0	(0.0%)	6	(7.3%)	46	(56.1%)	**82**	**(100%)**
2006	1	(1.6%)	3	(4.8%)	3	(4.8%)	17	(27.0%)	0	(0.0%)	9	(14.3%)	30	(47.6%)	**63**	**(100%)**
2007	1	(1.3%)	4	(5.3%)	3	(3.9%)	21	(27.6%)	0	(0.0%)	9	(11.8%)	38	(50.0%)	**76**	**(100%)**
2008	1	(1.5%)	1	(1.5%)	2	(2.9%)	20	(29.4%)	1	(1.5%)	6	(8.8%)	37	(54.4%)	**68**	**(100%)**
2009	2	(3.3%)	1	(1.7%)	2	(3.3%)	16	(26.7%)	0	(0.0%)	12	(20.0%)	27	(45.0%)	**60**	**(100%)**
2010	2	(3.3%)	0	(0.0%)	3	(5.0%)	14	(23.3%)	0	(0.0%)	10	(16.7%)	31	(51.7%)	**60**	**(100%)**
2011	0	(0.0%)	1	(1.8%)	1	(1.8%)	23	(41.8%)	0	(0.0%)	13	(23.6%)	17	(30.9%)	**55**	**(100%)**
2012	1	(1.7%)	1	(1.7%)	3	(5.1%)	21	(35.6%)	2	(3.4%)	11	(18.6%)	20	(33.9%)	**59**	**(100%)**
2013	2	(2.4%)	6	(7.2%)	2	(2.4%)	31	(37.3%)	0	(0.0%)	11	(13.3%)	31	(37.3%)	**83**	**(100%)**
2014	4	(5.6%)	2	(2.8%)	2	(2.8%)	26	(36.1%)	0	(0.0%)	16	(22.2%)	22	(30.6%)	**72**	**(100%)**
2015	2	(2.3%)	5	(5.7%)	4	(4.5%)	26	(29.5%)	0	(0.0%)	5	(5.7%)	46	(52.3%)	**88**	**(100%)**
2016	2	(2.9%)	4	(5.7%)	6	(8.6%)	24	(34.3%)	0	(0.0%)	14	(20.0%)	20	(28.6%)	**70**	**(100%)**
Total	**26**	**(2.2%)**	**40**	**(3.3%)**	**67**	**(5.6%)**	**367**	**(30.5%)**	**5**	**(0.4%)**	**156**	**(13.0%)**	**541**	**(45.0%)**	**1,202**	**(100%)**

**Data sourced from the Centre for Disease Control and Prevention, USA*

There are several methods used to sterilize food prior to consumption, including chlorine, high pressure processing, the use of UV light and high temperature treatments. Research has shown that chlorine can be effective at reducing *Salmonella* contamination in tomatoes but only when used at appropriate concentrations (80). This may be less effective due to the strength of the attachment of the bacteria to fruit and vegetables, as well as the difficulty in accessing inner parts of fruit and vegetables. Both UV light and the use of high temperatures to eliminate *Salmonella* in fruit and vegetables have been shown to be effective. However, high levels of both types of interventions are needed to successfully kill or eliminate *Salmonella* from fruit and vegetables, and they have been shown to damage the produce being treated in some instances (70).

As shown, each of these methods have limitations in terms of reducing the contamination on the surface of fruit and vegetables, and do not address the issue of internalisation. Visible blue light is a new prevention measures being investigated. Cucumbers were used to test the effectiveness of this prevention method in killing bacteria. The results showed that the use of visible blue light at appropriate levels killed between 80 and 100% of *Salmonella* (88). The investigation of new methods of sanitisation of fruit and vegetables should continue. A combination of regulation, legislation and auditing of suppliers to ensure good agricultural practices is critical, which remains a challenge for internationally marketed products.

Discussion

The recent outbreaks of *Salmonella* reported in the USA have identified cucumbers as a novel vehicle for *Salmonella* outbreaks. With the number and severity of cases associated with the most recent outbreaks of *Salmonella* associated with produce, it is unlikely that the increase in outbreaks caused by fruit and vegetables is artefactual and represents a real change in the epidemiology of *Salmonella*. The sizeable geographic spread also suggests that the outbreaks are caused by a source early in the supply chain, prior to distribution, which is supported by trace-back investigations. Whilst cucumbers are a novel vehicle for *Salmonella* outbreaks, outbreaks associated with other types of fruit and vegetables have increased in recent decades such as papayas, tomatoes and melons (67, 32, 40-51). This is due to contamination on the surface of produce as well as the possibility of bacteria internalization (67, 78-81). There are a number of ways in which produce can become contaminated during the growing, storage and delivery stages, including insufficiently sanitized irrigation water and processing equipment (69, 75-77).

Increases in the consumption of fruit and vegetables and the increased distance between distribution and sale may account for some of these infections. However, the recent outbreaks raise several issues that require exploration, including possible changes to farming practices, changes in the number, frequency and location of imports of cucumbers, and the need for tighter regulations for farming and exportation of fruit and vegetables. Of the trace-back investigations that have been conducted and reported, it appears that many cucumber outbreaks in the USA have been caused by produce imported from Mexico (21).

Given the limited availability of prevention methods for consumers to reduce their own risk, food safety at the pre-harvest and production phase is important. There are currently several methods available to sterilize fruit and vegetables including the use of chlorine, UV light and high temperature treatments (69, 80). However, each of these methods have limitations in relation to fruit and vegetables. There are new technologies such as visible blue light being explored to protect fruit and vegetables from contamination (84).

The emergence of less common serotypes among *Salmonella* isolates raises the question of whether these serotypes should be incorporated in foodborne surveillance programmes for this food group (vegetables and fruits). There are several possible reasons behind this emergence. The first theory is that these serotypes are traditionally found in nonhuman sources (e.g. food and live animals), for which routine surveillance was limited due to international trade concerns (6). With the rise in incidence of outbreaks related to vegetables and fruits, testing of nonhuman sources as part of traceback investigations brings to light these serotypes. Another possibility is that of a real change in epidemiologic features of salmonellae, which warrants further epidemiologic studies.

The list of outbreaks in this review is non-exhaustive and does not reflect the true incidence of *Salmonella* worldwide. It is highly possible that publication bias is present as outbreaks outside Northern America, Australia and Europe may be under-represented for various reasons: use of languages other than English for reporting, absence of an active surveillance and reporting system, or lack of mandatory laboratory culture protocols for foodborne outbreaks.

Conclusion

It is clear the numbers of *Salmonella* outbreaks caused by fruit and vegetables are increasing, with new, less common serotypes emerging among nonhuman isolates. Further investigation into this issue is required to better understand the role of fruit and vegetables in *Salmonella* outbreaks and new effective methods for sanitization at the production stage are needed.

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