The Epidemiology of *Salmonella enterica* Outbreaks in Australia, 2001–2016

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Salmonella enterica is an important cause of foodborne illness in Australia, regularly causing high-profile outbreaks involving commercially-available foods. We used the national register of foodborne outbreaks to review the transmission pathways, settings, serotypes, and food vehicles of *Salmonella* outbreaks in Australia between 2001 and 2016. We examined trends over time of implicated food vehicles in outbreaks where there was statistical, microbiological, or descriptive evidence. Of the 990 *Salmonella* outbreaks reported, 79% (778/990) were suspected or confirmed to have been transmitted through contaminated food. Of these, 61% (472/778) occurred in food premises and 84% (656/778) were caused by *Salmonella* Typhimurium. Eggs and egg-containing foods were the most frequently identified food vehicle. Outbreaks due to egg-based sauces and Vietnamese style sandwiches, which often contain pâté and raw egg butter, increased, while outbreaks due to poultry meat, beef, pork, other sandwiches, and other desserts had a decreasing trend from 2001 to 2016. Identifying food vehicles and the *Salmonella* serotypes causing outbreaks in Australia provides important evidence for food regulation strategies and control measures.

Keywords: disease outbreaks, eggs, Australia, foodborne disease, *Salmonella* Typhimurium

INTRODUCTION

Non-typhoidal *Salmonella enterica* spp. infection from contaminated food is an important cause of both sporadic gastroenteritis and outbreaks internationally. In Australia, the incidence of infection due to *Salmonella* spp. in the community is estimated to be 185 infections per 100,000 population per year (Kirk et al., 2014). While only a small proportion of *Salmonella* cases are epidemiologically linked to outbreaks [6.6% of notifications in 2011 (OzFoodNet Working Group, 2015)], outbreaks can be widespread and expensive for regulators and industry (Scharff et al., 2016). OzFoodNet—Australia's enhanced foodborne disease surveillance network, has published annual surveillance reports between 2001 and 2011, which report an annual median of 36 (range 26–61) salmonellosis outbreaks nationally that are confirmed or suspected to be caused by contaminated food, with the majority due to *Salmonella* Typhimurium (OzFoodNet Working Group, 2003, 2015).

The investigation of outbreaks to identify and control the source of infection is an essential public health action to prevent further cases. Review of the *Salmonella* serotypes and associated food vehicles identified during outbreaks can assist with the development of targeted population-level interventions and prevention strategies to reduce the incidence of *Salmonella* serotypes associated with these food vehicles. International studies have attributed *Salmonella* outbreaks to food commodities, finding that eggs were the most commonly implicated food vehicle in the United States of America (USA) (28% of outbreaks), poultry in the United Kingdom (UK) (20.5% of outbreaks), and all meats in Latin America (24% of outbreaks) (Gormley et al., 2011; Pires et al., 2012; Jackson et al., 2013; Painter et al., 2013). In Australia, outbreaks of salmonellosis have been associated with a variety of foods including eggs, chicken and other poultry, pork, beef, lamb, fish, fresh produce, and nuts (Ashbolt et al., 2002; OzFoodNet Working Group, 2012). While there is evidence that outbreaks associated with eggs in Australia have increased (Moffatt et al., 2016), the food vehicles responsible for outbreaks of salmonellosis have not been systematically assessed before.

In this study, we used the national foodborne disease outbreak register data to describe the epidemiology of foodborne *Salmonella* outbreaks in Australia between 2001 and 2016.

MATERIALS AND METHODS

We used the OzFoodNet outbreak register, the national register of foodborne disease outbreaks in Australia, to examine all reported outbreaks from 1 January 2001 to 31 December 2016 where non-typhoidal *Salmonella* spp. was listed as the etiological agent. Australian states and territories who investigate the outbreaks enter standardized outbreak data into this national repository, including information on: the setting of the outbreak; where the food was prepared (if applicable and defined in **Supplementary Information 1**); number of symptomatic cases; number of cases with laboratory-confirmed *Salmonella* spp., number of cases hospitalized, number who died during the outbreak (the relative contribution of illness due to salmonellosis to each death is unknown); median incubation period of cases; median duration of illness; geographical location of exposures (local government area, multiple local government areas, multiple health department regions, state-wide, multi-state); mode of transmission; food vehicle; type of investigation (case series, cohort, case-control) and evidence (statistical, microbiological, descriptive); and *Salmonella* spp. serotype classified in accordance with the White-Kauffmann-Le Minor scheme (Grimont and Weill, 2007).

An outbreak was defined as ≥2 cases of *Salmonella* spp. orientated by person, place or time, or an increase in the number of salmonellosis cases above what is normally expected and where an investigation was undertaken to try to determine the source of illness. A foodborne or suspected foodborne outbreak was defined as an outbreak where cases had consumed a common food or meal that was implicated in causing their illness. We defined statistical, microbiological, and descriptive evidence as in Moffatt et al. (2016). If an analytical epidemiological study was undertaken with a statistically significant association

observed between a food vehicle and illness, the food vehicle was considered to have statistical evidence. Microbiological evidence was obtained when *Salmonella* was detected or cultured from the implicated food vehicle, food premises, processing, or primary production environment. Microbiological investigations and analytical studies were not undertaken in all outbreaks. An outbreak was considered to have descriptive evidence if there was information collected from the epidemiological and/or the environmental health investigations that implicated the food vehicle, which the outbreak investigation team considered compelling. This would include, for example, if an unsafe food preparation practice of a food reportedly eaten by at least some outbreak cases was observed during the environmental health investigation.
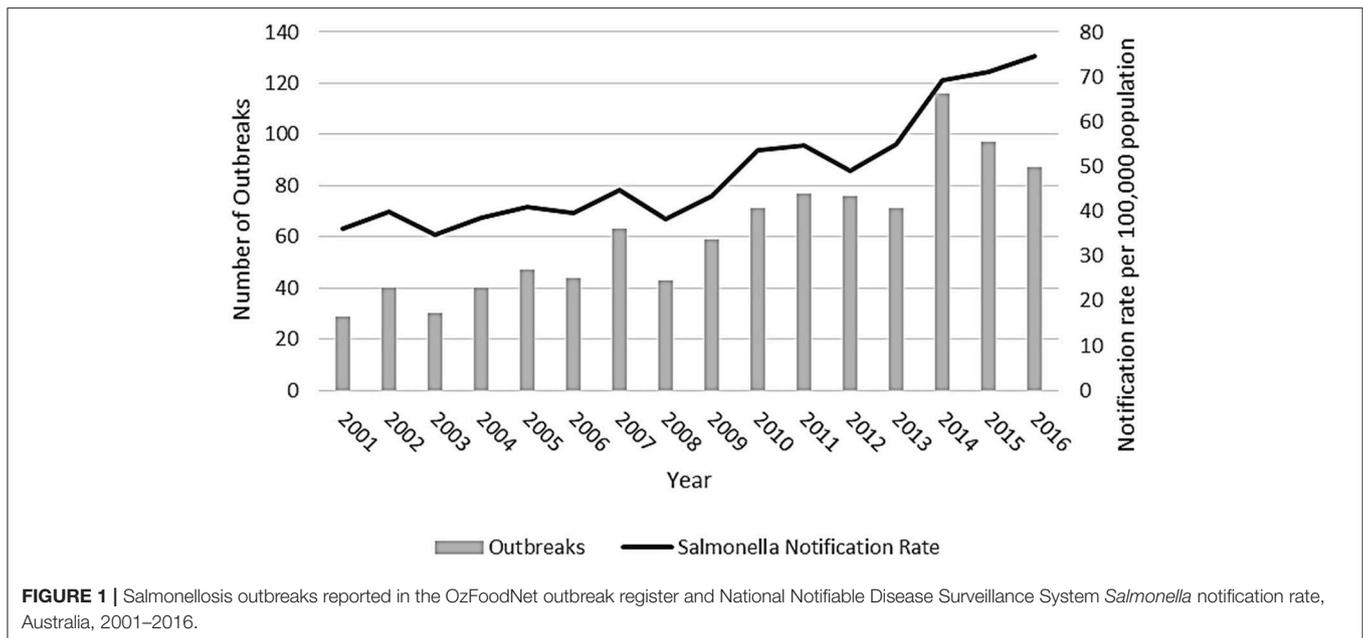
Outbreaks where <2 people had laboratory-confirmed *Salmonella* spp. infection and there was no microbiological evidence implicating a food were excluded ($n = 35$). Duplicate entries of multi-state outbreaks using OzFoodNet outbreak reports (Ashbolt et al., 2002; OzFoodNet Working Group, 2007) ($n = 2$) and outbreaks where another pathogen besides *Salmonella* spp. was detected or isolated in cases ($n = 3$) or in the food vehicle ($n = 2$) were excluded. There was one outbreak in the outbreak register included in our analysis where a serotype was unable to be determined.

We compared the number of outbreaks per year to the national salmonellosis notification rate using data from the National Notifiable Disease Surveillance System (Department of Health, 2018). Food vehicles were grouped into food categories (**Supplementary Information 1**). As the food vehicle field only contained the name of the implicated food or meal, ingredient lists were obtained through internet-based recipe searches. Our food categories included egg-based sauce, desserts containing raw or lightly cooked eggs, other desserts, eggs (other), poultry, beef, pork, lamb, fish, crustacean/mollusc, fruits, vegetables, nuts, sprouts, bánh mì (Vietnamese style sandwiches), other sandwiches, salads, sushi/kimbap/gimbap, tahini or helva, dips, and mixed dishes. If there were insufficient details in the food vehicle field to categorize the food, we categorized it as undetermined. Food vehicle categories were examined by (i) evidence type and (ii) trend over time.

Descriptive analyses were performed in Stata SE 14 (StataCorp 2014) and graphs were created in Microsoft Excel 2013. Due to the importance of *S.* Typhimurium in Australia, we used chi-square tests for homogeneity to assess differences between outbreaks due to *S.* Typhimurium and non-Typhimurium serotypes. We used the ptrend command to calculate a chi-square statistic for trend to assess trends in food vehicles over time. Permission for data access was granted by OzFoodNet and ethics approval was obtained through the Australian National University Human Research Ethics Committee (2017/494).

RESULTS

From 1 January 2001 to 31 December 2016, there were 990 outbreaks due to *Salmonella* spp. reported by Australian state and territory health authorities. The number of outbreaks reported per year ranged from 29 outbreaks in 2001 to 116 outbreaks in 2014 (**Figure 1**).

FIGURE 1 | Salmonellosis outbreaks reported in the OzFoodNet outbreak register and National Notifiable Disease Surveillance System *Salmonella* notification rate, Australia, 2001–2016.

Transmission

Most *Salmonella* spp. outbreaks were of foodborne or suspected foodborne transmission (79%; 778/990) (**Table 1**). In these 778 outbreaks, a total of 14,708 people were reported to be ill, with a median of 9 people per outbreak (range 2–442). Overall, 66% (9,683/14,708) of people affected in these outbreaks had laboratory-confirmed *Salmonella* spp., 15% (2,191/14,708) were hospitalized, and 0.3% (48/14,708) died. The median incubation period was available for 64% (500/778) of outbreaks, with a median of 24 h (range of medians 7–192 h). Median illness duration was available for 72% (560/778), with a median of 168 h (range of medians 10–504 h).

Setting

Implicated meals were prepared in food premises for the majority of foodborne or suspected foodborne outbreaks (**Table 2**), including 40% (314/778) in restaurants, 8% (63/778) in take-away stores, 7% (51/778) in bakeries, 4% (29/778) in commercial caterers, 1% (8/778) in national franchised fast food stores, 0.5% (4/778) in grocery stores/delicatessens, and 0.4% (3/778) on cruises or airlines. Home kitchens (18%, 142/778) were the next most common setting. In 10% (80/778) of outbreaks, food was prepared in institutional settings, including 5% (39/778) in aged care facilities, 0.8% (6/778) in schools, 0.8% (6/778) in hospitals, 0.6% (5/778) in child care centers, 0.6% (5/778) in camps, and 2% (19/778) in other institutional settings such as correctional or military facilities. In the remaining 11% (84/778) of outbreaks, food was prepared at a market, fair/festival, or mobile service; commercially manufactured food; imported food; primary produce; prepared in other settings; or prepared in unknown settings (**Table 2**).

Serotype

Thirty-nine different non-typhoidal *Salmonella* serotypes were identified among the 778 foodborne or suspected foodborne outbreaks. Most outbreaks were due to *Salmonella* Typhimurium (84%, 656/778). *Salmonella* Saintpaul was the next most common cause of outbreaks (2%, 15/778), followed by *Salmonella* Virchow (2%, 12/778), *Salmonella* Singapore (1%, 9/778), *Salmonella* subsp I (1%, 8/778), and *Salmonella* Infantis (1%, 8/778) (**Table 3**). No other serotype caused more than five outbreaks over the 16-year period assessed.

A higher proportion of outbreaks where food was prepared in food premises were due to *S*. Typhimurium (63%) than to non-Typhimurium *Salmonella* ($p < 0.01$). There was no difference in the reported number of *S*. Typhimurium and non-Typhimurium *Salmonella* outbreaks where food was prepared in private kitchens or in institutions. There was no difference in the number of people ill, the number of people hospitalized, the male-to-female ratio, or the median age of those affected in foodborne or suspected foodborne outbreaks caused by *S*. Typhimurium compared to non-Typhimurium *Salmonella* in all settings.

The number of *S*. Typhimurium outbreaks generally increased over time, with 15 foodborne or suspected foodborne *S*. Typhimurium outbreaks reported in 2001, peaking at 88 outbreaks reported in 2014. In comparison to the previous year, in 2016, the number of *S*. Typhimurium outbreaks and the associated number of cases in these outbreaks decreased, whereas, the number of associated cases in non-Typhimurium *Salmonella* outbreaks increased. This was largely due to four multi-state non-Typhimurium *Salmonella* outbreaks in 2016 (**Figure 2**).

Food Vehicles

A food vehicle was listed in the OzFoodNet outbreak register for 69% (537/778) of foodborne or suspected foodborne outbreaks. Of these, there was statistical and/or laboratory evidence to support the food vehicle as the cause of the outbreak for 50% (271/537) of outbreaks. Where there was no statistical

TABLE 1 | Number of reported *Salmonella* spp. outbreaks, ill persons, laboratory-confirmed infections, hospitalizations, and deaths by transmission pathway, Australia, 2001–2016.

Transmission	Number of outbreaks (% of total)	Number ill (% of total)	Number laboratory confirmed (% of ill)	Number hospitalized (% of ill)	Number died (% of ill)
Foodborne or suspected foodborne	778 (79)	14,708 (88)	9,683 (66)	2,191 (15)	48 (0.3)
Waterborne or suspected waterborne	13 (1)	164 (1)	101 (62)	11 (7)	1 (0.6)
Person-to-person	30 (3)	259 (2)	134 (52)	45 (17)	4 (2)
Animal-to-person	4 (0.4)	34 (0.2)	28 (82)	0 (0)	0 (0)
Unknown	165 (17)	1,585 (9)	1,440 (91)	362 (23)	9 (0.6)
Total	990 (100)	16,750 (100)	11,386 (68)	2,609 (16)	62 (0.4)

TABLE 2 | Number of reported foodborne or suspected foodborne *Salmonella* spp. outbreaks, ill persons, laboratory-confirmed infections, hospitalizations, and deaths by setting food prepared, Australia, 2001-2016.

| Setting	Number of outbreaks (% of total)	Number ill (% of total)	Number lab confirmed (% of ill)	Number hospitalized (% of ill)	Number died (% of ill)
Food premises	472 (61)	9,505 (65)	5,919 (62)	1,448 (15)	10 (0.1)
Home kitchens	142 (18)	1,150 (8)	664 (58)	261 (23)	2 (0.2)
Institutions	80 (10)	1,323 (9)	615 (47)	185 (14.0)	31 (2)
Market, fair/festival, or mobile service	9 (1)	102 (0.7)	64 (63)	23 (23)	0 (0)
Commercially manufactured food	10 (1)	420 (3)	412 (98)	42 (10)	4 (1)
Imported food	2 (0.3)	48 (0.3)	48 (100)	11 (23)	0 (0)
Primary produce	12 (2)	427 (3)	425 (99)	75 (18)	1 (0.2)
Other	18 (2)	500 (3)	353 (71)	43 (9)	0 (0)
Unknown	33 (4)	1,233 (8)	1183 (96)	103 (8)	0 (0)
Total	778 (100)	14,708 (100)	9,683 (66)	2,191 (15)	48 (0.3)
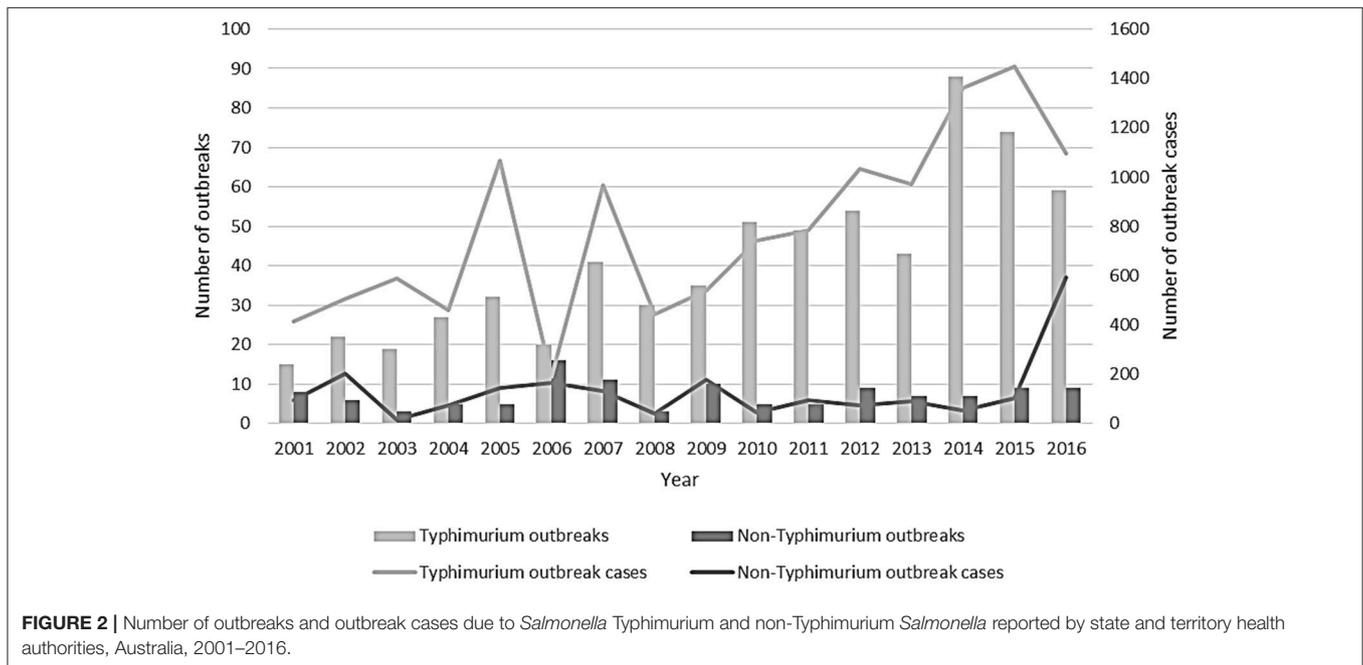
FIGURE 2 | Number of outbreaks and outbreak cases due to *Salmonella* Typhimurium and non-Typhimurium *Salmonella* reported by state and territory health authorities, Australia, 2001–2016.

or laboratory evidence, the food vehicle was supported by descriptive evidence in 38% (205/537) of outbreaks, and there was no evidence to support the food vehicle in the remaining 11% (61/537) of outbreaks. We excluded the 61 outbreaks with

no evidence from further analysis, leaving 476 outbreaks with a food vehicle listed.

In our food categories, frequently identified food vehicles in outbreaks were eggs and egg-containing foods (**Table 4**). Eggs,

Serotype	Number of outbreaks (%)	Number ill (% of total)	Number hospitalized (% of ill)	Sex (% of ill)			Median age
				Male	Female	Unknown	
Typhimurium	656 (84)	12,550 (85)	1,885 (15)	5360 (43)	6094 (48)	1096 (9)	31
Saintpaul	15 (2)	197 (1)	30 (15)	110 (56)	87 (44)	0 (0)	32
Virchow	12 (2)	127 (0.9)	21 (17)	59 (47)	66 (52)	2 (1)	28
Singapore	9 (1)	102 (0.7)	6 (6)	48 (47)	54 (53)	0 (0)	37
Infantis	8 (1)	67 (0.5)	15 (22)	26 (39)	41 (61)	0 (0)	55
Subsp I	8 (1)	91 (0.6)	15 (16)	54 (60)	37 (40)	0 (0)	28
Anatum	5 (0.6)	339 (2)	26 (8)	140 (41)	199 (59)	0 (0)	39
Bovismorbificans	4 (0.5)	138 (0.9)	34 (25)	53 (38)	38 (27)	47 (34)	34
Litchfield	4 (0.6)	108 (0.7)	8 (7)	86 (80)	22 (20)	0 (0)	46
Montevideo	4 (0.6)	62 (0.4)	10 (16)	29 (47)	33 (53)	0 (0)	27
Potsdam	4 (0.6)	101 (0.7)	15 (15)	37 (36)	64 (64)	0 (0)	34
Other	49 (6)	826 (6)	126 (15)	319 (39)	483 (58)	24 (3)	32
Total	778 (100)	14,708 (100)	2,191 (14.9)	6321 (43)	7218 (49)	1169 (8)	31

egg-based sauces (e.g., mayonnaise, aioli, hollandaise, tartare), desserts containing raw or lightly cooked eggs (e.g., tiramisu, fried ice cream, ice cream, mousse, custard), and fresh pasta eaten lightly cooked or with a lightly cooked egg based sauce, were the identified food vehicle in 238/476 (50%) of *Salmonella* spp. outbreaks. *S.* Typhimurium was the responsible serotype in 95% (226/238) of these outbreaks (see **Supplementary Information 2** for all serotypes for all food categories). Chicken and other poultry were the implicated food vehicle for 34/476 (7%) and pork for 15/476 (3%) outbreaks (**Table 4**), with 28/34 (82%) and 9/15 (60%) due to *S.* Typhimurium, respectively (**Supplementary Information 2**). Other food source animals, including beef, lamb, fish, and crustaceans/molluscs, were each identified as the food vehicle for 1% of these outbreaks. Fruits, vegetables and sprouts were each responsible for around 1% of outbreaks, but unlike outbreaks involving animal-derived food vehicles, these were more common for non-Typhimurium serotypes ($p < 0.001$) (**Table 4**; **Supplementary Information 2**).

Outbreaks due to sprouts, salads, Vietnamese sandwiches, fruits, nuts, tahini/helva, and dips tended to affect more people, with a median outbreak size of more than 15 cases (**Table 4**). Between 2001 and 2016, there was an increase in the proportion of outbreaks due to egg-based sauces ($p < 0.001$) and Vietnamese style sandwiches ($p < 0.001$), while poultry ($p = 0.033$), beef ($p = 0.046$), pork ($p = 0.047$), other sandwiches ($p = 0.048$), and other desserts ($p = 0.017$) had a decreasing trend over this time period (**Supplementary Information 3**).

DISCUSSION

Outbreaks of non-typhoidal *Salmonella* spp. are a significant and high-profile cause of foodborne illness in Australia. We found an increasing trend of outbreaks in Australia, particularly between 2008 and 2014, beginning before the introduction of culture-independent diagnostic testing (May et al., 2017). This is similar to the trend in the USA, where there was an increase

in the number of outbreaks reported between 2008 and 2013 (Centers for Disease Control Prevention, 2018). The increasing trend of outbreaks in Australia, together with comparatively high and increasing *Salmonella* spp. notification rates (Ford et al., 2016), emphasizes the continued importance of identifying food vehicles in outbreaks and implementing control strategies throughout the food chain to prevent illness.

Similar to the USA and Canada, eggs and foods containing eggs were the most commonly reported food vehicle in Australian foodborne or suspected foodborne *Salmonella* spp. outbreaks (Jackson et al., 2013; Belanger et al., 2015). Eggs were the responsible food vehicle in 50% of these outbreaks in Australia, compared to 28% in the USA (Jackson et al., 2013) and 39% in Canada (Belanger et al., 2015). We took a conservative approach in attributing outbreaks to eggs, as eggs may have also been the responsible food vehicle where there was more than one high risk ingredient (e.g., Vietnamese style rolls, sandwiches, and salads). While the proportion of outbreaks associated with poultry meat, beef and pork in Australia declined from 2001 to 2016, egg-based sauces, desserts containing raw or lightly cooked eggs, and Vietnamese style sandwiches, which usually contain a raw-egg butter and/or pork or chicken liver pâté, were increasingly associated with *Salmonella* outbreaks over the time period.

As most foodborne and suspected foodborne *Salmonella* outbreaks, including most *S.* Typhimurium outbreaks were linked to commercial food premises, additional interventions targeted at *Salmonella* control measures in these settings are required, particularly around the preparation of foods containing raw or lightly cooked eggs (Moffatt et al., 2016). While there are state-based guidelines, there are no rules or restrictions on the use of raw eggs in ready-to-eat foods in Australia (Moffatt et al., 2016). As Australian states and territories have oversight of food safety regulation, some states have implemented control measures across the supply chain to try to reduce the burden of egg-related salmonellosis, including targeted communication

TABLE 4 | Median number of cases affected and number of outbreaks by type of evidence due to food vehicles, Australia, 2001–2016.

	Median number of outbreak cases (range)	Outbreaks with statistical or laboratory evidence		Outbreaks with descriptive evidence		Total	
		Number	%	Number	%	Number	%
Raw egg desserts*	10 (2–140)	58/106	55	48/106	45	106/476	22
Egg-based sauce	14 (2–319)	43/79	54	36/79	46	79/476	17
Eggs, other	10 (2–143)	20/47	43	27/47	57	47/476	10
Mixed dishes	10 (2–90)	24/36	67	12/36	33	36/476	8
Poultry	11 (2–391)	20/34	59	14/34	41	34/476	7
Sandwiches, other	10 (3–213)	9/24	38	15/24	63	24/476	5
Desserts, other	13 (4–202)	18/23	78	5/23	22	23/476	5
Vietnamese sandwiches	17 (2–85)	7/17	41	10/17	59	17/476	4
Pork	10 (3–27)	10/15	67	5/15	33	15/476	3
Salads	18 (3–350)	8/10	80	2/10	20	10/476	2
Sushi	9.5 (3–85)	5/8	63	3/8	37	8/476	1
Beef	8.5 (4–15)	2/6	33	4/6	67	6/476	1
Pasta	6 (3–23)	2/6	33	4/6	67	6/476	1
Lamb	6 (3–43)	3/5	60	2/5	40	5/476	1
Fish	3 (3–14)	2/5	40	3/5	60	5/476	1
Sprouts	17 (4–126)	4/5	80	1/5	10	5/476	1
Crustacean/ mollusc	4 (2–23)	2/5	40	3/5	60	5/476	1
Fruits	29 (17–144)	4/4	100	0/4	0	4/476	0.8
Vegetables	10 (5–311)	3/4	75	1/4	25	4/476	0.8
Tahini or helva	24 (3–51)	3/3	100	0/3	0	3/476	0.6
Dips	33 (2–442)	2/3	67	1/3	33	3/476	0.6
Nuts	24 (19–43)	3/3	100	0/3	0	3/476	0.6
Undetermined	18 (2–50)	19/28	68	9/28	32	28/476	6

*Desserts containing raw or lightly cooked eggs (see **Supplementary Information 1** for more information)

and education for bakeries, mandatory training at retail level, industry food safety plans, and the vaccination of many laying flocks against *S.* Typhimurium (NSW Food Authority, 2007; Groves et al., 2016; Ford et al., 2018).

Unlike in other countries where *S.* Enteritidis is more prevalent in eggs, *S.* Typhimurium caused most (84%) foodborne or suspected foodborne *Salmonella* spp. outbreaks between 2001 and 2016 (Gormley et al., 2011; Pires et al., 2012; Jackson et al., 2013; Belanger et al., 2015), with only 3 outbreaks of *S.* Enteritidis reported during this time period. The majority of fresh produce outbreaks associated with fruits, vegetables and sprouts were caused by non-Typhimurium serotypes, with *S.* Saintpaul, *S.* Litchfield, and *S.* Oranienburg causing more than half of the outbreaks associated with these food vehicles. While few in number, outbreaks associated with sprouts, nuts, fruit and some fresh salad produce, which are usually consumed raw, were generally large due to the wide distribution of these food products. Food vehicle identification is often long and difficult for these types of fresh produce outbreaks as these foods are frequently poorly recalled and reported by outbreak cases during food history interviews. Also, as most horticulture products are not packaged and labeled and there is high product turnover, food trace-back investigations are difficult and associated public health interventions can be delayed for these reasons (Munnoch et al.,

2009). In Australia, there is currently no national horticulture primary production and processing standard, except for seed sprouts (Food Standards Australia New Zealand, 2011), so it is important to identify interventions to target these food vehicles.

While there have been multiple cohort or case-control studies undertaken during outbreaks to identify the food vehicle causing illness, there have been few published case-control studies of sporadic *Salmonella* illness in Australia. Without this evidence, it is difficult to compare whether the food vehicles that cause outbreaks identified in this study are the same as those that cause sporadic illness. Also, while individual risk factors, such as age and sex, have been identified to be important risk factors for sporadic illness in Australia (Ford et al., 2016), in this study, there was little difference in demographic characteristics of cases in foodborne or suspected foodborne *S.* Typhimurium and non-Typhimurium *Salmonella* outbreaks. This suggests that the individual risk factors of age and sex are not as important in outbreaks as they are with sporadic illness. While there was no data on the immune status of people exposed to outbreaks, the highest number of deaths occurred in outbreaks in institutional settings, including aged care facilities and hospitals where large numbers of immunocompromised people are expected.

A limitation of this study is that while OzFoodNet commenced in 2001, not all states and territories were routinely reporting data into the outbreak register until 2003, so some outbreaks may have been missed prior to 2003. In this study, 17% of *Salmonella* spp. outbreaks had an unknown mode of transmission. While it is likely that illness in many of these outbreaks was transmitted through contaminated food, there was insufficient evidence available to conclude this, so data presented in this paper is likely to under-represent the true number of foodborne outbreaks of salmonellosis in Australia. In addition to the 17% of outbreaks with an unknown mode of transmission there were: 25% of outbreaks that had a suspected foodborne/foodborne mode of transmission identified with an unknown food vehicle; 6% of suspected foodborne/foodborne outbreaks that had no evidence to support the food vehicle; and the food vehicle in an additional 6% of suspected foodborne/foodborne outbreaks could not be categorized because the meal listed lacked sufficient details (undetermined) or contained multiple foods. In addition, 38% of outbreaks were attributed to a food vehicle with descriptive evidence alone. This may be because not all outbreaks are conducive to an analytical investigation (Moffatt et al., 2016), food or environmental sampling is not always routinely performed, or because cross-contamination can make it difficult to identify a single food vehicle. While cross-contamination is likely to be an important aspect in many outbreaks (OzFoodNet Working Group, 2015; Osimani et al., 2016), another limitation of this study is that there was insufficient data to quantify the importance of cross-contamination in these Australian outbreaks.

As Australia moves toward a national strategy to reduce foodborne illness from *Salmonella*, data on *Salmonella* outbreaks, significant serotypes, and the food vehicles that cause illness are important for monitoring and surveillance, which can be used to provide evidence for effective control measures (Food Regulation Secretariat, 2018). Consistent with other studies, eggs and egg-containing foods were the most common cause of outbreaks in Australia over the period 2001–2016 causing significant morbidity in the population. Control measures have been, and continue to be implemented around preparation of egg-containing foods, particularly in food premises. Additional interventions focused on fresh produce items, such as a horticulture primary production and processing standard, could be strengthened since these vehicles can cause larger outbreaks. While collecting evidence about the food vehicles that cause outbreaks is important in the implementation of control measures, it can be challenging and further research on causes of sporadic illness and the importance of cross-contamination for *Salmonella* outbreaks in Australia could identify important public health interventions.

AUTHOR CONTRIBUTIONS

LF conceived the paper with feedback from all authors and conducted the analysis and drafted the paper. All authors made contributions to the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2018.00086/full#supplementary-material

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