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Outbreak investigations of *Salmonella* and frozen raw breaded chicken: the mitigation of a significant public health issue in Canada

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Abstract

In May 2017, whole-genome sequencing (WGS) became the primary subtyping method for *Salmonella* in Canada. As a result of the increased discriminatory power provided by WGS, 16 multi-jurisdictional outbreaks of *Salmonella* associated with frozen raw breaded chicken products were identified between 2017 and 2019. The majority (15/16) were associated with *S. enteritidis*, while the remaining outbreak was associated with *S.* Heidelberg. The 16 outbreaks included a total of 487 cases with ages ranging from 0 to 98 years (median: 24 years); 79 hospitalizations and two deaths were reported. Over the course of the outbreak investigations, 14 frozen raw breaded chicken products were recalled, and one was voluntarily withdrawn from the market. After previous changes to labelling and the issuance of public communication for these products proved ineffective at reducing illnesses, new industry requirements were issued in 2019, which required the implementation of measures at the manufacturing/processing level to reduce *Salmonella* to below detectable amounts in frozen raw breaded chicken products. Since implementation, no further outbreaks of *Salmonella* associated with frozen breaded chicken have been identified in Canada, a testament to the effectiveness of these risk mitigation measures.

Introduction

Non-typhoidal *Salmonella* species are one of the leading causes of domestically acquired foodborne illness in Canada. It is estimated that non-typhoidal salmonellosis infections account for 87,510 domestically acquired foodborne illnesses, 925 hospitalizations, and 17 deaths in Canada each year [1], resulting in substantial costs to the healthcare system and significant impacts to the economy from lost productivity [2–6]. Previous epidemiological and food safety investigations have identified the consumption and/or improper handling of poultry and/or poultry products as important risk factors for developing salmonellosis, particularly those associated with *Salmonella enterica* serovar Enteritidis [7–10].

Salmonella Enteritidis is the most commonly reported *Salmonella* serotype in Canada, representing 35% of all *Salmonella* cases reported to the National Enteric Surveillance Program in 2021 [11]. Despite its significant burden of illness, there were very few investigations into outbreaks of *S. Enteritidis* at the national level prior to 2017. Pulsed-field gel electrophoresis (PFGE) and phage typing were traditional subtyping methods used to identify clusters of related illness during that time. However, due to the limited discriminatory power of these subtyping methods, and the high degree of clonality of *S. Enteritidis*, the ability to differentiate between strains using these methods was limited [12–14]. *S. Enteritidis* isolates were often identified as having the same or similar phage types or PFGE patterns, regardless of whether or not they were linked to a common source [15, 16]. Without enhanced genetic resolution to differentiate isolates of the same serotype, many discrete clusters or outbreaks of *S. Enteritidis* illness went undetected.

In May 2017, the Public Health Agency of Canada (PHAC) transitioned to whole-genome sequencing (WGS) as the primary subtyping method for detecting clusters of genetically related *Salmonella* illness. The increased discriminatory power provided by WGS improved the ability to differentiate between isolates that would otherwise be indistinguishable by PFGE or phage typing

[17–19]. As a result, there was a substantial increase in the number of discrete *Salmonella* clusters detected at the national level starting in 2017, as well as a greater confidence in linking genetically related isolates to a common source [20]. In addition to the clinical isolates identified through culture-based diagnostic testing, prospective (i.e. real-time) WGS was also initiated for all food isolates from retail samples collected through the FoodNet Canada sentinel site surveillance system [21] and isolates from the Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS)/FoodNet Canada on-farm surveillance, and by the Canadian Food Inspection Agency (CFIA) for microbial pathogen isolates recovered from food. Sequencing results for both clinical and non-clinical isolates were routinely integrated nationally, allowing investigators to determine whether any available non-clinical isolates would be considered genetically related to the clusters of human illness being assessed. This, in turn, contributed to hypothesis generation during outbreak investigations, as it provided microbiological evidence linking cases to a possible food source.

The risk of human illness associated with the consumption of frozen raw breaded chicken has a well-established history in Canada, and misconceptions among consumers are known to play an important role in this risk [22–25]. Prior to April 2019, most frozen breaded chicken products sold in Canada were raw and required thorough cooking prior to consumption. These products, however, were breaded and typically par-fried prior to being frozen and packaged for sale at retail, resulting in a golden-brown cooked appearance. As a result, many consumers did not exercise the same precautions as they would with other raw chicken products (e.g. fresh chicken breasts and whole chicken) and even reported using non-prescribed cooking methods such as microwaving [22, 23].

Prior to 2017, only one multi-jurisdictional outbreak of *S. Enteritidis* linked to frozen raw breaded chicken products was identified and investigated nationally, in 2015 [26]. In contrast, between 2017 and 2019, following the implementation of prospective WGS as the primary subtyping method for *Salmonella* isolates, 16 multi-jurisdictional *Salmonella* outbreaks linked to frozen raw breaded chicken were investigated in Canada [27]. To summarize these investigations, and their impact on public health and food safety, this study will focus on three objectives: (1) expand upon Morton et al.'s rapid communication [27] to describe the epidemiological, laboratory, and traceback data for the 16 multi-jurisdictional *Salmonella* outbreaks linked to frozen raw breaded chicken products investigated between 2017 and 2019; (2) describe the new risk mitigation measures at the manufacturing/processing level implemented in 2019 in response to these outbreaks; and (3) provide an update on the public health impact of these measures on outbreaks in Canada 5 years later.

Methods

Surveillance and laboratory analysis

Clinical isolates from *Salmonella* cases were sequenced by the National Microbiology Laboratory (NML) or by a PulseNet Canada certified laboratory. Isolates recovered from non-clinical samples collected through FoodNet Canada sentinel site surveillance system [21] were also sequenced by the NML. These non-clinical samples included retail frozen raw breaded chicken products and intact raw chicken breast meat collected from three sentinel sites located in British Columbia, Alberta, and Ontario. Isolates recovered from non-clinical samples of frozen raw breaded chicken products collected from case's homes, through the food safety investigations, or through provincially led sampling programs were sequenced by either a PulseNet Canada certified laboratory, the NML, or CFIA laboratory. All *Salmonella* sequences, both clinical and non-clinical from 1 May 2017 to 31 December 2023, were uploaded to the PulseNet Canada national BioNumerics v 7.6.3 database for analysis and multi-jurisdictional cluster detection using whole-genome multilocus sequencing typing (wgMLST; Biomerieux, France). A *Salmonella* cluster was defined as two or more isolates genetically related by ≤10 wgMLST allele differences, where at least one isolate is clinical. For more common *Salmonella* serotypes, such as Enteritidis, Typhimurium, and Heidelberg, a cluster was defined as three or more isolates genetically related by ≤10 wgMLST allele differences, where two of the three isolates were within ≤5 wgMLST allele differences of each other and at least one isolate is clinical. Allele ranges were expanded as appropriate during an investigation based on available laboratory, epidemiological, and traceback evidence (e.g. two clusters >0–10 wgMLST allele differences apart may be investigated together if demographics, geographic distribution, isolation dates, and/or exposure information suggested a common source). Clusters were considered multi-jurisdictional if they contained clinical isolates from two or more provinces and territories.

Epidemiological investigations

Multi-jurisdictional *Salmonella* clusters identified through WGS were assessed by PHAC and prioritized for epidemiological follow-up based on a variety of considerations including but not limited to: serotype, case counts, demographic profiles, the degree of genetic relatedness (i.e. allele range), the geographic distribution, temporality of cases, and the presence of environmental or food isolates. During epidemiological follow-up with provincial/territorial authorities involved, available food and exposure data for cases were provided to PHAC. In some instances, this included focused frozen raw breaded chicken product-specific questionnaires administered at the time of initial interview. Following the review of preliminary exposure information, select cases (e.g. those with more recent exposures, those with good recall as noted in an initial interview) were re-interviewed by either PHAC or an interviewer at the local health unit using hypothesis generating questionnaires or focused questionnaires (e.g. a frozen raw breaded chicken product-specific questionnaire). If, at either the initial interview or re-interview, cases reported consuming any frozen raw breaded chicken product during their exposure period, leftover product was asked about (including details required for traceback) and, if available, product was collected and tested for the presence of *Salmonella* at public health laboratories. If a product tested positive for *Salmonella*, the recovered isolates would undergo WGS, as described above. Cases that were re-interviewed were also asked for consent for investigators to access their purchase records, if they shopped at grocery chains with loyalty card programs.

Food safety investigations

When a cluster resulted in epidemiological and/or microbiological evidence to indicate that a frozen raw breaded chicken product was a vehicle of infection (i.e. multiple cases reporting exposure to the same brand of frozen raw breaded chicken product and/or a frozen raw breaded chicken product isolate matching clinical cases by WGS), data were provided to the CFIA for further investigation and assessment.

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Traceback investigations were conducted by the CFIA using available brand, lot code, and purchase location information for products reported by cases at initial interview and/or re-interviews or from relevant food samples matching by WGS to outbreak cases, with the goal of identifying a common source. FoodNet Canada enhanced data collection when sampling products at retail (i.e. collection of Universal Product Codes (UPCs), best before dates, branding information, and production establishment number) also contributed to traceback for specific products associated with illnesses.

The evidence provided through the epidemiological, microbiological, and traceback investigations was considered in combination to determine the appropriate risk mitigation measures for each outbreak (i.e. product recall, risk communications, inspection and review of practices at implicated facilities, and communication with industry partners).

Results

Following the implementation of prospective WGS, a total of 16 multi-jurisdictional outbreaks of *Salmonella* associated with frozen raw breaded chicken products were collaboratively investigated between 2017 and 2019 (Table 1).

Laboratory investigations

Of the 16 outbreaks, the majority (15/16) were associated with *S. Enteritidis*, while the remaining outbreak was associated with *S.* Heidelberg. The degree of genetic relatedness varied across outbreaks. One outbreak had an allele range of 0–11 wgMLST, nine outbreaks had allele ranges within 0–10 wgMLST, and six of the outbreaks had an allele range that fell within 0–5 wgMLST. Two outbreaks (Table 1; outbreaks 3 and 16) consisted of two genetically distinct clusters each, but were investigated as a single outbreak due to epidemiological data that linked the clusters. One outbreak (outbreak 13) consisted of a sub-cluster of isolates that grouped together by 0–2 wgMLST allele differences of a larger cluster of isolates within 0–10 wgMLST allele differences.

Fourteen of the 16 outbreak clusters (87.5%) included one or more non-clinical isolates. As of 31 December 2023, there were a total of 103 non-clinical isolates genetically related to the 14 outbreaks; the last non-clinical match to an outbreak cluster was reported in May 2019. Ninety-nine isolates (96%) were recovered from various frozen raw breaded chicken products, and the remaining four isolates were from intact raw chicken breast ($n = 3$) and an unknown animal sample ($n = 1$). The 99 isolates from frozen raw breaded chicken products represent less than 30 unique products, with between 2 and 11 isolates per product. Seventy-one of the 99 isolates (72%) recovered from frozen raw breaded chicken products were from products collected from case homes during outbreak investigations. The remaining 28 isolates (28%) were recovered from samples taken through the FoodNet Canada retail surveillance program.

Epidemiological investigations

The total number of laboratory-confirmed salmonellosis cases included in these outbreak clusters ranged from 4 to 90 (median: 26) with a cumulative total of 487 cases from across all 13 provinces and territories: British Columbia ($n = 33$), Alberta ($n = 75$), Saskatchewan ($n = 16$), Manitoba ($n = 25$), Ontario ($n = 178$), Québec ($n = 94$), New Brunswick ($n = 27$), Nova Scotia ($n = 16$), Prince Edward Island ($n = 6$), Newfoundland and Labrador ($n = 12$), Northwest Territories ($n = 2$), Yukon ($n = 1$), and Nunavut ($n = 2$). Ages of cases ranged from 0 to 98 years (median: 24 years), and 52% of cases were male. Of the 284 cases with information available, there were a total of 79 (28%) hospitalizations and two deaths reported. The epidemiological evidence collected during each of these 16 investigations implicated frozen raw breaded chicken products as a likely source. Of the 16 outbreaks, 12 (75%) were associated with frozen raw breaded chicken products and four (25%) were associated with both fresh poultry and frozen raw breaded chicken products.

Food safety investigations and product recalls

The CFIA conducted food safety investigations for 14 of 16 outbreaks linked to frozen raw breaded chicken products. Of the 14 outbreaks with a food safety investigation, 12 resulted in product recalls or voluntary product withdrawals; 9 of 12 outbreaks resulted in one recall or voluntary product withdrawal each, while 3 of 12 outbreaks resulted in two product recalls each (Table 1). The CFIA issued food recall warnings informing consumers of the recalls and advising the public to not consume the recalled products. All food recall warnings were issued over a 22-month period, between 12 July 2017 and 24 May 2019 [28]. Four outbreak investigations did not result in a recall, as there was insufficient evidence to implicate a specific frozen raw breaded chicken product.

The frozen breaded chicken products recalled or voluntarily withdrawn from the market included chicken nuggets ($n = 7$), burgers ($n = 3$), strips ($n = 2$), fries ($n = 2$), and popcorn chicken ($n = 1$). The implicated products fell under six different brand names and two different manufacturers, with two products bearing no brand name. The two manufacturers were among the largest in Canada. Follow-up at the manufacturer was conducted by the CFIA for the implicated products identified during each investigation. After a specific lot of product was implicated in an investigation, the CFIA worked with the manufacturer to identify other products produced with the same chicken input lots and to confirm distribution. The investigations did not identify failure in Good Manufacturing Practices (GMP) as a potential cause of the outbreaks. Distribution of implicated products varied, but extended to all provinces and territories in Canada.

Public communications

To communicate risks associated with frozen raw breaded chicken products to the public, PHAC published Public Health Notices to the Government of Canada website for each investigation. The Public Health Notices provided a summary of each outbreak, advice not to eat, sell, or serve the recalled frozen raw breaded chicken products and advice on the proper handling and preparation of frozen raw breaded chicken products. In September 2018, following an increasing number of outbreaks linked to these products, PHAC transitioned towards the development of an overarching Public Health Notice to communicate information on all outbreaks of *Salmonella* linked to raw chicken investigated since the implementation of WGS in May 2017, including frozen raw breaded chicken products [29]. The Public Health Notices were promoted via the Government of Canada's social media platforms on Facebook and X (formerly known as Twitter).

On 13 September 2018, Canada's Council of Chief Medical Officers of Health (CCMOH) issued a statement informing consumers of the ongoing risks associated with frozen raw breaded

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Table 1. Multi-jurisdictional outbreaks of *Salmonella* associated with frozen raw breaded chicken products and associated product recalls in Canada, 2017–2023

Outbreak #	Symptom onset date range by month and year	Serotype	Number of cases investigated in outbreak	Median age (range)[a]	Sex (% male)[a]	Allele range during the outbreak investigation	Number of clinical isolates genetically related to outbreak cases after outbreak investigation closed[b,c] (reported date of most recent illness by month and year)	Number of isolates recovered from frozen raw breaded chicken products genetically related to outbreak cases[b,c]	Products recalled (month and year of recall)
Source: Frozen raw breaded chicken products									
1	April 2017–June 2017	Enteritidis	13	15 (3–66)	69%	0–3.0	5 (October 2017)	1	Chicken nuggets (July 2017)
2	April 2017–July 2017	Heidelberg	9	39 (1–62)	33%	0–4.8	6 (January 2018)	0	No recall
3[d]	June 2017–October 2017	Enteritidis	22	41 (0–85)	41%	Cluster 1: 0.2–7.0 Cluster 2: 4.0–8.0	11 (August 2018)	17	Chicken burgers (October 2017) Popcorn chicken (October 2017)
4	November 2017–February 2018	Enteritidis	12	16 (1–80)	42%	0–2.6	6 (June 2018)	0	No recall
5[e]	December 2017–September 2018	Enteritidis	26	27 (7–84)	58%	0–11.2	0	6	Chicken burgers (October 2018) Chicken strips (November 2018)
6	June 2018–August 2018	Enteritidis	27	33 (1–78)	48%	0–2.6	2 (September 2018)	9	Chicken fries (July 2018)
7	June 2018–September 2018	Enteritidis	55	22 (1–88)	47%	0–9.4	9 (December 2018)	15	Chicken nuggets (July 2018)
8	June 2018–March 2019	Enteritidis	64	23 (0–98)	61%	0–9.0	4 (July 2020)	6	Chicken nuggets (January 2019) Chicken nuggets (February 2019)
9	July 2018–September 2018	Enteritidis	12	23 (0–81)	58%	0–6.7	5 (November 2018)	2	Chicken fries (October 2018)
10	September 2018–April 2019	Enteritidis	11	67 (9–95)	36%	0–10.0	9 (June 2020)	3	Chicken strips (May 2019)
11	December 2018–March 2019	Enteritidis	30	20 (1–59)	70%	0–9.0	7 (November 2020)	4	Chicken nuggets[f] (February 2019)
12	February 2019–April 2019	Enteritidis	4	61 (2–71)	0%	0–1.0	4 (January 2020)	2	Chicken nuggets (March 2019)
	Total	–	**285**	–	–	–	**68**	**65**	–

(*Continued*)

Table 1. (*Continued*)

Outbreak #	Symptom onset date range by month and year	Serotype	Number of cases investigated in outbreak	Median age (range)[a]	Sex (% male)[a]	Allele range during the outbreak investigation	Number of clinical isolates genetically related to outbreak cases after outbreak investigation closed[b,c] (reported date of most recent illness by month and year)	Number of isolates recovered from frozen raw breaded chicken products genetically related to outbreak cases[b,c]	Products recalled (month and year of recall)
Source: Chicken including frozen raw breaded chicken products									
13[g]	Apri 2017 –July 2017	Enteritidis	25	12 (1–72)	40%	0–2.0	100 (January 2022)	3[h]	No recall
14	April 2017–December 2017	Enteritidis	54	18 (1–92)	46%	0–8.7	8 (February 2018)	6	No recall
15	May 2017 –March 2018	Enteritidis	33	33 (1–73)	52%	0–7.8	64 (January 2019)	13	Chicken nuggets (March 2018)
16[d]	March 2018–July 2018	Enteritidis	90	31 (0–85)	56%	Cluster 1: 0–6.0 Cluster 2: 0–6.0	10 (December 2018)	12	Chicken burgers (June 2018)
	Total		**202**	–	–	–	**182**	**34**	–
	Overall total	–	**487**	–	–	–	**250**	**99**	–

[a]Based on available age and sex data.
[b]Data as of 31 December 2023.
[c]Duplicate isolates are possible.
[d]This outbreak consisted of two distinct clusters linked through epidemiological evidence. The wgMLST allele range is presented for each cluster.
[e]The allele range was expanded for this outbreak based on available epidemiological evidence.
[f]This product was voluntary withdrawn from the marketplace by the retailer.
[g]This outbreak consists of a sub-cluster of isolates that grouped together by 0–2 wgMLST alleles at the time of the investigation that were within a larger cluster of isolates within 0–10 wgMLST allele differences.
[h]Isolates recovered from FoodNet Canada retail samples of intact raw chicken breast were also identified as genetically related (n = 3).

chicken products and the importance of following proper food safety practices when handling and preparing these products for consumption [30].

Implementation of risk mitigation measures

In March 2018, as a result of the evidence built throughout the numerous outbreak investigations, the CFIA issued new requirements for industry to implement measures at the manufacturing/processing level to reduce *Salmonella* to below detectable amounts in frozen raw breaded chicken products [31]. The new requirements applied to all manufacturers, not just those implicated in the outbreaks and recalls. Products covered by these requirements included comminuted chicken meat products that are raw, breaded, and frozen, that appear 'ready-to-eat', and are packaged for sale at retail. Four options for applying these risk mitigation measures were provided, including (1) implementing a validated cooking process to achieve a 7-log reduction in *Salmonella*; (2) implementing a testing program for the raw chicken mixture used in these products to demonstrate that *Salmonella* is not detected; (3) implementing a testing program for the finished product to demonstrate that *Salmonella* is not detected; or (4) implementing a process or combination of processes that have been validated to achieve a 2-log reduction in *Salmonella* and testing program for the raw chicken mixture used in these products [32]. The requirements took effect on 1 April 2019, although measures could have been implemented by manufacturers anytime between the initial announcement in March 2018 and the 1 April 2019 deadline.

Public health impact of risk mitigation measures

Between the implementation of the industry requirements (1 April 2019) and 31 December 2023, there were no new multi-jurisdictional clusters of *Salmonella* associated with frozen raw breaded chicken products identified in Canada.

Following the closure of each of the 16 frozen raw breaded chicken outbreak investigations, genetically related clinical isolates continued to be reported in the clusters associated with the outbreaks. The number of clinical isolates added to each cluster as well as the reported date for the most recent illness is described in Table 1. As of 31 December 2023, a total of a 250 clinical isolates were added. Of those, 68 clinical isolates were identified as genetically related to the cases involved in the 12 frozen raw breaded chicken products outbreaks (range: 0 to 11 isolates; last clinical isolate reported in November 2020), and a total of 182 clinical isolates were identified as genetically related to the cases involved in the four outbreaks associated with fresh poultry *and* frozen raw breaded chicken (range: 8 to 100 isolates; last clinical isolate reported in January 2022; Table 1 and Figure 1). Notably, only 36 of the 250 clinical isolates were reported after the implementation of the industry requirements in April of 2019. The cases reported after the closure of outbreaks and after April 2019 could be a result of recalled product remaining in freezers, or the potential for various non-recalled contaminated product to still be in circulation even after 1 April 2019, given the typical one-year shelf life of these products. The addition of new clinical matches after 1 April 2019 could also be due to the ongoing circulation of some of these strains within the Canadian poultry industry, outside of frozen raw breaded chicken products.

No additional isolates recovered from frozen raw breaded chicken products have been added to the clusters associated with these outbreaks after 1 April 2019. Surveillance over this time was ongoing with FoodNet Canada continuing to collect and test frozen breaded chicken products and intact raw chicken breast meat at various retail locations.

Discussion

After the implementation of prospective WGS for *Salmonella* subtyping in Canada in 2017, 16 multi-jurisdictional outbreaks associated with consumption of frozen raw breaded chicken products were investigated, ultimately resulting in a nationwide industry requirement to reduce *Salmonella* in these products. Since this change was implemented, no new multi-jurisdictional clusters of *Salmonella* associated with frozen raw breaded chicken products have been identified in Canada, highlighting the significant public health impact of mitigating this risk at the manufacturing level.

As summarized above, the risk of human illness associated with the consumption of frozen raw breaded chicken products is well established. Studies prior to 2019 estimated that up to 40% of consumers considered frozen breaded chicken products to be precooked, potentially resulting in mishandling or improper cooking [22]. As described elsewhere [24], many factors contributed to consumer misconceptions about these products, such as (1) packaging which often includes photographs of fully cooked

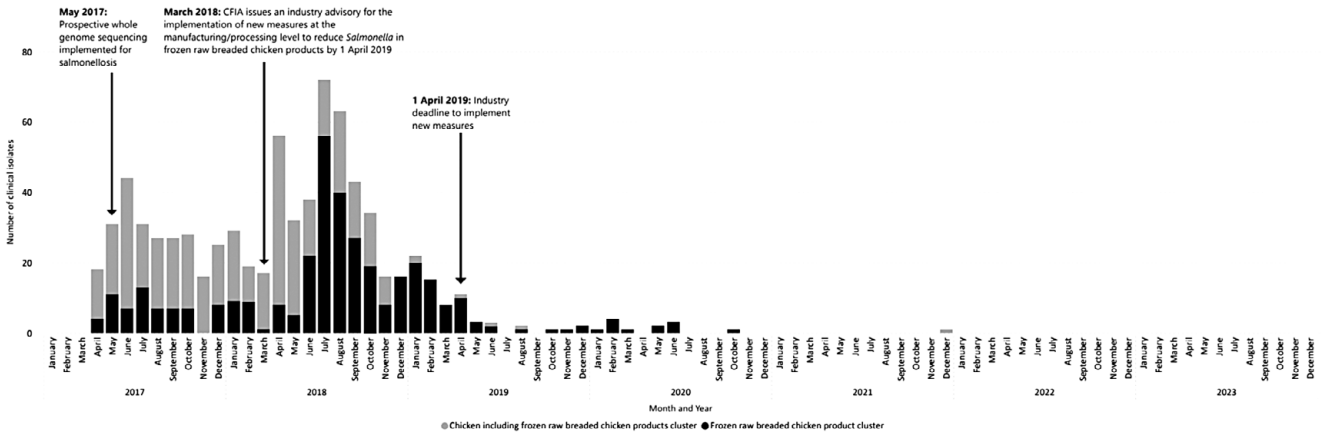

Figure 1. Number of Canadian clinical isolates by month and year based on the earliest date available (isolation, specimen collection, or reported date) genetically related to the 16 national outbreaks associated with frozen raw breaded chicken products.

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product, (2) the marketing of these products as 'quick and easy' meal options implying that minimal preparation is needed, and (3) the fact that consumers could discard the outer box, and thus discard handling and cooking instructions, in an effort to optimize freezer space. Far from a domestic issue, frozen raw breaded chicken products have also been associated with *Salmonella* illnesses and outbreaks in the USA [33, 34] and Australia [35], as well as in Denmark, Finland, France, Germany, Ireland, The Netherlands, Poland, Sweden, and the UK [36, 37].

To minimize misconceptions about these products, and thereby reduce risk, Canada implemented mandatory labelling measures in 2004 which required manufacturers of frozen raw breaded chicken products to include clear labels such as 'raw', 'uncooked', or 'must be cooked' near the product's name and to include clear and thorough cooking instructions on the outer packaging [38]. In 2015, following the first national outbreak of *S. Enteritidis* associated with frozen raw breaded chicken products [26], industry representatives were advised to develop clearer and more consistent labelling and messaging indicating that the products are raw and must be fully cooked, to include explicit warnings against microwaving the products, and to include cooking instructions on the inner packaging of the products [38]. Implementation of these labelling strategies was voluntary. However, despite all attempts by regulators and industry partners to provide consumers with information on the proper handling and preparation of frozen raw breaded chicken, *Salmonella* illnesses associated with these products continued to be reported across Canada.

The implementation of prospective WGS for *Salmonella* subtyping in 2017 and the routine integration of both clinical and non-clinical isolate subtyping results were key factors in Canada's ability to further highlight the significant burden of illness associated with frozen raw breaded chicken product exposure. Although there was a total of 487 laboratory-confirmed cases associated with the 16 outbreaks summarized in this study, this only represents a fraction of the illnesses associated with these products in the community. Based on Canadian burden of illness estimates [39], during the span of these outbreaks, there are estimated to have been at least 12,711 illnesses associated with frozen raw breaded chicken products that went unreported in Canada. Interestingly, for 15 of the 16 outbreaks described, genetically related cases continued to be reported even after product recalls had been initiated. The persistence of some of these strains within Canadian poultry beyond the product category of frozen raw breaded chicken emphasizes the importance of risk management along the farm to fork continuum, to continue to reduce the burden of illness associated with *Salmonella* and poultry exposure.

There are several considerations to highlight when interpreting the findings of this study. First, the COVID-19 pandemic has had a well-documented impact on reported cases and clusters of enteric diseases in Canada [40]. Because of this, trends in case and cluster reporting attributed to the implementation of industry requirements on 1 April 2019 could be confounded, at least somewhat, by underreporting seen during the pandemic starting in March 2020. However, it is notable that while decreases in the incidence of travel-related *Salmonella* were significant in Canada during the pandemic, the reported incidence of domestically acquired *Salmonella* was less impacted [40], and therefore less likely to affect or explain the trends noted in this study. Second, of the 16 outbreaks described in this study, four were associated with both frozen raw breaded chicken products *and* fresh poultry. In Canada, *Salmonella* is not considered an adulterant in raw poultry, and moreover, there are significant challenges in obtaining product and brand specificity for fresh poultry meat exposures from cases. As a result, fresh chicken has not historically been the subject of a recall from the market if it is associated with illness. This highlights a gap in the ability to mitigate poultry-related *Salmonella* illnesses in Canada and underscores the importance of existing and renewed efforts to reduce *Salmonella* in poultry at the source.

Overall, this study aims to highlight the significant burden of illness associated with frozen raw breaded chicken products and the need to consider consumer food safety knowledge and food preparation behaviours in partnership with risk management measures. With consumer-level interventions, such as changes to labelling and public communication having limited success in reducing illnesses associated with these products, a more upstream approach was needed and, eventually, implemented. By 1 April 2019, manufacturers of these products were required to implement risk mitigation measures, such as validated cooking processes and/or testing processes, to reduce *Salmonella* to below detectable amounts. This important effort transitioned the onus of risk management in this product category from the consumer to the manufacturer. As a testament to the success and effectiveness of the implemented industry requirements, no further outbreaks of *Salmonella* associated with frozen breaded chicken products have been identified since its implementation, illustrating how advances in laboratory methods, collaborative outbreak investigation, and an understanding of consumer behaviours have ultimately helped build the evidence needed to create regulatory change, mitigating a significant public health issue in Canada.

Data availability statement. The data from this study are not publicly available due to privacy concerns and legislative requirements.

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