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Research on major water and foodborne pathogens in South America: advancements and gaps

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The aim of this review was to understand the research that has been conducted in South American countries to detect or quantify major water and foodborne pathogens, with the aim of identifying advancements and gaps in food safety in the region. This systematic review focused on the following major bacterial pathogens: *Salmonella* spp., Shiga-toxin producing *Escherichia coli*, *Listeria monocytogenes*, and *Campylobacter* spp., along with the protozoal pathogens *Cryptosporidium* and *Giardia*. For this review, we searched for research articles conducted in Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, and Venezuela. This study identified the following as major advancements: (i) research articles on pathogens in the food chain in South America have increased in this decade and (ii) studies have diversified detection methods in different food groups. In addition, the following points were identified as major gaps: (i) most of the food safety research has been conducted in Brazil and Argentina and (ii) scarce studies have quantified foodborne pathogens, which is crucial for risk assessment. Strengthening the scientific evidence of human exposure to major pathogens in food and water is necessary in this region, and it should be prioritized in public research funding.

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Introduction

Countries in South America are important producers of fish, fresh produce, and meat, among other foods [1]. It is important to note that many countries in South America are even food net exporters, meaning that their amount of food exports are higher than their food imports [1]. This is very relevant in terms of food safety at the local and global level, since food produced in South America is consumed globally. Contamination of water and food is a worldwide burden affecting public health and the economies of many countries [2•]. The farm to fork concept has emphasized for years the importance of understanding pathogen contamination in an all-inclusive view, with the aim of understanding food contamination from water, pre-harvest, post-harvest, and finished products [3]. Among pathogens that are found from farm to fork are bacterial pathogens, such as *Salmonella enterica*, Shiga-toxin-producing *E. coli* (STEC), *L. monocytogenes*, and *Campylobacter* spp., which are commonly found throughout the production chain [4], along with protozoal pathogens, such as *Cryptosporidium* and *Giardia*, which are mainly found in water [5,6•]. Although all these pathogens represent major burdens in South America [2•], the amount of scientific information on the presence of them in distinct food groups is inexistent [7]. The main objective of this review was to understand the research that has investigated the presence of major water and foodborne pathogens in South American countries, with the aim of identifying advancements and gaps in the research conducted to understand microbiological contamination in the region.

Methodology

The search of published articles that have investigated human cases of infection with water and foodborne pathogens in the target countries was performed using the electronic database PubMed using the searching algorithms 'foodborne + surveillance + South America' and 'foodborne + surveillance + country', which included searches in Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, and Venezuela. We excluded articles using the exclusion criteria in Suppl. Table 1. The search and subsequent review of the abstracts and/or full texts identified 41 potentially relevant studies that were analyzed. The main bacterial pathogens that were found to cause most cases of water and foodborne illness were further analyzed. These included the following pathogens: *Salmonella* spp. (10 articles), STEC (3 articles), *Campylobacter* spp. (2 articles), and *L. monocytogenes* (3 articles). A total of 7 articles were found for protozoa. It is important to note that, most of the articles were case reports (13 articles) and articles on active surveillance upon an event (26 articles) (e.g., an outbreak). Notably, the major food producers in the region, Brazil and Argentina, contributed with the majority of the articles, and only a small number of reports came from the other countries [1]. In addition, more than 50% of the articles included in this systematic review had been published in this decade (2010–2017).

Once we identified the main pathogens that accounted for most human cases of infection reported in scientific articles in the target country, as described above, we searched for the research conducted on these pathogens in food and/or water. The search was performed using the electronic database PubMed using the following searching algorithms: 'food + pathogen + country', 'food prevalence + pathogen + country', 'water + pathogen + country', and 'water + prevalence + pathogen + country'. Here, we focused on studies that described the presence and or quantification of these pathogens in the food chain. The exclusion criteria are shown in Suppl. Table 1. Using this approach, we analyzed a total of 208 articles, 54 studied *Salmonella*, 44 STEC, 47 *L. monocytogenes*, 25 *Campylobacter*, and 38 *Cryptosporidium* and *Giardia* (Suppl. Table 2). In eight of these articles, more than one of the listed pathogens were studied. In this systematic review, we also related the number of articles describing foodborne pathogen surveillance in humans and the number of articles about these pathogens in water and food. Using this database, we identified the following as major advancements: (i) research articles on pathogens in the food chain in South America have increased in this decade, and (ii) studies have diversified detection methods in different food groups; moreover, the following aspects were identified as major gaps: (i) most of the food safety research has been conducted in Brazil and Argentina, and (ii) scarce studies have quantified foodborne pathogens, which is crucial for risk assessment.

Advancement 1: research articles on pathogens in the food chain in South America have increased in this decade

We found 80 articles published between 1980 and 2009, whereas a total of 128 articles were found that were published between 2010 and 2017 (Figure 1 and graphical abstract). It is worth mentioning that many researchers in South America publish in journals that are not indexed in the database used [8], which could represent an underestimation of the research conducted in microbial water and food safety. The trend of increasing numbers of publications in the region is transversal to different disciplines [8]. Significantly, the studies analyzed have shown that more techniques for detection are being used, which have included studies using commercial rapid-detection methods (e.g., VIDAS) to develop PCR protocols for the detection of bacterial pathogens, as well as filtration/flotation techniques and PCR protocols for protozoa detection. In addition, based on our exclusion criteria, various articles that generated important data on phenotypic and genetic characterizations (e.g., subtyping or whole genome sequencing) of previously isolated bacterial pathogens were excluded, though these articles denote important scientific data to be further analyzed.

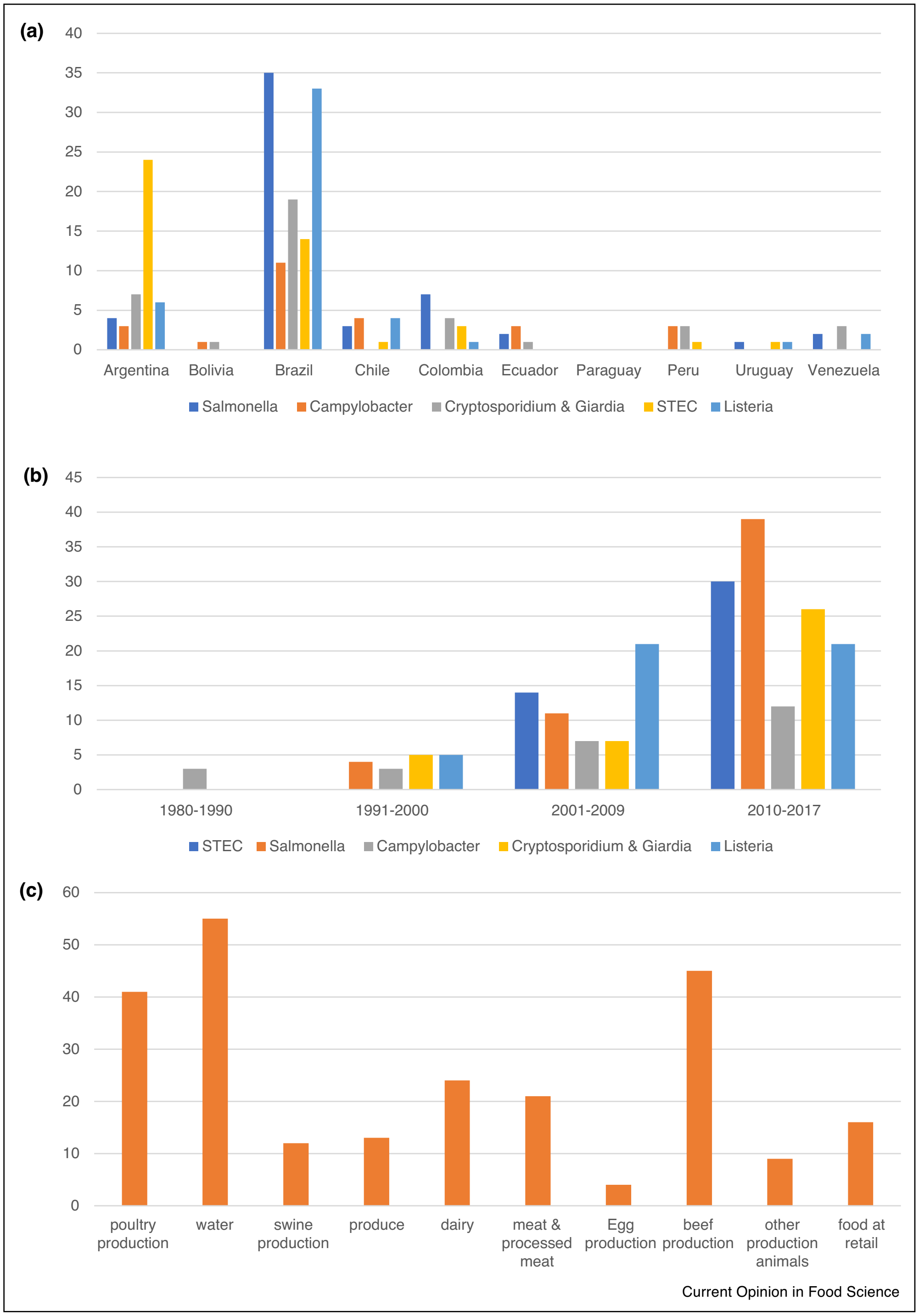
Advancement 2: studies have diversified detection methods in different food groups

In the analyzed articles, we found that the groups studied included poultry, swine, beef, eggs, dairy, meat, processed meat, retail food, produce, drinking water, and irrigation water (Table 1 and Figure 1). Most of the analyzed articles studied the presence of *Salmonella* and *Campylobacter* in the poultry production chain (38 articles) and the presence of STEC in beef production (39 articles, mostly published in Argentina). These production chains were studies from animals at the farm though the whole production chain, including the abattoir environments and carcasses (Table 1). For decades, poultry food safety has been one of the major concerns in terms of microbial contamination [9,10]. Studies in the region have shown that for researchers in South America, poultry has been prioritized. For the studies conducted on L. monocytogenes, dairy (e.g., cheese) has been the food group most investigated to detect *L. monocytogenes*, importantly, cheese is one of the foods commonly attributed to listeriosis cases. We also found that the microbial quality of water has been studied, mostly for *Cryptosporidium* and *Giardia*, but also for *Salmonella, STEC* and *Campylobacter* in surface and irrigation water and drinkable water (55 articles). These studies on water safety are relevant, in terms of food safety, since water used for agriculture is now part of the important regulatory aspects of the US Food Safety Modernization Act [11]. In recent food safety outbreaks, human cases have been associated with the contamination of different food types, including fruits, vegetables, spices, and processed foods [12,13]; in South America, incipient studies have broader the food matrixes commonly investigated to include produce, salads, and processed meats (Table 1), representing an important advancement.

Gap 1: most of the food safety research has been conducted in Brazil and Argentina

Most of the research articles on major water and foodborne pathogens in South America have been generated in Brazil and Argentina (Figure 1). This finding is not surprising since Brazil is the only country that budget more the 1% of the gross domestic product for research [8]. A 2015 FAO report showed the total public research expenditure in agriculture in selected countries in South America. This report highlights Brazil as the country in the region with the highest expenditure, followed by Chile [1]. Our results reflect this difference in expenditure and show a disparity among the studied countries in

Figure 1



Graphical representation of published articles in countries in South America on major water and foodborne pathogens. **(a)** Number of articles by country that have studied *Salmonella, Campylobacter*, STEC, *Listeria monocytogenes*, and *Cryptosporidium & Giardia*. **(b)** Number of total articles published in South America per decade. **(c)** Number of articles that studied the target pathogen in distinct food groups.

the number of articles published on food safety, with Brazil accounting for 54% of all articles analyzed, followed by Argentina with 21% of the articles, and Colombia with 7% of the articles (graphical abstract). In addition, the articles published in Brazil were conducted on more food groups and used a wider range of methodologies. For example, in the studies conducted to detect *Cryptosporidium* and *Giardia*, techniques such as immunomagnetic

Table 1

Summary of the number of articles identified that were accepted based on the inclusion criteria.

	Number of articles identified (food or water matrix analyzed)[b]				
Country[a]	*Salmonella*	*Campylobacter*	*L. monocytogenes*	STEC	*Cryptosporidium & Giardia*
Argentina	4 (chickens, pigs, chicken carcasses)	3 (carcasses from pork, chicken and cows, chicken production chain)	6 (animals, soft cheeses, sausages, environment)	24 (beef, water, feces and environment, dairy products, sausages, beef carcasses, clinical samples, cattle)	7 (water, sewage, soil)
Brazil	35 (carcasses from pork and carcasses, raw milk, eggs, mayonnaise, ostrich production chain, water, packed vegetables, lettuce, avocado, strawberries, eggs, hot dogs, sausages, ground beef, chicken legs)	11 (chicken carcasses, poultry processing plant, chickens, milk, sausages, hot dogs, ground beef, chicken legs)	33 (raw milk, cheese, lamb, horsemeat, poultry, fruits, ham, pork, food environment, vegetables, bovine carcasses, fish)	14 (beef, water, cattle, feces and environment, dairy products, sausages, beef carcasses, clinical samples, animals)	19 (surface water, bottled water, sewage, watersheds, drinking water, shellfish, soil, leafy greens, cows)
Bolivia	0	1 (water, soil, crops)	0	0	1 (wastewater)
Chile	3 (water, chickens, pork, and calves)	4 (hens, pigs, cows, geese, chicken, frozen chicken, chicken carcasses, turkey, pork meat)	4 (vegetable salads, cattle ground meat, RTE foods)	1 (beef and sausages)	0
Colombia	7 (fast food, chicken carcasses, chicken meat, laying hens, eggs)	0	1 (RTE foods)	3 (different foods, beef, sausages)	4 (drinkable and waste water)
Ecuador	2 (chicken, ducks, pigs)	3 (chicken, ducks, pigs, guinea pigs (raised for food))	0	0	1 (chicken, ducks, pigs)
Paraguay	0	0		0	0
Peru	0	3 (chickens)	0	1 (dairy products and vegetables)	3 (vegetable, wastewater, drinkable water)
Uruguay	1 (poultry, eggs)	0	1 (frozen, deli meats, RTE foods, and cheese)	1 (animals)	0
Venezuela	2 (poultry, beef slaughter)	0	2 (vegetables, tomatoes)	0	3 (water, wastewater, animal feces)

[a] Countries were ordered alphabetically.
[b] Number of articles identified based on selection criteria defined in Suppl. Table 1.

separation (IMS) and direct immune fluorescence assays (DFA) were used, which are sophisticated techniques for pathogen detection. Importantly, the use of both IMS and DFA is recommended in method 1623-1 of the US Environmental Protection Agency [14]. This indicates that these are well recognized methodologies. Regarding *Cryptosporidium* and *Giardia*, 37 studies included in the analysis were performed in water sources and only 1 was performed in food (produce). This finding is interesting as although both parasites have commonly been detected in water (including drinking water, superficial water, and residual water), there are few investigations on the presence of these protozoa in food that could have been irrigated with those waters. More studies should be conducted on superficial water used to irrigate crops and produce that is destined to be consumed by humans. Our revision indicates the need to generate more scientific data on the detection of foodborne pathogens in food and water in many of the South American countries.

Gap 2: scarce studies have quantified foodborne pathogens, which is crucial for risk assessment

In our revision, we found that 5/54 studies counted *Salmonella*, 3/25 studies counted *Campylobacter*, 2/44 counted STEC, and 18/38 studies counted *Cryptosporidium* and *Giardia*. The FAO/WHO Coordinating Committee for Latin America and the Caribbean (CCLAC) report in 2014 recommended increasing the data on consumer exposure to foodborne pathogens [15]. Current articles mostly report the presence of important water and foodborne pathogens in distinct food groups, but not the amount of these pathogens present in a given food. The counts of pathogens in different food groups is crucial information to be used in quantitative risk assessments. This can help to determine the risk of a given food for consumers, critical information for risk-based decision making [16•]. Unfortunately, in South America, we found very few studies that have made this information available.

Actions in food safety regulation, training, and agreements in South America

In the region, we have demonstrated a market increase in food safety research (Figure 1). However, a number of important events that have encouraged this research have not been published in indexed journals but instead are available in governmental or organizational reports (e.g., FAO or WHO). Examples of significant events might include the Bovine Spongiform Encephalopathy (BSE) scandal in 1989 [17], the creation of the Asia-Pacific Economic Cooperation (APEC) in 1989 [18], the Uruguay Round Agreements in 1994 [19], the creation of PulseNet in 1996 [20], and the creation of PulseNet in Latin America and the Caribbean in 2004 [20]. It is worth mentioning that most of the events have been encouraged by the regulatory aspects of the destination market of food produced in the region [3], since market access drives food safety efforts in South America [15]. In terms of articles available on the presence of these pathogens in food, it appears that reports of human cases and outbreaks are the major drivers of research (Figure 1). Promising new technologies, such as Next-Generation Sequencing, could improve foodborne surveillance [21]. The fact that outbreaks can be traced back to a single processing plant in a remote country [22] may modify the current scenario. Thus, we expect research in this region to continue increasing in the following years.

Conclusions

In South America, both water and food safety are relevant. These countries are important members of the global food trade, with a variety of foods being consumed locally and exported globally. Although research articles in the field of food safety appear to have increased, important gaps in the current knowledge need to be filled. It is necessary to strengthen human capability to conduct good quality research that can be published in indexed journals with global access. In order to scientifically report human exposure to major pathogens in water and food, financial resources to generate these important data are crucial.

Conflict of interest

The authors of this paper declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.cofs.2018.03.001.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest

1. Food and Agriculture Organization of the United Nations Regional Office for the Latin America and the Caribbean: *FAO Statistical Yearbook Latin America and the Cribbean Food and Agriclture*. 2014. Available at http://www.fao.org/3/a-i3592e.pdf.

2. • Kirk MD, Pires SM, Black RE, Caipo M, Crump JA, Devleesschauwer B, Döpfer D, Fazil A, Fischer-Walker CL, Hald T *et al.*: **World Health Organization Estimates of the Global and Regional Disease Burden of 22 Foodborne Bacterial, Protozoal, and Viral Diseases, 2010: a data synthesis**. *PLoS Med* 2015, **12**:e1001921.
Article is a comprehensive study that characterized the global burden of foodborne diseases, which include the region revised in this article.

3. **Approaches to empower the implementation of new tools to detect and prevent foodborne pathogens in food processing**. *Food Microbiol* 2017 http://dx.doi.org/10.1016/J.FM.2017.07.009.

4. Scallan E, Hoekstra RM, Angulo FJ, Tauxe RV, Widdowson MA, Roy SL, Jones JL, Griffin PM: **Foodborne illness acquired in the United States-Major pathogens**. *Emerg Infect Dis* 2011, **17**:7-15.

5. Nyachuba DG: **Foodborne illness: is it on the rise?** *Nutr Rev* 2010, **68**:257-269.

6. • Ryan U, Haijjawi N, Xiao L: **Foodborne cryptosporidiosis**. *Int J Parasitol* 2017 http://dx.doi.org/10.1016/J.IJPARA.2017.09.004.
Article reports the importance of *Cryptosporidium* as a foodborne pathogens and major routes of contamination.

7. Akhtar S, Sarker MR, Hossain A: **Microbiological food safety: a dilemma of developing societies**. *Crit Rev Microbiol* 2014, **40**:348-359.

8. Van Noorden R: **The impact gap: South America by the numbers**. *Nature* 2014, **510**:202-203.

9. Chai SJ, Cole D, Nisler A, Mahon BE: **Poultry: the most common food in outbreaks with known pathogens, United States, 1998–2012**. *Epidemiol Infect* 2017, **145**:316-325.

10. Chousalkar K, Gole VC: **Salmonellosis acquired from poultry**. *Curr Opin Infect Dis* 2016, **29**:514-519.

11. Allende A, Datta AR, Smith WA, Adonis R, MacKay A, Adell AD: **Implications of new legislation (US FSMA) and guidelines (EC) on the establishment of management systems for agricultural water**. *Food Microbiol* 2017 http://dx.doi.org/10.1016/J.FM.2017.10.002.

12. Callejón RM, Rodríguez-Naranjo MI, Ubeda C, Hornedo-Ortega R, Garcia-Parrilla MC, Troncoso AM: **Reported foodborne outbreaks due to fresh produce in the United States and European union: trends and causes**. *Foodborne Pathog Dis* 2015, **12**:32-38.

13. Van Doren JM, Neil KP, Parish M, Gieraltowski L, Gould LH, Gombas KL: **Foodborne illness outbreaks from microbial contaminants in spices, 1973–2010**. *Food Microbiol* 2013, **36**:456-464.

14. United States Environmental Protection Agency: *Method 1623: Crysptosporidium and Giardia in Water by Filtration/IMS/FA. EPA: 815-R-05-002*. 2005. Available at https://www.epa.gov/sites/production/files/2015-07/documents/epa-1623.pdf.

15. Leake L: *Food Quality and Safety: Food safety in South America*. 2015. Available at http://www.foodqualityandsafety.com/article/food-safety-in-south-america/.

16. • Dong QL, Barker GC, Gorris LGM, Tian MS, Song XY, Malakar PK: **Status and future of Quantitative Microbiological Risk Assessment in China**. *Trends Food Sci Technol* 2015, **42**:70-80.
Article describes the importance of quantitative data to implement QMRA and the role of this in policy making in food safety.

17. Ricketts MN: **Public health and the BSE epidemic**. *Curr Top Microbiol Immunol* 2004, **284**:99-119.

18. Asia Pacific Economic Cooperation. History. Available at: https://apec.org/About-Us/About-APEC/History.

19. World Trade Organization. The Uruguay Round. Available at: https://www.wto.org/english/thewto_e/whatis_e/tif_e/fact5_e.htm.

20. Scharff RL, Besser J, Sharp DJ, Jones TF, Peter G-S, Hedberg CW: **An economic evaluation of PulseNet**. *Am J Prev Med* 2016, **50**:S66-S73.

21. Bergholz TM, Moreno Switt AI, Wiedmann M: **Omics approaches in food safety: fulfilling the promise?** *Trends Microbiol* 2014, **22**:275-281.

22. Hoffmann M, Luo Y, Monday SR, Gonzalez-Escalona N, Ottesen AR, Muruvanda T, Wang C, Kastanis G, Keys C, Janies D *et al.*: **Tracing origins of the salmonella bareilly strain causing a food-borne outbreak in the United States**. *J Infect Dis* 2015 http://dx.doi.org/10.1093/infdis/jiv297.