



## Research Paper

# Managing *Listeria* by Cleaning and Disinfection: Experiences from Food Processing Industries and from Manufacturers of Cleaning and Disinfection Agents <sup>☆</sup>



S. Langsrud <sup>1,\*</sup>, E. Heir <sup>1</sup>, M.E. Pedersen <sup>1</sup>, B. Moen <sup>1</sup>, P. Teixeira <sup>2</sup>, K. Corbett <sup>3</sup>, D. Rip <sup>3</sup>, P. Gouws <sup>3</sup>, J. Kovacevic <sup>4</sup>, J. Waite-Cusic <sup>5</sup>, G.C. Fletcher <sup>6</sup>, E. Fox <sup>7</sup>, V. Michel <sup>8</sup>, A. Hanin <sup>9</sup>, A. Alvarez-Ordóñez <sup>10</sup>, A. Moreno Switt <sup>11</sup>, A. Urzúa Caracci <sup>11,†</sup>, D. Rivera <sup>12</sup>, G. Dørum <sup>1</sup>, T. Møretrø <sup>1</sup>

<sup>1</sup> Nofima AS - Norwegian Institute of Food, Fisheries and Aquaculture Research, PB 210, NO-1431 Aas, Norway

<sup>2</sup> Universidade Católica Portuguesa, CBQF - Centro de Biotecnologia e Química Fina – Laboratório Associado, Escola Superior de Biotecnologia, Rua Diogo Botelho 1327, 4169-005 Porto, Portugal

<sup>3</sup> Centre for Food Safety, Department of Food Science, Stellenbosch University, South Africa

<sup>4</sup> Food Innovation Center, Oregon State University, Portland, OR 97209, USA

<sup>5</sup> Food Science and Technology, Oregon State University, Corvallis, OR 97331, USA

<sup>6</sup> The New Zealand Institute for Plant and Food Research Limited, Private Bag 92169, Auckland Mail Centre, Auckland 1142, New Zealand

<sup>7</sup> Department of Applied Sciences, Northumbria University, Newcastle Upon Tyne NE1 8ST, UK

<sup>8</sup> Departement of Food Microbiology, ACTALIA, 74 800 La Roche sur Foron, France

<sup>9</sup> ACTALIA, Food Safety Unit, 310 rue Popielujko 50 000 Saint-Lô, France

<sup>10</sup> Department of Food Hygiene and Technology and Institute of Food Science and Technology Univ Leon, Leon 24071, Spain

<sup>11</sup> School of Veterinary Medicine, Pontifical Catholic University of Chile, Ave Vicuna Mackenna 4860, Santiago 7820436, Chile

<sup>12</sup> Facultad de Medicina Veterinaria y Agronomía, Universidad de Las Américas, Campus Providencia. Manuel Montt 948, Santiago, Chile

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## ABSTRACT

Effective cleaning and disinfection (C&D) are crucial to control *Listeria monocytogenes* in the food processing environments (FPE). There is a lack of studies examining the effect of C&D agents and practices in the FPE. The aim of the present study was to collect practical experiences from food processing facilities and compare them with the guidelines for control of *L. monocytogenes*. The experiences of 130 food processors from 15 countries were collected by a web-based survey, and 12 manufacturers of C&D agents from six countries were interviewed. Most of the food processors (64%) reported detection of *Listeria* spp. in their FPE at least once in the last five years, with 13% reporting repeated detection in the same sampling location for a period of over three months. Alkaline cleaning agents (72%) and disinfectants based on peracetic acid (48%) or quaternary ammonium compounds (QAC; 36%) were the most used products. Large variations were found in the composition of C&D agents, both regarding additives and the concentrations of biocidal agents. For drains and floors, changing C&D practices (frequency, concentration, exposure time) was reported to eliminate reoccurring *L. monocytogenes* by 12 out of 27 respondents. For equipment, upgrading or replacing parts was reported successful by 6 out of 20 respondents. No association was found between the active ingredient in C&D agents used and the elimination of *Listeria* spp.. Industry guidelines should be kept updated to support hygiene best practice and stricter requirements for environmentally friendly and low-toxicity C&D agents.

*Listeria monocytogenes* is a foodborne pathogen primarily associated with consumption of ready-to-eat (RTE) food (EFSA BIOHAZ Panel

et al., 2018; Sibanda et al., 2023; Zhang et al., 2021). It has been reported that 45% of listeriosis cases are linked to consumption of

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\* Corresponding author.

E-mail address: [solveig.langsrud@nofima.no](mailto:solveig.langsrud@nofima.no) (S. Langsrud).

<sup>†</sup> Present address: San Sebastián University (USS), Faculty of Natural Sciences, School of Veterinary Medicine, Chile.

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meat products, 26% to dairy products, 12% to fruit and vegetables, and 8% to seafood (FAO and WHO, 2022). In a European risk assessment, fish was identified as the category of RTE food that most often contains *L. monocytogenes*, but meat products accounted for the most cases of illness (EFSA BIOHAZ Panel et al., 2018). Additionally, a recent meta-analysis found consumption of fish products ranked highest among risk foods associated with sporadic listeriosis cases (Leclercq et al., 2021).

*L. monocytogenes* can be found sporadically on most types of raw food materials because it is widely distributed in outdoor environments and has several entry points into the food chain (Fagerlund, Idland, et al., 2022; Vidovic et al., 2022). In many outbreaks, the source of contamination is *L. monocytogenes* colonizing FPE niches, such as equipment, floors, and drains. This harborage of *L. monocytogenes* causes repeating contamination of products over weeks or years (Ferreira et al., 2014). In a review of 86 listeriosis outbreaks with a known source of contamination (2005–2020), *L. monocytogenes* contaminating the food products was traced back to the FPE in 59% of incidents, while contaminated raw materials were responsible for 6% of the outbreaks (FAO and WHO, 2022). While the former contamination route can be mainly attributed to missing or inadequate cleaning and disinfection (the term sanitation is also used, but from herein we will use C&D to refer to cleaning and sanitation/disinfection), the latter may occur because of process deviation (e.g., inadequate heating) or the absence of lethal processing steps (e.g. cold-smoked salmon).

*L. monocytogenes* can establish itself in the FPE due to its ability to grow under various conditions, including refrigeration temperatures, and can multiply between cleaning cycles when conditions are favorable (Carpentier & Cerf, 2011; Fagerlund et al., 2017). While specific genomic profiles have not been definitively linked to the persistence (survival over time in the same location), certain sequence types of *L. monocytogenes* are more prone to colonize food processing environments (Fagerlund, Idland, et al., 2022; Maury et al., 2016). In a Norwegian study, genes that encoded for increased biofilm formation and tolerance to chemical antimicrobials were more frequent in *L. monocytogenes* variants found across several meat and/or salmon factories compared with those found only in one factory, sporadically, or from the outdoor environment (Fagerlund, Wagner, et al., 2022). While *L. monocytogenes* that are suspended or dried on surfaces are easily detached and killed by regular C&D agents, they may become resistant if given the time and opportunity to attach to rough surfaces, form biofilms, and adapt to sublethal concentrations of the C&D agents (Chaturongkasumrit et al., 2011; Fagerlund et al., 2020; Fagerlund et al., 2017; Moretro et al., 2017; Somers & Wong, 2004). Thus, C&D agents and procedures for routine C&D may differ from those necessary to address a persistent *L. monocytogenes* problem.

A common wet C&D process consists of a rinsing step, followed by applying a cleaning agent (detergent), rinsing, applying a disinfectant (i.e. sanitizer in North America), rinsing, and eventually drying. The Codex Alimentarius Code of Practice for Food Hygiene and guidelines for controlling *L. monocytogenes* recommend to follow the manufacturer's instructions regarding concentration, time, temperature, and mechanical force (scrubbing, turbulence) for the use of C&D agents (FAO and WHO, 2007, 2023). It should be noted that no standard tests for documenting the efficacy of cleaning agents are recognized. However, disinfectants require approval by national or regional authorities based on their established efficacy in standardized biocidal efficacy tests. There are variations between countries (e.g., different requirements exist for sanitizers and disinfectants in the US), but usually these tests are applied on cells that are suspended, dried on surfaces, or forming mono-culture biofilms. The criterion for passing the test is to achieve a 4–5 log reduction (European Committee for Standardization, 2019a, 2019b; European Committee for Standardization, 2005). It is important to note that C&D in food pro-

cessing is not a sterilization step. However, the low or zero tolerance for contamination of final products with *L. monocytogenes* drives the importance of total elimination of the pathogen from food contact surfaces.

While there is a wealth of studies on the effect of single bactericidal compounds on *L. monocytogenes*, often aiming to study resistance mechanisms, there is a limited number of studies comparing the efficacy of commercial C&D products, which often contain several additives affecting the efficacy. Some comparative laboratory studies show high efficacy (>3 log reduction) of a range of different commercial agents toward *L. monocytogenes* biofilms (Brauge et al., 2020; Dhowlaghar et al., 2018; Fernandes et al., 2015; Olszewska et al., 2016; Aarnisalo et al., 2007), while others show insufficient efficacy (Chaturongkasumrit et al., 2011; Fagerlund et al., 2020; Fagerlund et al., 2017; Liu et al., 2006; Aarnisalo et al., 2000). Moreover, in comparable studies, conflicting results are sometimes found. Thus, while quaternary ammonium compounds (QACs) were shown to be more effective than peracetic acid and hypochlorite on biofilms on stainless steel in one study (Dygico et al., 2021), another study demonstrated the contrary (Gronholm et al., 1999). The diversity of results may be explained by differences in the composition of commercial agents and may also be governed by strain differences or material surface topography. An investigation involving comparable products from various manufacturers showed significant differences, which may be attributed to variations in the concentrations of active substances and the potential influence of additives (Cruz & Fletcher, 2012). Overall, the evidence from the available studies demonstrates that the efficacy of disinfectants may be reduced significantly in the presence of food soils and on worn or rough surfaces (Chaturongkasumrit et al., 2011; Cruz & Fletcher, 2012; Ohman et al., 2024; Aarnisalo et al., 2007; Aarnisalo et al., 2000). Therefore, care should be taken when extrapolating results from laboratory studies to practical use, as there may be poor correlation between laboratory and industrial tests (Dygico et al., 2021).

As pointed out by a recent risk assessment by the European Food Safety Authority (EFSA) BIOHAZ panel, there is a knowledge gap with regard to the efficacy of industrial-scale corrective actions to eliminate *L. monocytogenes* from FPEs in the scientific literature (EFSA BIOHAZ Panel et al., 2023). Most of the studies considered in the assessment showed no or limited effect of the actions implemented (e.g. more frequent or thorough C&D, more frequent disinfection of drains with peracetic acid or full wash-downs) (Hammons et al., 2017). The studies demonstrating elimination of *L. monocytogenes* through changes in C&D routines lacked specification of the agents used or commonly used agents were applied (chlorinated alkaline and cationic disinfectant). In summary, neither laboratory nor industrial scientific studies on the efficacy of commercial C&D agents are in collective agreement to support specific types of cleaning or disinfection agents. The aim of the present study was to map C&D agents and practices commonly used by meat, dairy, and seafood processing facilities and collect practical experiences on their efficacy for managing *Listeria* spp..

## Methods

**Web-based survey.** A questionnaire targeting fish, meat, and cheese producers was developed (Supplementary A), involving the complete research team (all authors, consisting of scientists with experience from working with *L. monocytogenes* in FPE in nine countries) and the project reference group (quality managers from the Norwegian salmon industry). Information about sampling methodologies for *Listeria* spp. and *L. monocytogenes*, detection of *L. monocytogenes* in the last five years, C&D agents used, and corrective actions after repeated positive detection of *Listeria* spp. were gathered. Also, questions about their business (country, products, number of employees) were included. The questionnaire was translated from Norwegian into Eng-

lish, Spanish, French, and Portuguese and shared with food processors/corporations and industry organizations in all nine countries. Reminders were sent once. The responses were anonymous.

One respondent was excluded from the sample for being outside the target group. Categorical data from the survey were first organized and summarized in Excel using pivot tables. Statistical analyses were then conducted in the R computing environment (version 4.5.2 (R Core Team, 2025)). A Chi-square test was used to assess whether there is an association between the detection of *Listeria* and food categories (meat, seafood, cheese). Ordinal logistic regression was used to investigate the effect of food category (meat and seafood relative to cheese) and sampling method (cloths/sponge vs only swabs (small or large)) on *Listeria* detection (Not found < Sporadic < Repeated at least twice in a row in the same sampling point). This approach estimates how these factors influence the odds of belonging to a higher contamination category, where 'Repeated' represents the most severe outcome. The proportional odds assumption was assessed using a Brant test. Fisher's exact test was used to test correlations between *Listeria* spp. detection and C&D use and the efficacy of interventions.

**Interviews with manufacturers of cleaning and disinfection agents.** A structured guide for interviewing suppliers of C&D products and services was developed. Suppliers in New Zealand (1), Norway (3), Portugal (2), South Africa (3), the UK (1), and the USA (2) were interviewed. The suppliers were asked what types of products they recommend for different types of C&D, if they recommend rotation between different agents, restrictions on using new agents and methods, and future developments. Most of the manufacturers had a broad portfolio of products, and customers from different types of food industries. All provided services include advice and problem-solving for hygiene issues.

The interviews were analyzed manually. For each question, the response was coded (e.g. assigning the recommended agents mentioned by the manufacturer to the type of agent, assigning approaches for eliminating persistent strains into categories) and transformed the responses into categorical data.

**Review of cleaning and disinfection agents.** Safety data sheets (SDS) for 113 of the 117 (SDSs for four agents were not available) C&D agents reported in the survey were collected. For each product, the minimum in-use concentration of active compounds (found by multiplying the lowest concentration of the compound in the concentrate by the lowest recommended in-use dilution) and maximum in-use concentration (found by multiplying the highest concentration of the compound in the concentrate by the lowest recommended in-use dilution) were calculated. The C&D agents were categorized according to the main active compounds (Table 1), and for each category, the median maximum and median minimum concentrations were calculated. It should be noted that it is not possible to estimate the exact user-concentrations of active compounds as the concentration in the concentrates was given as intervals.

**Guidelines for food processors.** Guidance documents for food processors on *L. monocytogenes* control (governmental documents, reports, papers) were gathered through Google searches, visits to governmental agency websites, and materials previously collected by the authors. Guidelines specifically targeting products other than meat, seafood, and dairy products or not available in English were excluded. For guidelines providing advice on C&D agents or physical disinfection, the following information was gathered: (1) which C&D agents or approaches were recommended, (2) if keeping to suppliers' recommendations was mentioned or not, and (3) if equipment dismantling was mentioned or not.

**Ethics.** Ethical approval of the survey and the interviews was received from the Norwegian Agency for Shared Services in Education and Research (SIKT), reference number 313101.

## Results and discussion

**Respondents to the survey and interviews.** A total of 130 responses were received from food producers. The survey was originally distributed in nine countries; however, responses were received from fifteen countries, due to it being shared with other locations abroad. One facility produced both meat and cheese products, 54 produced seafood (33 salmon and/or trout, six shellfish, one white fish, 14 several types of fish/shellfish), 54 meat products, and 21 dairy products. Roughly half (26/54) of the seafood processors produced RTE uncooked (cold-smoked, sushi, marinated shellfish) and/or heat-treated (hot-smoked, fish cakes, boiled shellfish, etc.) products. About 76% (42/55) of the meat processors produced RTE products, with seven processors not using preservatives. Most (18/22) of the dairy processors produced cheese made from pasteurized milk. Over half of the cheese-producing facilities (12/22) made soft cheese or cream cheese, with the remaining factories manufacturing semi-hard or hard cheeses. Eleven of the respondents were food processors employing less than 10 full-time equivalent employees, 60 had 10–100 full-time equivalents, and the remaining 60 were staffed by over 100 full-time equivalents. The share of establishments with more than 100 full-time equivalents was 56%, 43%, and 37% for seafood, meat, and dairy, respectively.

The processors were asked to choose one product/processing line for reporting about hygiene and *Listeria* spp. detection (not specifying analysis of *L. monocytogenes* or *Listeria* spp., Figure 1). The responses were categorized as meat, seafood, and cheese and "Other foods" (one of the meat factories reported on a processing line for dried spices and blends and one dairy processor reported on yogurt production). Responses from countries with less than five respondents were pooled and categorized as "Other countries".

Eighty-one processors (81/126; 64%) reported detecting *Listeria* spp. in the FPE at least once in the previous five years (Fig. 2). One third (33%) found *Listeria* spp. sporadically, suggesting that colonization by the pathogen was effectively prevented by their C&D program. However, 13% reported recurrent *Listeria* spp. detection at the same sample point over a period of three months or more, indicating a persistently contaminated niche. There was a significant difference in reoccurring positive detections between the type of food processed ( $p < 0.001$ ). Ordinal logistic regression showed that relative to cheese factories, meat factories had over six times higher odds of being in a worse contamination category ( $p$ -value 0.005), while seafood factories had more than sixteen times higher odds ( $p$ -value  $< 0.001$ ). Four factories did not respond to the question about *Listeria* spp. in the FPE. Repeated findings of a *Listeria* spp. positive sample at the same location in at least two consecutive sampling events were most common in drains (26 cases, 20%), followed by equipment (22 cases, 17%), and floors (18 cases, 14%). Seven seafood processors (13% of seafood processors, 5% of total respondents) reported challenges with *Listeria* spp. in vacuum systems. Further, the odds of reporting higher contamination increased by about threefold for factories using cloth or sponge for sampling compared to swabs ( $p$ -value 0.008, Fig. 2). As shown earlier, significantly higher rates of *Listeria* spp. are detected when using sponges or composite-ply tissue as compared to cotton swabs (Kovacevic et al., 2009). The higher incidence of recurrent detection of *Listeria* spp. among seafood processors may partly be due to a higher proportion using sponges and/or cloths for sampling the FPE (82.7% for seafood vs 32.8% for cheese and meat processors). The incidence of *Listeria* spp. in the present investigation seems similar to what is found previously, with detection in 60–81% of the facilities and the highest frequency in drains and floors (Henriques et al., 2014; Langsrud et al., 2010; Leong et al., 2017; Reinhard et al., 2018).

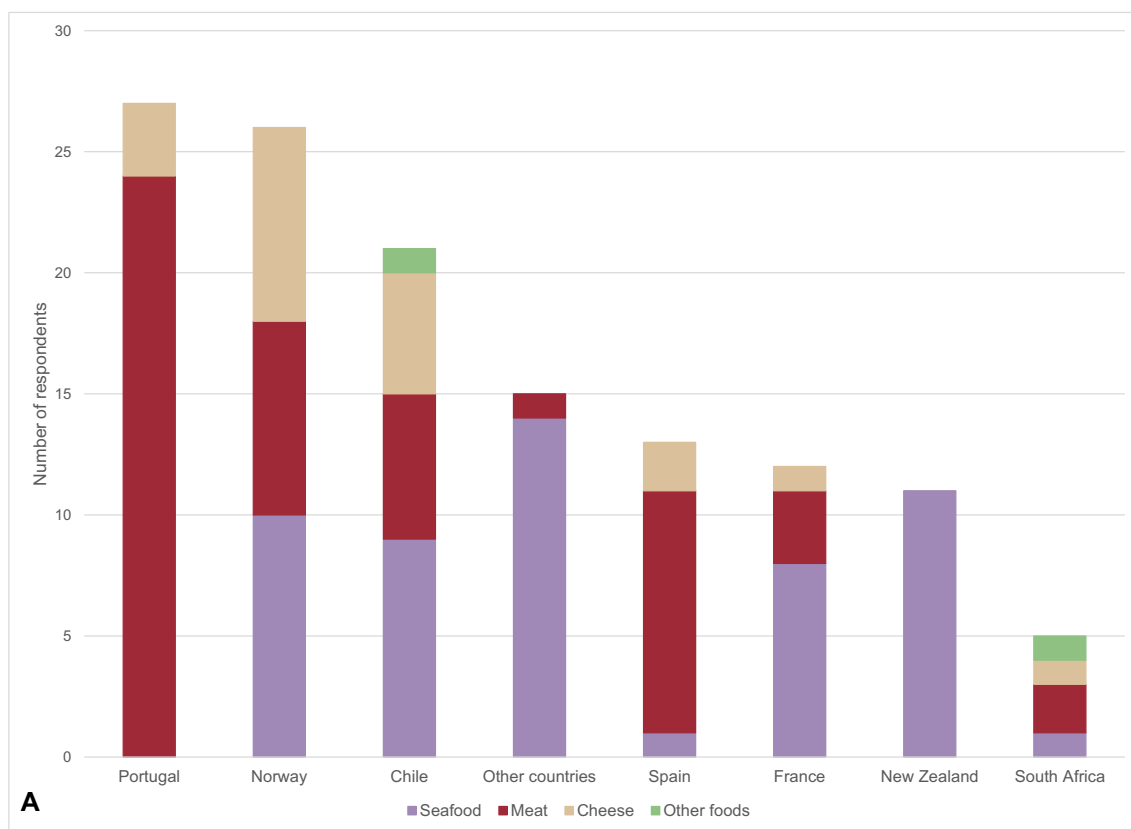
**Table 1**

Range of recommended user concentrations of main active agents in commercial cleaning and disinfectant agents of different categories. Median concentrations are calculated from the user recommendations and data sheets

Type	Category	Manufacturers	Active compounds	Median Conc. (%)*
Cleaning agent	Alkaline	Applied Aglo, Aquatig, Diversey, Ecolab, Hancroft, Kersia **, Lilleborg, Novadan, Yara	NaOH KOH	0.15–1.00 0.10–0.40
	Chlorinated alkaline	Aquatig, Diversey, Ecolab, Envirochem, Hancroft, Kersia, Lilleborg, Novadan, Wesmar	Sodium hypochlorite NaOH KOH	0.02–0.23 0.050–0.30 0.050–0.30
	Acid	Aquatig, Diversey, Ecolab, Kersia, Lilleborg, KiiltoClean Oy, Yara	Phosphoric acid Nitric acid	0.075–0.60 0.15–1.00
Disinfectant	Peracetic acid	Aquatig, Christeysn, Clark Products, Diversey, Ecolab, Kersia, Lilleborg	Peracetic acid	0.01–0.075
			Acetic acid	0.05–0.27
			H <sub>2</sub> O <sub>2</sub>	0.09–0.25
	Hydrogen peroxide	Diversey, Ecolab	H <sub>2</sub> O <sub>2</sub>	0.01–0.02
			Hypochlorite	0.02–0.12
Quaternary ammonium compounds	Aquatig, Blendwell chemicals, Ecolab, Lilleborg	Sodium hypochlorite	0.03–0.15	
		Amine	0.01–0.1	
Cleaning agent& Disinfectant	Hypochlorite Amine	Arrow, Christeysn, Diversey, Ecolab, Hancroft, Proquimia, Truclean/ITW, Wesmar, Zep Inc	Benzalkonium chloride, Didecyldimethyl ammonium chloride	0.0031–0.0066
			Amine	0.0035–0.070
Cleaning agent& Disinfectant	Hypochlorite Amine	Diversey, Paredes, Proquimia Kersia	N-(3-aminopropyl)-n-dodecylpropane-1,3-diamine	0.035–0.070
			Sodium hypochlorite	0.08–0.33
Cleaning agent& Disinfectant	Hypochlorite Amine	Diversey, Paredes, Proquimia Kersia	N-(3-aminopropyl)-n-dodecylpropane-1,3-diamine	0.01–0.025

\* Range from median minimum to maximum concentration (w/v) of active components for products within the category.

\*\* Agents from Kersia include agents previously supplied by Holchem, since Holchem is now a part of Kersia.



**Figure 1.** Distribution of survey respondents. Processors that reported to produce several categories of products are assigned to the category produced at the processing line they considered when reporting about *Listeria* monitoring and use of C&D agents. A) Distribution divided by food category and country. The “Other countries” category consisted of the USA, the UK, Belgium, Lithuania, Estonia, Germany, Poland, and Taiwan. The “Other foods” category includes a company producing yogurt and one producing dried spices and blends. B) Map showing the distribution of respondents.

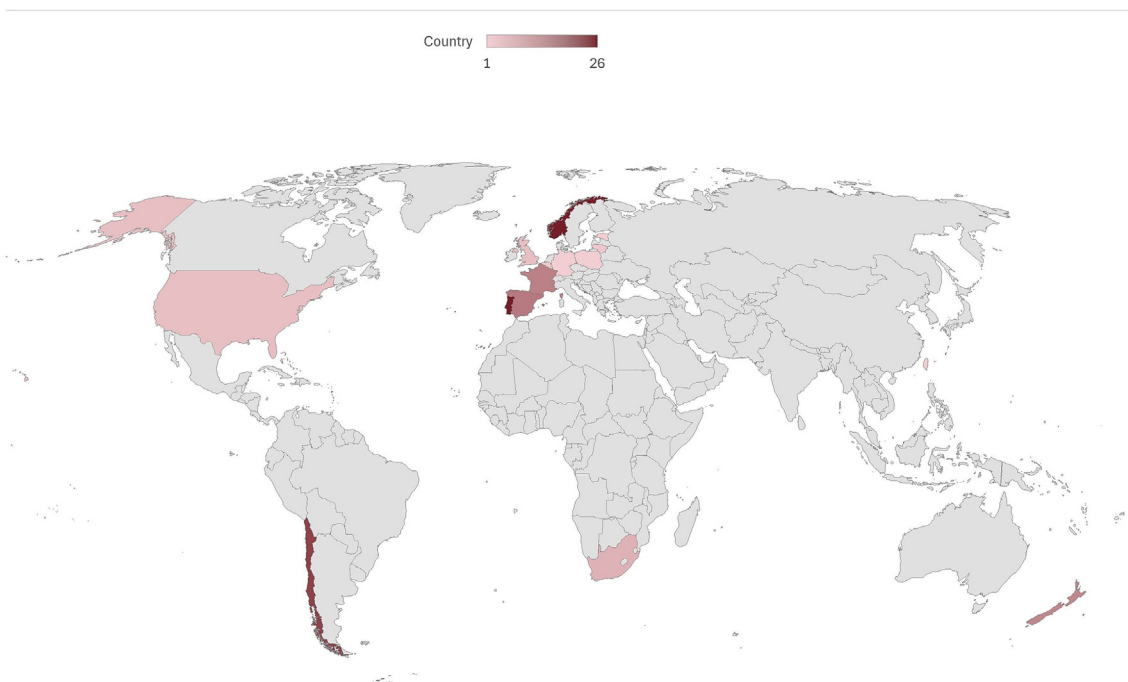


Fig. 1 (continued)



Figure 2. Self-reported (n = 130) detection of Listeria spp. in the processing facilities divided by food category and sampling method. Total numbers per product category are shown.

Compared with other studies, a strength of the present study is the wide coverage (number and distribution of food processors reached directly or indirectly through the C&D manufacturers), resulting in a

quite broad overview of which C&D agents are commonly used, how often food processors detect Listeria spp. in the FPE and which strategies they have found more effective. Still, it should be noted that the

results cannot be regarded as a quantitative, representative survey of the situation in the food industry worldwide. Also, it is not possible to collect information about all factors that may influence *Listeria* spp. occurrence (e.g. zone separation, hygiene state of equipment, raw material control, exact processing and C&D routines) through questionnaire and interviews. The reason is that it would require a number and type of questions beyond what is reasonable to demand from someone responding voluntarily to a survey or an interview. Finally, a web-based self-reporting can never give a full in-depth understanding of a physical reality.

**Common cleaning and disinfection agents.** In total, 104 out of the 130 respondents provided information about C&D agents (See [Supplementary Table B1](#) for details). Among the 83 food producers that provided sufficient information about cleaning agents, 72% reported using a chlorinated alkaline product, 40% an alkaline agent without chlorine, 28% an acidic cleaning agent, and 10% an enzymatic cleaning agent ([Fig. 3, Supplementary Table B1](#)). A total of 32 of the respondents used more than one agent. Cleaning products from 13 different suppliers were reported. Chlorinated alkaline products dominated in all countries, except in Norway, where alkaline agents without chlorine were used by about as many processors as chlorinated agents. Some processors, located in France, South Africa, or Spain, used enzymatic cleaning agents. Chlorinated alkaline agents dominated among facilities processing meat and seafood, while acidic cleaning agents were relatively more common among cheese producers ([Fig. 3](#)), likely due to the need to manage mineral deposits in the latter ([Wilkin et al., 2017](#)).

Interviews with C&D manufacturers aligned with the web survey, as all manufacturers ( $n = 12$ ) mentioned the use of alkaline detergents for cleaning, with most of them (8/12) also mentioning chlorinated alkaline products. Seven (7/12) manufacturers of C&D agents recommended rotation between alkaline and acidic cleaning agents, with the alkaline agent for regular cleaning and the acid wash occasionally (e.g., once a week or once a month). Acid cleaners were mentioned as specifically important for the dairy industry to remove films of mineral salts. One of the C&D manufacturers provided an enzyme cleaner as an environmentally friendly option, but its high cost limits its use. Two of the manufacturers of C&D agents mentioned that they did not offer enzyme-based cleaning agents because of concerns about their health impacts, specifically allergies.

Among the 80 food processors that provided sufficient information, 48% reported using peracetic acid, 36% QAC, 20% hypochlorite, 11% alcohol, 8% amines, and 8% hydrogen peroxide ([Fig. 4](#)). A total of 29 respondents used more than one agent (See [Supplementary Table B1](#) for details). Oxidative agents (peracetic acid and chlorine) were reported more frequently by respondents located in Norway and those producing cheese and nitrogen compounds (QAC and amines) were more common among respondents from southern Europe and processors of meat and seafood. Less frequent use of QAC in cheese production may be due to the risk of inhibiting starter cultures. The recommendations from the manufacturers of C&D agents were partly in accordance with the factory survey results. Of 12 manufacturers, 10, eight, and six recommended peracetic acid, QAC, and/or amines, respectively, for regular disinfection. Peracetic acid was described as a fast-acting, environmentally friendly, and effective disinfectant, but it was mentioned that the use of peracetic acid-based agents requires proper ventilation and sufficient personal protective equipment to protect workers. In an older report from the UK food industry (based on 117 sites), 55% of the facilities used QAC, 38% hypochlorite, 26% alcohol, and only 7% peracetic acid ([Holah et al., 2002](#)). A striking difference is the much higher use of peracetic acid and lower use of hypochlorite reported by the industry respondents and manufacturers of C&D agents in the present study. Most probably, there has been a change in the use of C&D agents over the last 20 years: Five of the C&D manufacturers claimed that the use of QAC has declined, due to reports of resistance development and regulatory restrictions. Four

manufacturers of C&D agents stated that the use of hypochlorite was declining, due to corrosion issues and concerns for the formation of carcinogenic compounds and pollution of the environment. Expected replacement products for chlorine and QAC-based agents were peracetic acid-, chlorine dioxide-, and amine-based agents. However, it should also be mentioned that one manufacturer mentioned that they were developing new agents based on new combinations of QAC.

**Composition of cleaning and disinfection agents.** [Table 1](#) shows an overview of the main active compounds as reported in safety/user information in different categories of C&D agents. One should be aware that the SDSs may not include all components in the formulations but are usually only required to list those ingredients that are potentially harmful to people or the environment if at a sufficiently high concentration. Also, differences in regulations between countries may lead to differences in which type of compounds are required to be reported in SDSs.

**Cleaning agents.** Most (11/12) of the manufacturers of C&D agents claimed that their recommendations of cleaning products, concentrations, and temperatures depend on the type and load of soil (e.g. chlorinated alkaline for heavy loads of fat and protein), water hardness (products with chelators), and the surface materials (corrosion inhibitors for soft metals). Thus, no specific cleaning product is suitable for all purposes. This was aligned with the information given by the food producers, which in general reported the use of more than one cleaning product. As an example, one of the respondents used three different alkaline cleaners from the same supplier to clean, respectively, crates, knives, and small equipment, and factory production lines.

Among the 81 food processors reporting the use of alkaline cleaning agents, a total of 48 products from 11 suppliers were reported. Of those, 28 agents contained NaOH, six contained KOH, and nine contained both NaOH and KOH. The reported pH values of the working concentrations were pH 10–13.5, with most at pH 12–13. NaOH and KOH solubilize and saponify organic soils, especially proteins and fat ([Stanga, 2010](#)). Twenty-seven of the agents contained hypochlorite, which enhances the cleaning effect of alkaline agents by oxidizing and breaking up organic matter ([Stanga, 2010](#)). The chemical composition of the cleaning agents varied considerably, and most agents (except those for Cleaning-in-place (CIP)) were complex formulations of several chemicals with different functions, including foaming or gel surfactants, stabilizers/emulsifiers, corrosion inhibitors, sequestrants (water softeners), and wetting agents. A total of 42 different chemical compounds were declared in the SDSs, and half (21) were only present in a single cleaning agent. The most common additives were alkylamine oxide (foamer and surfactant, 16 agents) and EDTA (chelator, eight agents). Eight agents claimed to have disinfecting properties in addition to cleaning, of which seven contained hypochlorite, and one contained amine (N-(3-aminopropyl)-n-dodecyl-propane-1,3-diamine) as the active biocidal compounds. Such compounds are often marketed as one-step C&D. In the US, these agents still require two applications (e.g one for cleaning and one for disinfection).

Among the 23 food producers reporting the use of acidic cleaning agents, a total of 15 products from seven different suppliers were specified. As minerals are often acid-soluble, acidic agents are effective in removing mineral deposits ([Lelieveld et al., 2016](#)). The most common acids in the products were phosphoric acid (nine agents) and nitric acid (seven agents), which are generally considered to have the most powerful cleaning effect ([Stanga, 2010](#)). With the exception of cleaning agents intended for CIP, the acidic cleaning agents contained surfactants with foaming properties, emulsifiers, and corrosion inhibitors. The user solutions of the agents had a pH within the range of 1–3.

Among the eight food processors using enzymes for cleaning, only three products were specified. One product was reported to contain the protease subtilisin, but otherwise, there was little information about the chemical content in the SDS. Two of the food producers used enzyme wash once a week, while others did not provide information on the frequency of use.

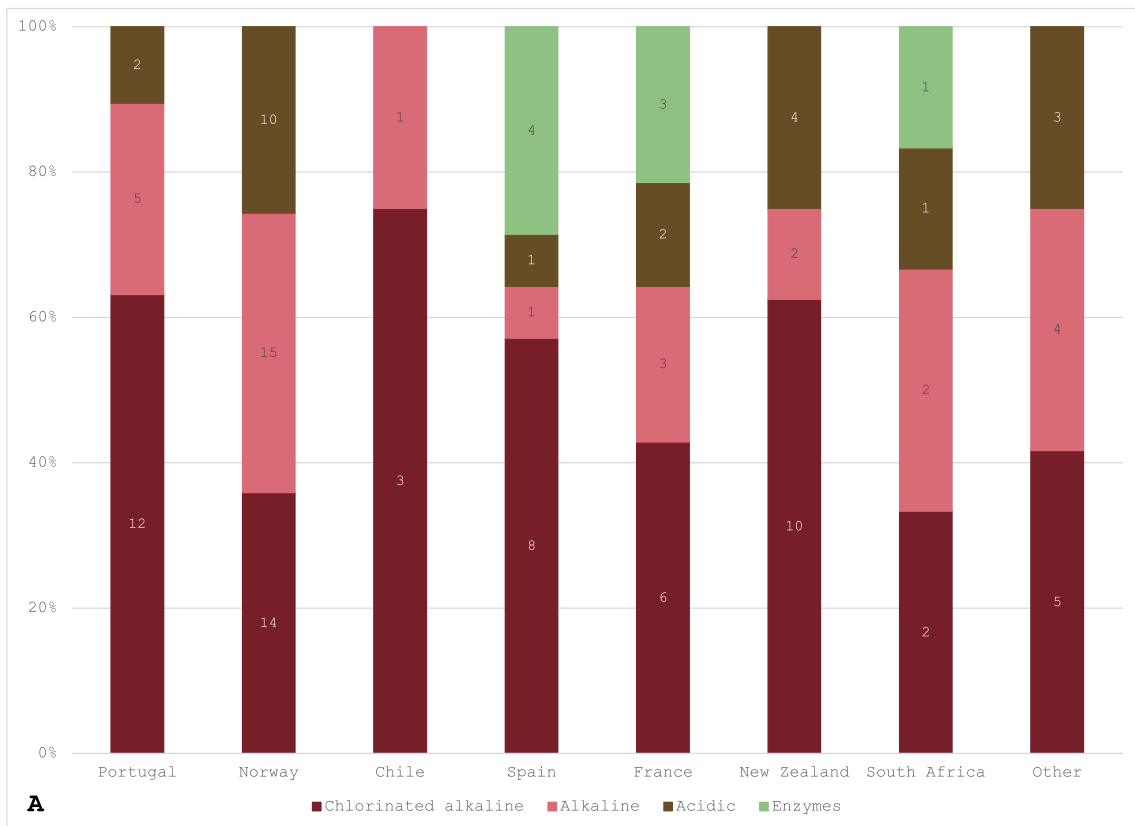


Figure 3. Self-reported (n = 83) use of cleaning agents divided by country (A) and food category (B). Total numbers and frequencies are shown.

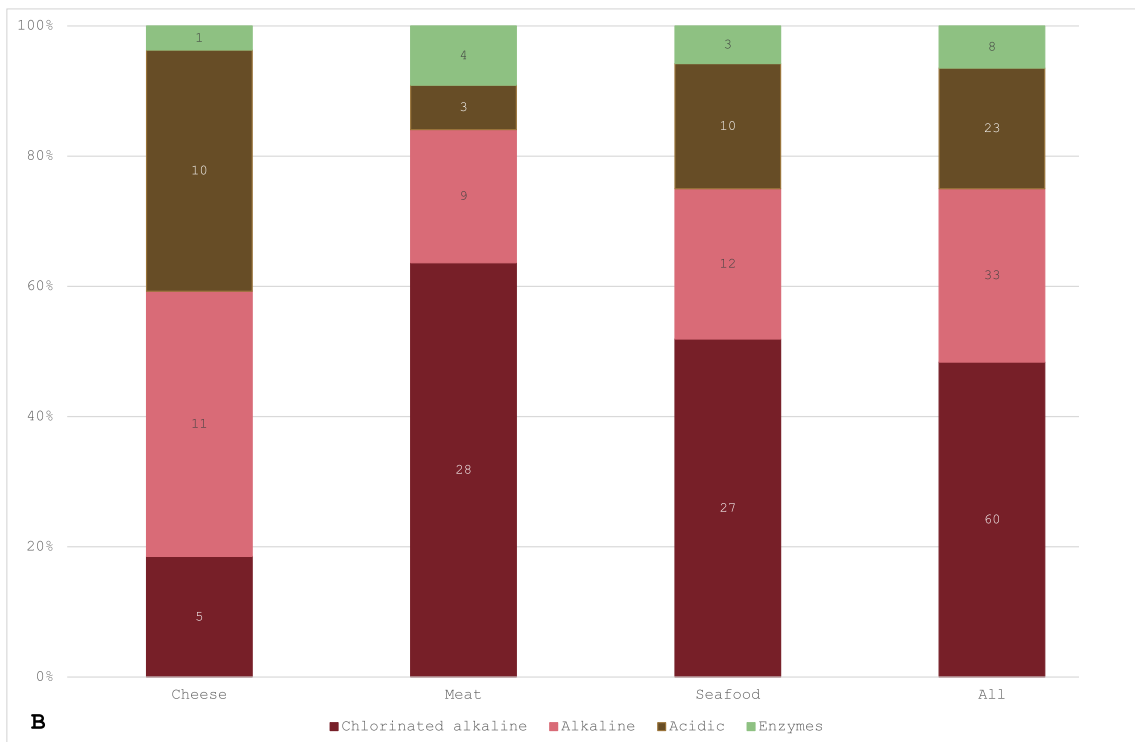


Fig. 3 (continued)

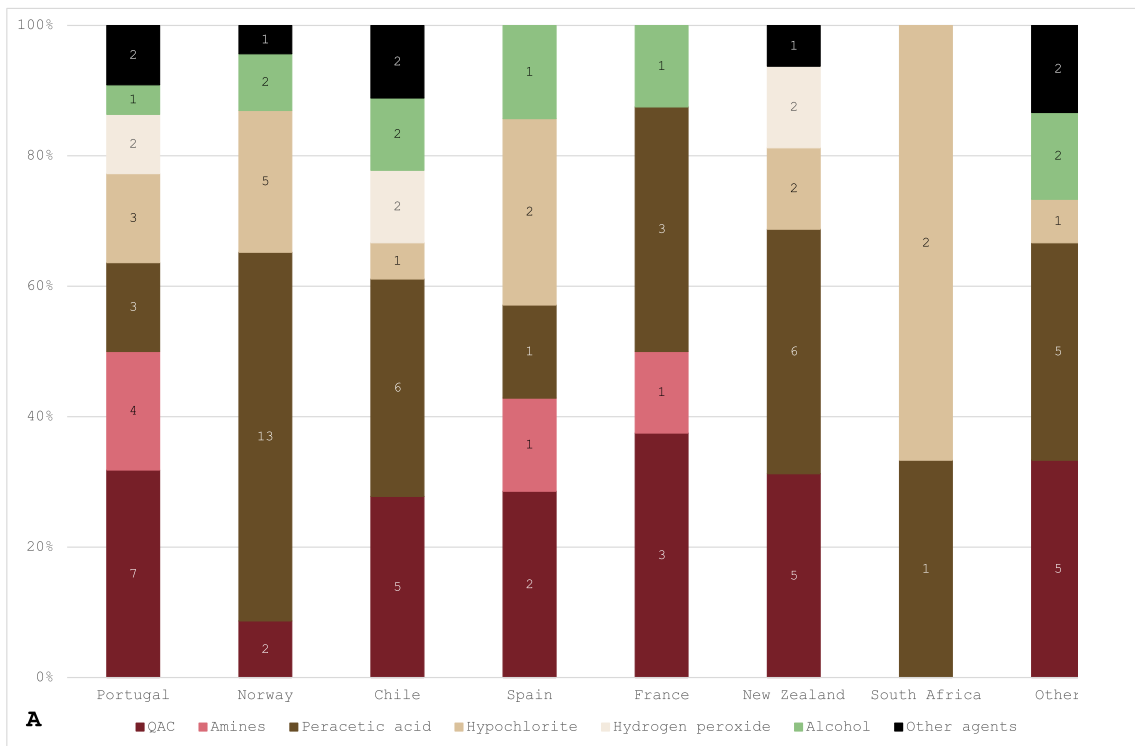


Figure 4. Self-reported ( $n = 80$ ) use of disinfecting agents divided by country (A) and food category (B). Total numbers and frequencies are shown. The “Other agents” category was chlorine dioxide (2), hot water (2), amphoteric tenside (2), glutaraldehyde (1), and ozone (1).

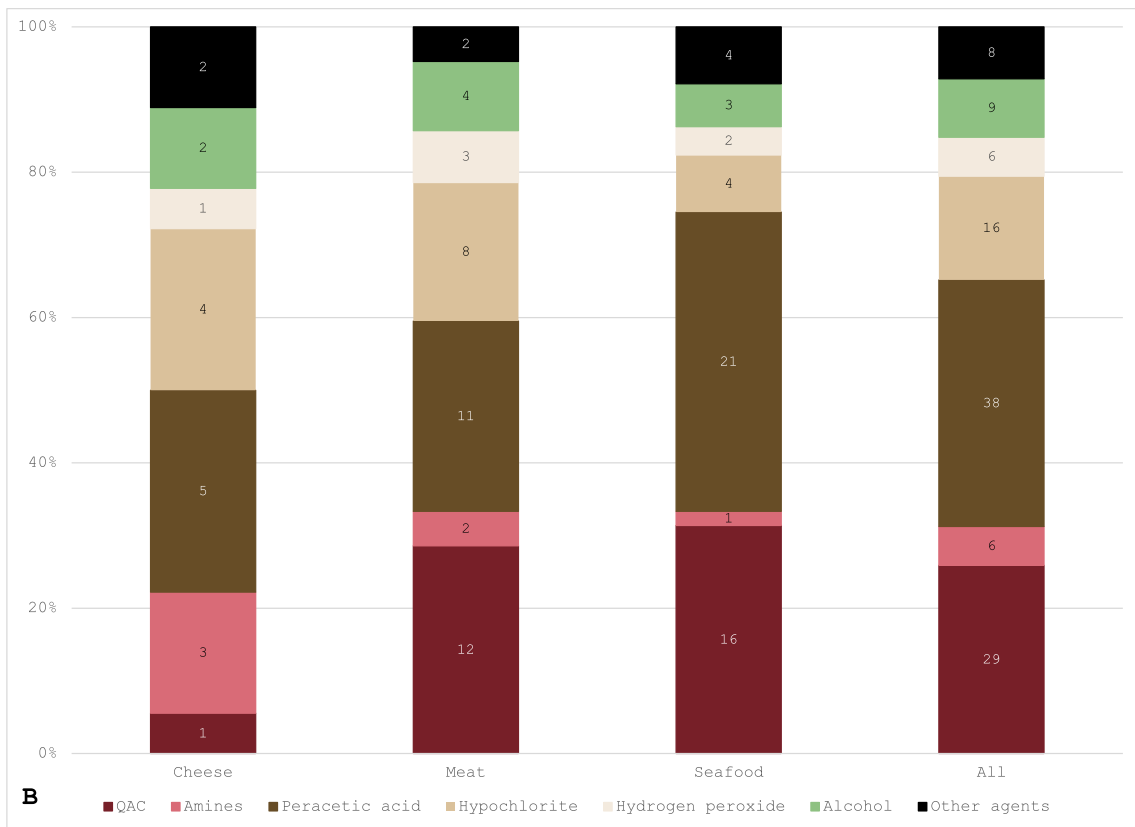


Fig. 4 (continued)

**Disinfectants.** Among the 38 food processors using peracetic acid/hydrogen peroxide for disinfection, 19 agents from seven manufacturers were reported. Most (15/19) of the agents contained peracetic acid, acetic acid, and hydrogen peroxide, while three agents also contained octanoic acid/peroctanoic acid. Four agents contained only hydrogen peroxide, without peracetic acid/acetic acid. All these compounds are oxidizers with a broad spectrum effect against microorganisms and are generally regarded as environmentally friendly (Lelieveld et al., 2016). In addition to the oxidizers, a total of 22 chemical compounds were declared in the SDS (17 of them only in one or two agents), with most declaring surfactants, emulsifiers, stabilizers, and a few foaming agents. The pH for the in-use solution ranged between 2 and 6, with most agents in the range of pH 2.5–3.5.

Among the 29 food processors using QAC for disinfection, a total of 17 agents from nine suppliers were reported. The pH for the working solution ranged from 6 to 10. Benzalkonium chloride was the most common QAC (11 products), but most products contained several different QACs. A total of 24 additional chemical compounds were declared in the SDSs, of which 18 compounds were reported in individual agents. Ethanol was the most common compound besides QAC (four agents), and surfactants with foaming ability were common. Unique ingredients to QAC-based agents included biguanide and pine oil, which also have antimicrobial properties (McDonnell & Russell, 1999; Mourey & Canillac, 2002).

All amine-based products contained N-(3-aminopropyl)-n-dodecyl propane-1,3-diamine as the active compound and were alkaline with a pH in the range 10–13. This is a relatively new type of disinfectant often marketed as “QAC-free”. The most common accessory ingredients in amine-based disinfectants were EDTA (chelator), NaOH (alkaline), and lauryldimethylamine oxide (surfactant).

Among the 16 food producers reporting the use of hypochlorite for disinfection, five products with hypochlorite as the main active compound were specified: Four as liquids and one in powder form. All agents were alkaline with pH values of 10–12. Only four alcohol-based products were listed, with one being an alcohol-based wipe. Two products contained ethanol, and two contained isopropanol.

**Relation between cleaning and disinfection agents and *Listeria* spp. detection.** When comparing the relation between detection of *Listeria* spp. in the FPE in the past (no/sporadic detection vs. recurrent detection in the same location) and use of C&D agents today (e.g. using or not using QAC for disinfection), no significant correlation was found for any agents ( $p > 0.05$ ). However, one should note that more information would be required to conclude about such associations. Without detailed information about past use of C&D agents, as well as the monitoring program and how it was performed, it is unclear whether those processors that reported no/sporadic detection failed to detect the pathogen, or if those reporting about problems had used ineffective agents in the past. Also, colonization by *Listeria* spp. is likely influenced by several factors, including the thoroughness of cleaning, C&D parameters, hygienic design, humidity, temperature, cross-contamination frequency etc. Also, large variations in the use of and content of C&D agents within each category were found which will also affect the efficacy. This is supported by an earlier report which found large variation in effect across products with the same active compounds (Cruz & Fletcher, 2012). Carefully designed experiments are required to determine whether specific types of C&D agents are more effective (Ohman et al., 2024). However, as the results of the present study and the conflicting results in laboratory studies indicate, a change of C&D agents may not be the most important measure to consider for processing plants with recurring detection of *Listeria* spp.

**Elimination of recurring *Listeria* spp.** Actions performed by 27 food producers after repeated findings of *Listeria* spp. in drains or on floors are shown in Figure 5 (for details, see Supplementary Table B2). To eliminate *Listeria* spp. from the drains or floors, most (20/27) reported cleaning more thoroughly and/or more frequently, with nine completing a full wash-down of their production facilities.

Seven took specific actions to limit cross-contamination (e.g. new C&D routines to avoid splashing from floors or drains) and 14 increased environmental sampling. Although the distribution of *Listeria* outcomes appeared to differ somewhat between interventions applied, the differences were not statistically significant ( $p$ -value 0.09).

Among all the producers with recurring *Listeria* spp. in drains and floors, 13 succeeded in eliminating *Listeria* spp., 10 reduced its occurrence, two did not eliminate or reduce it, and two did not know the outcome of the interventions. Overall, changing C&D agents or procedures (more frequent C&D or higher concentrations) was reported to eradicate *Listeria* spp. from floors or drains (Fig. 5) by the highest number of respondents (12 out of 21). A variety of products were reported as effective (diamine, peracetic acid, hypochlorite, chlorine dioxide, chlorinated alkaline, and acid cleaning agent). In all but two cases, several actions were combined to eliminate the problem. Examples of actions eliminating persistent *Listeria* spp. contamination included: (i) applying a powdered alkaline cleaner to the floor overnight and scrubbing; (ii) cleaning twice a week with high concentrations with sequential application of an acidic and an alkaline cleaner followed by disinfection with an amine-based agent; and (iii) more frequent cleaning (chlorinated alkaline) and disinfection (peracetic acid). One food processor eradicated *Listeria* spp. by upgrading the drain infrastructure, without implementing any changes to C&D routines.

Among the 20 respondents that reported repeated findings of *Listeria* spp. on equipment (e.g. conveyors, slicing machines), 12 increased sampling for *Listeria* spp., 14 introduced more thorough or more frequent cleaning, six altered their C&D procedures, and eight did a full washdown/reset (Fig. 6, see Supplementary Table B3 for details).

Among the nine processors that eliminated *Listeria* spp. contamination, six (6/9) maintained or replaced parts of the equipment, either as the sole corrective action (4/9) or combined with more thorough or frequent C&D (2/9). One food processor reported that *Listeria* spp. was eradicated by soaking in chlorine dioxide and another by changing to a peracetic acid-based disinfectant and more thorough C&D. The last among the nine reported that more thorough C&D solved the problem.

For the six processors that had repeated detection of *Listeria* spp. in vacuum systems, none had successfully solved their persistence problem. Four facilities maintained or upgraded their vacuum system, which reduced the incidence of *Listeria* spp. but did not eliminate it. Interventions such as a more thorough cleaning, changing cleaning agents and procedures, and a complete full wash down of the facility and maintenance activities were conducted. These tasks resulted in reduced frequency of *Listeria* spp. Detection, but did not eliminate it.

In situations where *Listeria* spp. was not eliminated by regular C&D, six of the manufacturers of C&D agents (6/12) recommended using higher concentrations of alkaline cleaners and/or disinfectants (peracetic acid or amine). One manufacturer recommended to clean several times with different cleaning agents to remove soil and biofilm that have accumulated over time. Using a disinfectant based on peracetic acid was recommended by 6/12 manufacturers, amine by 2/12, and respectively acid QAC (QAC with peroxide), biguanide, chlorine dioxide, and enzyme-based cleaning agents by single manufacturers of C&D agents. Applying mechanical energy to detach biofilm with *L. monocytogenes* was mentioned by five (5/12) of the manufacturers interviewed, and fogging disinfection by four (4/12).

According to previous studies, poor equipment cleanability, inadequate C&D, and improper zoning are the main risk factors for the persistence of *L. monocytogenes* in food processing factories (Belias et al., 2022; EFSA BIOHAZ Panel et al., 2023). In the present study, about half of the respondents managed to eradicate *Listeria* spp. by improved C&D or maintenance/replacements, while others failed. More in-depth studies comparing factories managing and not managing *L. monocytogenes* incidence are needed to not only point on risk factors for persistence but also solutions.

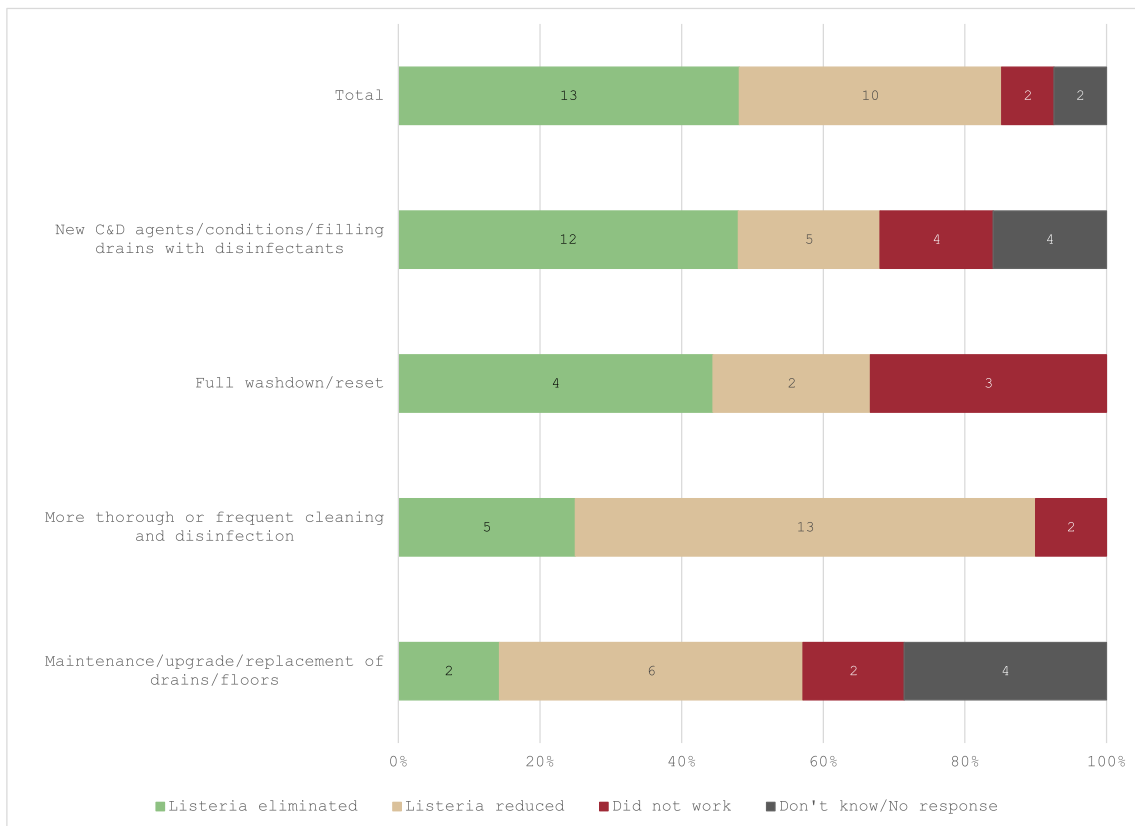


Figure 5. The effectiveness of different measures to eliminate *Listeria* spp. after repeated detection in drains or floors. The number of respondents and percentages are shown.

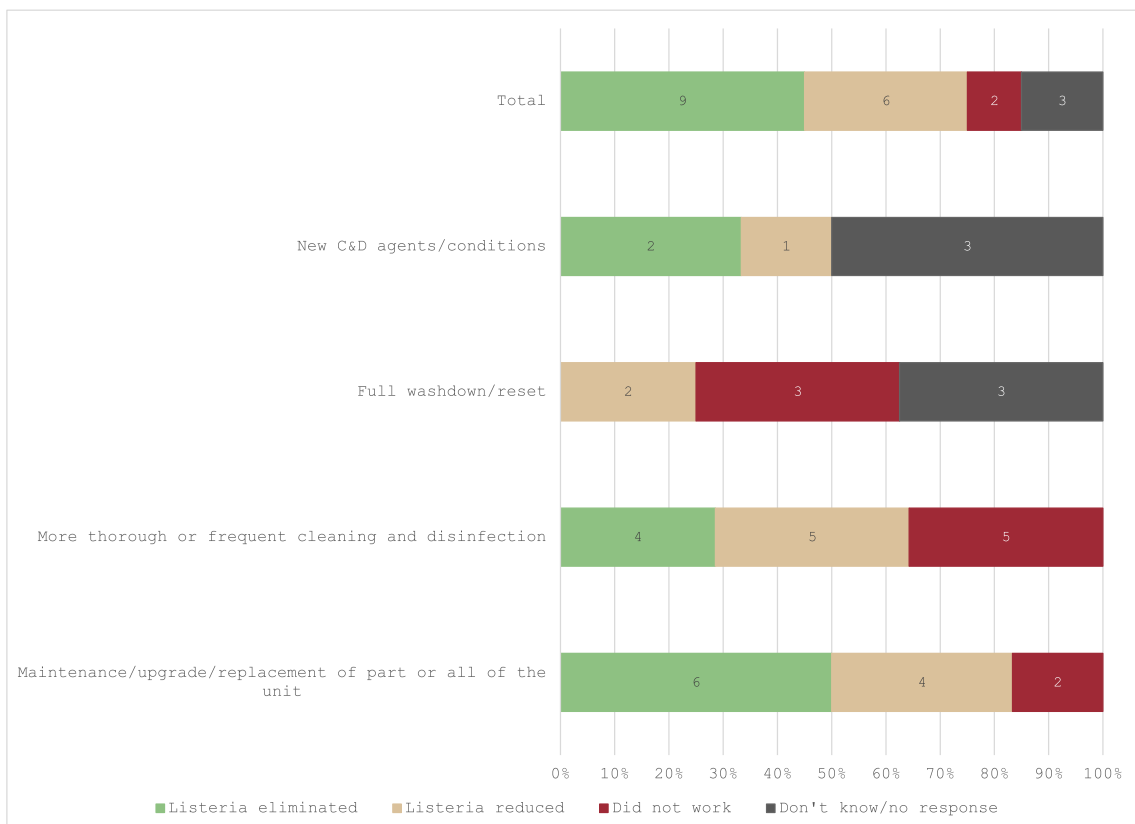


Figure 6. The effect of different measures to eliminate *Listeria* spp. after repeated detection on equipment. The number of respondents and percentages are shown.

**Table 2**  
Industry guidelines on the control of *L. monocytogenes*

Title	Region	Food category	Year	Disinfection recommended*					Reference
				PA	QAC	Chl	Heat	Rotation	
The control and management of <i>L. monocytogenes</i> contamination of food	Ireland	Food	2005	X	X	X	X	X	(Food Safety Authority of Ireland, 2005)
Industry guideline to prevent contamination from <i>L. monocytogenes</i> .	US	Pork	2006	X	X	X	X	X	(Tompkin et al., 2006)
Controlling <i>L. monocytogenes</i> in Post-lethality Exposed Ready-to-Eat Meat and Poultry Products	US	Meat and poultry	2014	X	X			X	(Food Safety Inspection Service, 2014)
Best practice Guidance for controlling <i>L. monocytogenes</i> (Lm) in retail delicatessen	US	Meat and poultry	2023		X	X			(Food Safety Inspection Service, 2023)
<i>L. monocytogenes</i> guidance on environmental monitoring and corrective actions in at-risk foods	US	RTE	2014				X		(Brouillette et al., 2014)
Guidance Document: Guidance for the Control of <i>L. monocytogenes</i> in Ready-to-eat Foods	New Zealand	RTE	2017		X		X	X	(Ministry for Primary Industries, 2017)
Control of <i>L. monocytogenes</i> - guidance for the U.S. dairy industry	US	Dairy	2017	X	X	X	X		(Wilkin et al., 2017)
Control of <i>L. monocytogenes</i> in Ready-To-Eat Foods: Guidance for Industry Draft Guidance	US	RTE	2017	X	X	X	X	X	(US Food and Drug Administration, 2017)
Ready-to-eat seafood pathogen control manual	US	RTE seafood	2018	X	X		X		(National Fisheries Institute, 2018)
Control of <i>L. monocytogenes</i> - guidance for the South African dairy industry	Africa	Dairy	2018	X	X	X	X		(Dairy Standard Agency, 2018)
Policy on <i>L. monocytogenes</i> in ready-to-eat food	Canada	RTE	2023					X	(Health Canada, 2023)
Guidelines on the Application of General Principles of Food Hygiene to the Control of <i>L. monocytogenes</i> in Foods	US	RTE	2009	X	X				(FAO and WHO, 2007)

\* PA: Peracetic acid; QACs: Quaternary ammonium compounds; Chl: Chlorine; Rotation: Alternating between different disinfectants.

**Compliance with guidelines.** Among the available guidelines to control *L. monocytogenes*, 12 contained advice on C&D (Table 2). Guidelines covered single countries or Europe, and either targeted certain food categories or were generalized to RTE products. All but one (Food Safety Inspection Service, 2023) of the guidance documents refer to the pioneering work of Dr. R. Bruce Tompkin on controlling *L. monocytogenes* in the meat industry (Tompkin, 2002). Therefore, they often refer to or repeat Tompkin's recommendations about the use of C&D agents. Most guidelines reinforce the use of approved chemicals and emphasize that the technical specifications (concentrations, time, temperature, flow) provided by the manufacturer are required to ensure efficacy. This aligns with what several manufacturers of C&D agents stated; when assisting food facilities that are not able to control *L. monocytogenes*, they initially checked that C&D routines were followed.

For those 10 guidelines mentioning specific disinfectants, all recommend using QAC to prevent (or eliminate) *L. monocytogenes*. Peracetic acid was recommended in 8/10 guidelines and noted to eradicate biofilms. QAC and peracetic acid-based disinfectants were among those most reported by food processors in the present study and also recommended by most manufacturers of C&D agents; therefore, it seems that most food processing facilities are compliant with the guidelines. Other disinfectants mentioned by a few guidelines are chlorine- ( $n = 6$ ) and iodine ( $n = 5$ )-based agents (Dairy Standard Agency, 2018; Food Safety Authority of Ireland, 2005; Food Safety Inspection Service, 2023; Tompkin et al., 2006; US Food and Drug Administration, 2017; Wilkin et al., 2017). Iodine-based agents were not used by any of the respondents to the survey. It should be noted that several types of active compounds used by the food industry or recommended by the manufacturers of C&D agents are not mentioned in any guidelines, neither positively nor negatively, such as disinfectants based on amphoteric tensides, amines, biguanides, or aldehydes, or cleaning agents based on enzymes.

Drains and floors are mentioned specifically in some guidelines, advising to use caustics for cleaning and powder versions of QAC, peracetic acid, or hydrogen peroxide for sanitation. This is in general agreement with what was reported by processors in this study, where a range of different chemicals had been used to eradicate *Listeria* spp.

from drains and floors. However, it should be noted that increased frequency, concentration, and exposure time appeared to be more important than the use of a specific chemistry.

Many (8/12) guidelines mention heat (e.g., water, steam, oven/smoke chamber) as options for disinfecting equipment that is difficult to clean (Table 2), but this was reported by only one food processor. The reasons for not using heat were not investigated, but could be due to practical constraints (e.g. lack of large heating ovens) that equipment does not tolerate high temperatures (e.g. conveyor belts), and concerns related to the safety of the cleaning personnel. In the recommendations targeted to the dairy industry, peracetic acid, chlorine dioxide, and ethanol wipes are mentioned as options during deep-cleaning of equipment (Dairy Standard Agency, 2018; Wilkin et al., 2017).

Rotation between disinfectants is suggested by several (6/12) guidelines; however, only one guideline mentions specifically rotating between cleaning agents (Food Safety Inspection Service, 2014). This is in contrast with the recommendations from manufacturers of C&D agents, where seven (7/12) emphasized the importance of rotating cleaning agents and four (4/12) disinfectants. No specific questions about rotation were included in the questionnaire for food processors. Several (29/81) reported more than one type of disinfectant and/or cleaning agent (26/84), but they may have been used for different parts of the processing line. The effect of rotation of C&D agents should be investigated further (Bland et al., 2022).

## Conclusions

The efficacy of C&D in food processing facilities is dependent on several technical, biological, and physical factors, making it difficult to evaluate the efficacy of the agent itself through designed laboratory, pilot, or industrial experiments or through surveys and interviews. Cleaning agents based on strong alkaline or acids, both containing additives for enhanced effect, continue to be the primary choice for cleaning. For disinfection, there are many available chemistries that are used in the food industry, but peracetic acid, QAC-based agents, and chlorine seem to be the most applied. Notably, however, the results of this study have suggested that chlorine is expected to be

replaced by peracetic acid in the future, and QAC by amine-based products.

There is a need to update some of the guidelines for the food industry to reflect the present use and knowledge about C&D. Overall, there is no clear choice of a single type of cleaning or disinfectant agent to most effectively prevent or eradicate *L. monocytogenes*. However, evidence from this study suggests the agents currently in predominant use can effectively eliminate *Listeria* spp. when incorporated into a properly implemented hygiene plan. Optimizing hygiene practices, including the frequency of application, can lead to the control and eradication of persistent *Listeria* spp. contamination in the FPE. However, when C&D fails to eradicate *Listeria* spp., it may be necessary to remove the harborage site physically, by replacing the whole equipment or colonized parts of the equipment. To meet future requirements for more sustainable food production and the absence of *L. monocytogenes* in the FPE, there is a need to explore new technologies, and their efficacy should be compared with the standard C&D agents.

### CRedit authorship contribution statement

**S. Langsrud:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **E. Heir:** Writing – review & editing, Methodology, Investigation, Funding acquisition, Conceptualization. **M.E. Pedersen:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **B. Moen:** Writing – review & editing, Methodology, Investigation, Funding acquisition. **P. Teixeira:** Writing – review & editing, Methodology, Investigation. **K. Corbett:** Writing – review & editing, Methodology, Investigation. **D. Rip:** Writing – review & editing, Methodology, Investigation. **P. Gouws:** Writing – review & editing, Methodology, Investigation. **J. Kovacevic:** Writing – review & editing, Methodology, Investigation. **J. Waite-Cusic:** Writing – review & editing, Methodology, Investigation. **G.C. Fletcher:** Writing – review & editing, Methodology, Investigation. **E. Fox:** Writing – review & editing, Methodology, Investigation. **V. Michel:** Writing – review & editing, Methodology, Investigation. **A. Hanin:** Writing – review & editing, Methodology, Investigation. **A. Alvarez-Ordonez:** Writing – review & editing, Methodology, Investigation. **A. Moreno Switt:** Writing – review & editing, Methodology, Investigation. **A. Urzúa Caracci:** Writing – review & editing, Methodology, Investigation. **D. Rivera:** Writing – review & editing, Methodology, Investigation. **G. Dørum:** Writing – review & editing, Writing – original draft, Formal analysis. **T. Møretro:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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### Appendix A. Supplementary material

Supplementary material to this article can be found online at <https://doi.org/10.1016/j.jfp.2026.100793>.

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